2ND EDITION



Textbook of

ORAL ANATOMY, HISTOLOGY, PHYSIOLOGY and TOOTH MORPHOLOGY







K Rajkumar | R Ramya

Wolters Kluwer

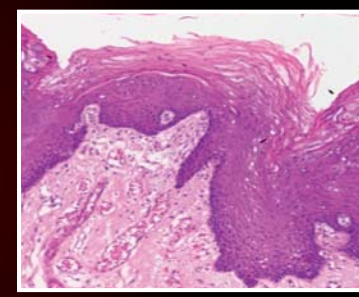
Textbook of
Oral Anatomy, Histology, Physiology and Tooth Morphology

2ND EDITION



Textbook of

ORAL ANATOMY, HISTOLOGY, PHYSIOLOGY and TOOTH MORPHOLOGY





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Dedication

To my parents, my wife Dr. Shanthi, my children Divya and Karthik

K. Rajkumar

To the Creator, my parents, my loving daughter Pooja

R. Ramya

for their constant love, support and encouragement

and

To our students, who inspire us to be teachers

Foreword

A comprehensive book on Oral Anatomy and Oral Histology is the expectation of the first-year students of dentistry. In this book, the authors have, however, gone a step further and included Oral Physiology and Tooth Morphology, making it a handy single-volume book that suits the needs of the students. This book is simple to comprehend and at the same time exhaustive in its coverage. I consider the following features to be the highlights of the book:

- Subject is written and presented in a simple, lucid style, which makes it easy to understand and interesting to read.
- Appropriate schematic diagrams enhance grasping of knowledge.
- Tooth carving procedure presented in the book and demonstrated in the DVD is an additional feature that renders a practical approach to the subject and makes self-learning possible.
- Oral Histology slides with explanations provide for easy reference during practical sessions.

The authors have conceived this book with a broad vision so that it serves as a sound text for undergraduates in the first year and a useful supplement for the subsequent courses on preclinical and clinical conservative dentistry and prosthodontia. I am confident that undergraduate students will benefit immensely from this valuable textbook and even postgraduate exam aspirants would find it very useful.



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Preface to the Second Edition

Knowledge of the basics of oral cavity and the craniofacial complex forms the basis of dental curriculum. This textbook serves as a single source reference of Oral Anatomy, Tooth Morphology, Oral Physiology and Oral Histology to cover the fundamental biology of the oromaxillofacial region. This textbook has been a bestseller from the time of its launch for its lucid contents which favours immersive reading.

The second edition has been updated with the latest advances and other features to aid easy learning and better retention. With the advent of compulsory competitive examinations for entry into post-graduate examinations, students need to keep themselves updated for effective performance. All possible proven learning tools have been added for easy learning. These features aim to cater to the needs of students with varied levels of learning skills.

In the light of the above, the salient features of the second edition are:

- *Five new chapters* to enrich the knowledge base and understanding of students
- *Applied aspects* to enhance the clinical understanding of the subject
- An *Overview* at the beginning of each chapter to sensitize students with the contents of the chapter
- *Mind Maps* at the end of each chapter, an amazing learning tool to aid easy, coherent and organized recall
- *Flash cards*, an online resource which includes essentials of the chapter in a tabular form for quick revision

Preparation of this edition has involved tremendous efforts to ensure that all recent advances have been updated. Above all, the constant urge to make learning easy to the student community has been addressed by addition of proven learning tools. However, understanding the limitations of human efforts, we would be grateful to receive comments and suggestions for further improvement.

K. Rajkumar
R. Ramya

Preface to the First Edition

The oral cavity and the craniofacial complex contain a unique combination of varied tissue types and functions. Understanding the structure and functions of dental, oral and relevant extraoral tissues in depth forms the basis of the dental curriculum. A thorough knowledge of the anatomy, histology and the role of normal tissues in the physiology of the oral anatomical structures will aid in a better understanding of the pathology of these tissues and organs. Therefore, in this book we have explained Oral Anatomy, Tooth Morphology, Oral Physiology and Oral Histology together in order to present a comprehensive account of the fundamentals of biology of the oromaxillofacial region.

A first-year undergraduate usually finds it difficult to understand the overlapping concepts of the above-mentioned four subjects from different books and sources. We have attempted to address this difficulty by comparing and correlating the various topics in one handy volume. We hope this approach enables the students to acquire a more stable foundation upon which they can subsequently build their clinical knowledge.

While this book presents a holistic approach to Oral Anatomy, Tooth Morphology, Oral Histology and Oral Physiology, it specially emphasises Histology since an understanding of this subject is crucial for undergraduates. In addition to this, the book provides the following features to help undergraduates acquire a better understanding of the subject.

Salient Features

- Though a first-year textbook, it incorporates a 'clinical overview' of the various topics in each chapter. This will help students in appreciating the clinical applications of the concerned topics.
- A visual representation of 'step-by-step tooth carving techniques' in the ancillary DVD and instructions in the Tooth Morphology chapters will assist the students in their practical sessions.
- Key points and multiple choice questions at the end of each chapter will help the students in quickly revising the subject and assessing their understanding.
- The appendix on summary of histologic slides with lucid images and appropriate identification points will assist the students in their preparation for practical examinations.
- To arouse more interest in the subject, additional reading has been added for some of the Oral Histology topics. This will be useful for students seeking more detailed knowledge.

It has been our sincere endeavour to present a textbook which will serve as a sound foundation for the subsequent study of oral pathology and medicine. We hope that faculties and students find this approach useful. We would appreciate their comments and suggestions for further improvement and would gratefully acknowledge the same.

K. Rajkumar
R. Ramya

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The thought of second edition sounded simple and undemanding. Nonetheless, we understood that it was an arduous task from the time the new edition was proposed. A whirlwind of activities by a diligent team made this possible.

At this juncture, we bow to the benevolence of the divine for giving us this noble opportunity. With a feeling of utmost gratitude, we extend our warmest thanks to Chancellor Dr. T.R. Pachamuthu, SRM University; Chairman Dr. R. Shivakumar; and Dr. K. Ravi, Dean, SRM Dental College, for providing us with the positive academic environment to sustain this dream run. We extend our deepest thanks to Dr. T.R. Saraswathi who accepted to write the *Foreword* for the book.

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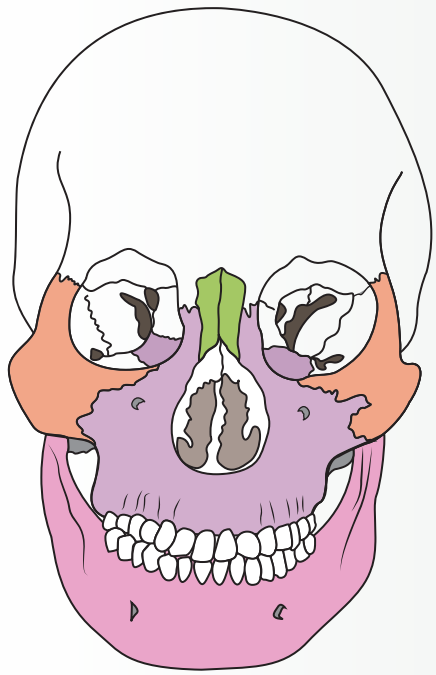
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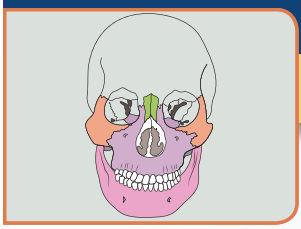
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SECTION I

Oral Anatomy



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CHAPTER 1

Introduction to Oral Anatomy

Overview

Oral anatomy is the study of the structures related to the oral cavity (which is commonly referred to as the mouth) and/or the face. The oral cavity is composed of various structures which play a vital role in essential physiologic activities such as speech, mastication and deglutition. The hard tissue unit of the oral cavity includes maxilla, mandible, other facial bones and most importantly the tooth and its supporting alveolar process. The soft-tissue unit of the oral cavity includes tongue, palate, lips, gingiva, cheek and salivary glands.

DEFINITION OF ORAL ANATOMY

Anatomy (Greek word *anatome—ana* = apart/ separate; *tome* = to cut open/ to cut apart) is a branch of biology and medicine that deals with the structure of living things. Knowledge of anatomy is the basis for understanding the other basic sciences such as physiology, microbiology and pathology as well as applied sciences such as medicine and surgery.

Oral anatomy is the study of the structures related to the oral cavity (which is commonly referred to as the mouth) and/or the face. It is the foundation for sound dental education and practice. This chapter aims at providing the necessary explanation to help understand the fundamental terminology and structural units associated with oral anatomy. Detailed descriptions of all the anatomical structures are dealt with in Chapters 2–7.

INTRODUCTION TO ORAL ANATOMY

The oral cavity, commonly referred to as mouth, is also called the buccal cavity. It is the most frequently used part of the human body and performs many functions which are vital and essential for the existence of the body. Being the origin of the alimentary canal that receives food, its primary function is related to the processing and digestion of food, and the secondary functions are those associated with speech, respiration, aesthetics and facial expressions.

A dentist's field of work is the oral cavity, which necessitates a thorough understanding of the oral structures for effective care of patients.

Significance of Oral Anatomy

With the ever-expanding frontiers of medicine, the necessity of super-specialization has attained paramount priority. Gone are the days when a single physician took care of all the problems of a patient. Today, there is a remarkable improvement in the quality of patient care and treatment, with a more focused management of disease processes. With the growth of subspecialties and super-specialization, there has arisen a definitive need for target-oriented and focused literature which emphasize the regional management of disease processes. Dentistry on its own can be considered as a specialized branch of health sciences focusing on the management of diseases of the teeth, oral cavity and perioral (around the mouth) structures. A very important component in the fundamentals of dental education is oral anatomy, which forms the basis of understanding the structure and function of components constituting the oral cavity, face, head and neck. In-depth knowledge of the oral and perioral structures, their relationship with the adjacent structures and relevant nomenclature is essential for the following reasons:

1. To identify/study normal structure and form
2. To recognize abnormalities
3. To understand disease processes by correlating abnormalities with normal structures

4. To lay a foundation for the study and practice of pathology
5. To aid in diagnosis and treatment of disease processes
6. To plan and perform surgical procedures

The study of the oral cavity can never be complete without the knowledge of the perioral structures, as the functioning of one anatomical unit depends on its interaction with the neighbouring units and in turn the body as a whole. The oral cavity has a direct structural as well as a direct and indirect functional relationship with the surrounding structures including the brain which mandates learning about the surrounding structures too.

Thus, oral anatomy broadly encompasses two major components:

1. Oral cavity (**Fig. 1.1**)
2. Perioral structures, which include the face, head and neck (**Figs 1.2—1.4**)

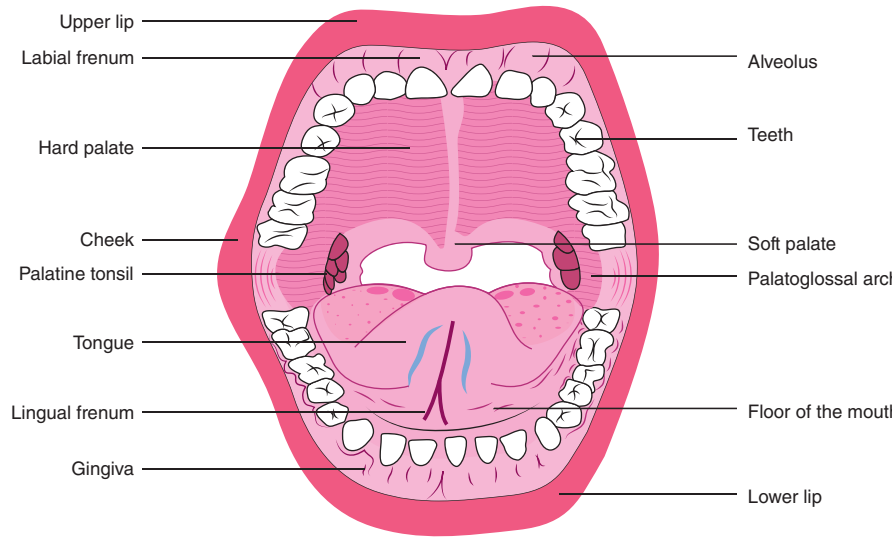


Figure 1.1 Components of the oral cavity.

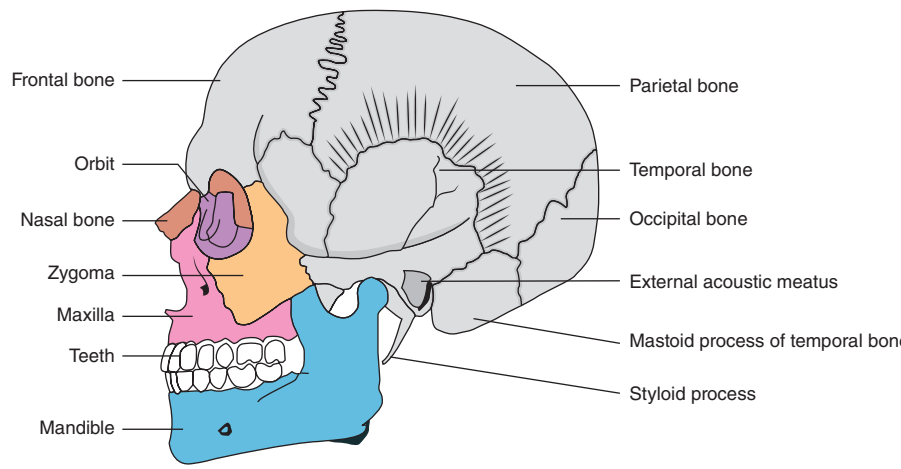


Figure 1.2 Skeletal components of the head.

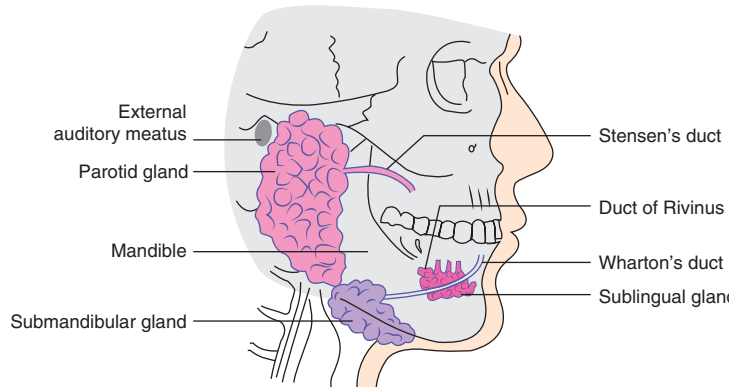


Figure 1.3 Major salivary glands.

ORGANIZATION OF THE ORAL CAVITY

The human body in totality or in parts (e.g. oral cavity) essentially consists of an outer integumentary system of skin or mucous membrane which contains/envelopes the inner structures. These inner components may be divided into the following:

1. **Viscera:** These are the internal organs that perform specific functions.
2. **Skeletal system:** It is composed of bones and joints which provide the structural framework for the form and function of the human body.
3. **Muscular system:** It consists of components which position and coordinate movements of the skeletal system and the viscera.
4. **Nervous system:** It consists of a network of nerves which help in the integration, coordination and functioning of all other systems by transmission of electrical impulses from the brain and the spinal cord.
5. **Vascular system:** It consists of arteries and veins which help in the supply and drainage of blood, respectively, to and from the tissues and the viscera.
6. **Lymphatic system:** These are structures that play a role in the locoregional defence of the human body through a network of lymphatic channels and collection centres called lymph nodes.

The descriptions of the above-mentioned components pertaining to the head and neck are discussed elaborately in individual chapters.

BOUNDARIES OF THE ORAL CAVITY

The extent of the oral cavity is demarcated by the following landmarks: hard and soft palates superiorly and the tongue and floor of the mouth inferiorly (**Fig. 1.4**). The anterior and lateral boundaries are formed by the lips, upper teeth and lower teeth while the palatoglossal folds on either side mark the posterior limiting point. The oral cavity is unique in the fact that it has a totally moist environment and is lined by mucous membrane.

DIVISIONS OF THE ORAL CAVITY

The oral cavity is an almost oval-shaped cavity with two basic components (**Fig. 1.4**):

1. Vestibule
2. Oral cavity proper

Vestibule/vestibulum oris (**Fig. 1.4**) is the space bounded by the lips and cheeks on the exterior and the gums and teeth within. It is lined by mucous membrane, which is kept moist by the secretions received from the salivary glands. This mucous membrane is continuous with the mucous lining of the lips, cheeks and alveolus of the upper and lower jaws. The vestibule communicates with the exterior of the body through the orifice of the mouth or the oral sphincter (also called the rima) and with the oral cavity proper on either side through a narrow space behind the wisdom teeth when the mouth is closed.

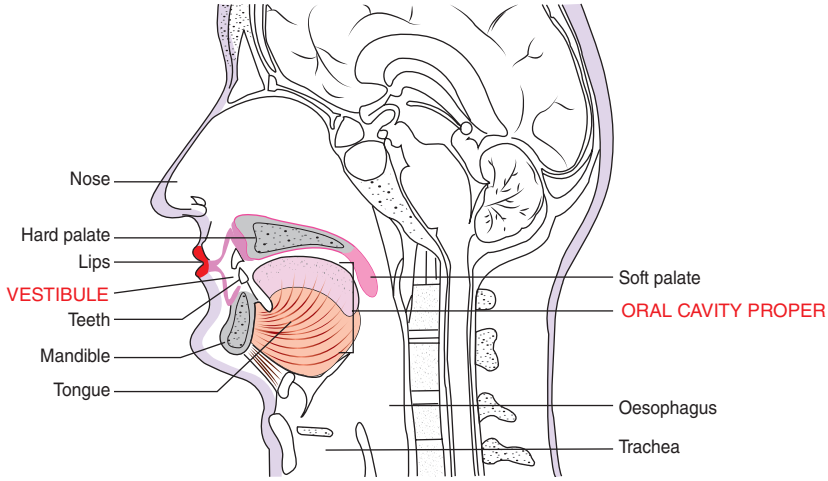


Figure 1.4 Boundaries of the oral cavity.

Oral cavity proper/cavum oris proprium (**Fig. 1.4**) is the area confined within the upper and lower dental arches. When the mouth is closed, the oral cavity proper is surrounded on all sides by the alveoli carrying the teeth. It communicates with the pharynx through a narrow inlet called the isthmus of fauces or oropharyngeal isthmus. Its roof is formed by the hard and soft palates and the floor by the tongue and the mucous membrane lining the floor of the mouth.

BASIC TERMINOLOGY

The following terminology is important to understand and simplify the description of individual anatomical structures of the oral cavity as well as their relationship to the adjacent organs. The terminology is clinically useful in describing the extent of any lesion in case sheets, surgical procedures or communicating with professionals.

1. **Superficial, intermediate and deep**
   (a) *Superficial:* Structures closer to the surface, that is skin or oral mucous membrane
   (b) *Intermediate:* Structures in between superficial and deep
   (c) *Deep:* Structures located much below the surface, at greater depths
2. **Medial and lateral** (**Fig. 1.5**)
   (a) *Medial:* Means 'towards the midline' or 'towards the middle' of the dental arch
   (b) *Lateral:* Means 'towards the sides' or 'towards the cheek'
3. **Internal and external**
   (a) *Internal:* Denotes the inner aspect
   (b) *External:* Denotes the outer aspect
4. **Anterior and posterior** (**Fig. 1.5**)
   (a) *Anterior:* Means towards the front of the mouth
   (b) *Posterior:* Means towards the back of the mouth
5. **Proximal/mesial and distal** (**Fig. 1.5**): These terms are commonly used in relation to the dentition. The proximal surfaces of the teeth may either be mesial or distal.
   (a) *Proximal/mesial:* Means towards the midline of the dental arch

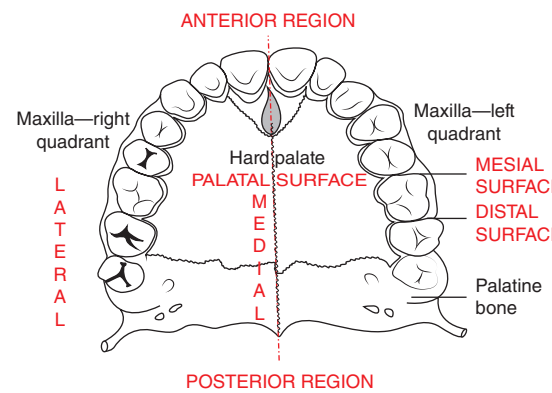


Figure 1.5 Maxilla—quadrants and surfaces.

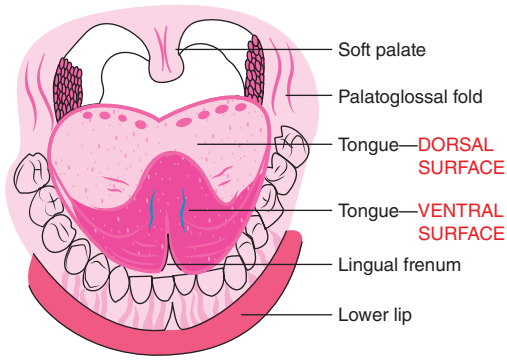


Figure 1.6 Dorsal and ventral surfaces.

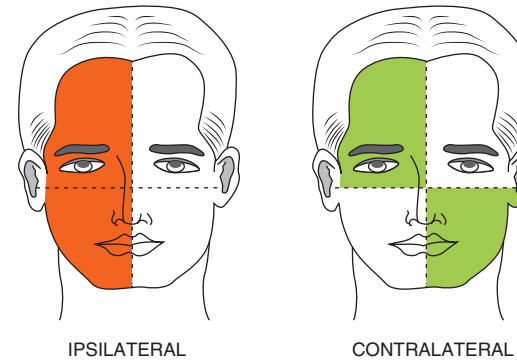


Figure 1.7 Ipsilateral and contralateral.

(b) *Proximal/distal:* Means away from the midline of the dental arch

When used in a context not related to the dentition, proximal refers to the regions closer to the trunk while distal refers to the part which is away from the trunk. For example, the condyle of the mandible is the proximal part of the mandible while the symphyseal region is the distal part.

6. **Dorsal and ventral** (**Fig. 1.6**)
   (a) *Dorsal:* Refers to the surface on the back or the upper surface of an organ. It also indicates the surface facing away from the ground.
   (b) *Ventral:* Refers to the surface on the front or the lower surface of an organ. It also indicates the surface facing towards the ground.
7. **Ipsilateral and contralateral** (**Fig. 1.7**)
   (a) *Ipsilateral:* Denotes 'on/related to' the same side. For example, the right arm is ipsilateral to the right leg.
   (b) *Contralateral:* Denotes the 'opposite side'. For example, the right arm is contralateral to the left leg.
8. **Inferior and superior**
   (a) *Inferior:* Denotes 'lower'
   (b) *Superior:* Denotes 'upper'
9. **Quadrants:** A quadrant is an anatomical segment formed by the division of the maxillary or mandibular arch by an imaginary midline. It divides each arch into a left half and a right half. The resulting four quadrants are named as follows (**Figs 1.5** and **1.8**):
   (a) Maxillary right quadrant
   (b) Maxillary left quadrant
   (c) Mandibular right quadrant
   (d) Mandibular left quadrant
10. **Occlusion:** It is the relationship of the teeth of the mandibular (lower jaw) and maxillary (upper jaw) arches at rest or during various movements of the mandible.
11. **Surfaces** (**Figs 1.5** and **1.8**): The surfaces of the various structures in the oral cavity are named based on the anatomical units nearby.
    (a) *Buccal:* Surface that faces the cheek
    (b) *Labial:* Surface that faces the lips
    (c) *Lingual:* Surface that faces/lies closer to the tongue
    (d) *Palatal:* Surface that faces/lies closer to the palate

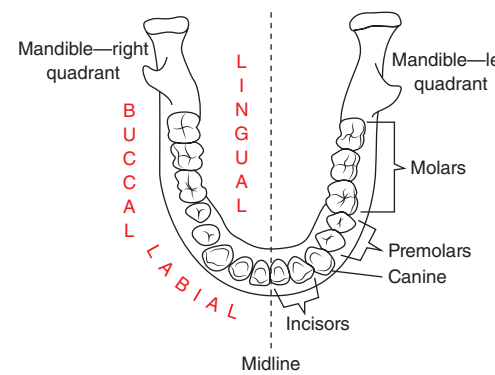


Figure 1.8 Mandible—quadrants and surfaces.

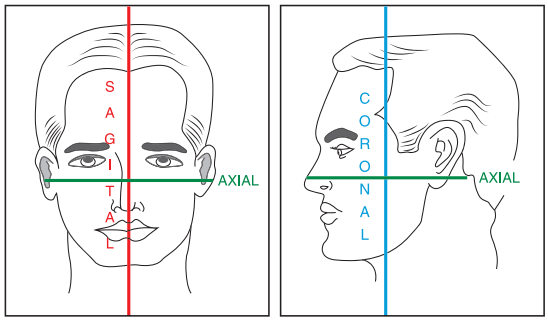


Figure 1.9 Anatomical planes.

12. **Anatomical planes** (**Fig. 1.9**): These are reference planes used to study deeper structures and their relationship to the adjacent anatomical units. They are two-dimensional representations of three-dimensional structures and are obtained by dissections in cadavers and imaging techniques in living subjects. The various planes are as follows:
    (a) *Median:* Plane that divides the body into right and left halves
    (b) *Sagittal:* Plane that divides the body/parts of the body into right and left unequal parts (**Fig. 1.10a**)
    (c) *Coronal:* Plane that divides the body/parts of the body into anterior and posterior parts. This plane is at right angles to the sagittal plane (**Fig. 1.10b**).
    (d) *Transverse/horizontal:* Plane that divides the body/parts of the body into upper and lower parts
    (e) *Axial:* Any cut/plane at right angles to the body or long axis of the body (**Fig. 1.10c**)

COMPONENTS OF THE ORAL CAVITY

The oral cavity and the perioral structures can be grouped into two major components:

1. **Hard tissues:** Skeletal unit (bones) and the dental unit (teeth)
2. **Soft tissues:** Tongue, cheeks, soft palate, lips, salivary glands and various other organs

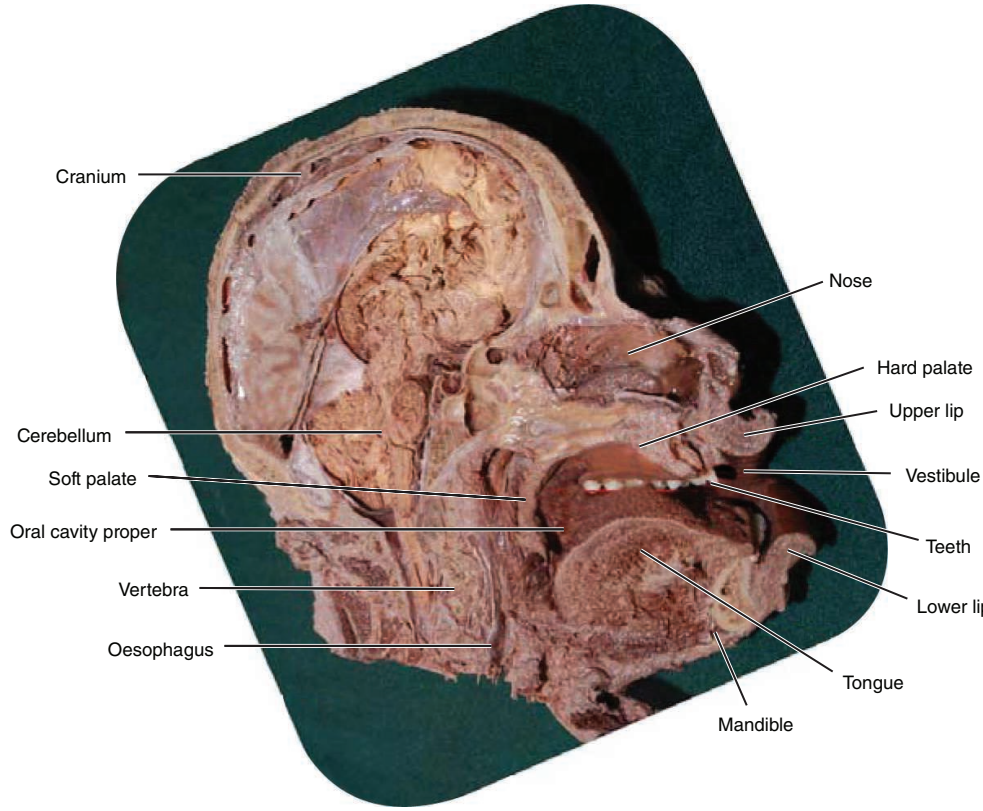
Hard Tissues

The hard tissues constituting the oral cavity and the perioral structures fall under the following two categories: perioral bones and dentition.

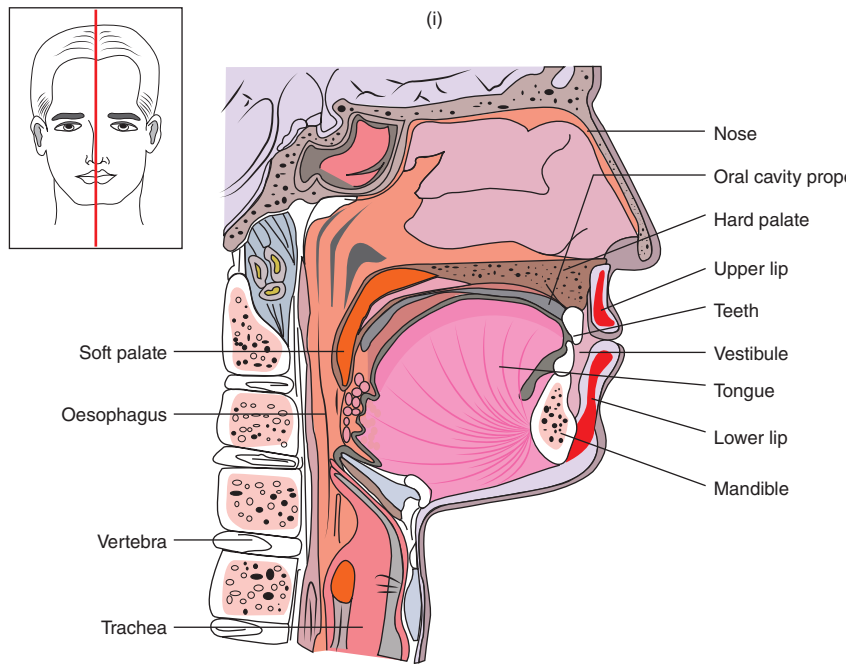
1. **Perioral bones**: These include the maxilla, the mandible and the other bones of the skull.
    (a) *Mandible* (**Fig. 1.2**) refers to the lower jaw. It is a movable sturdy bone that articulates with the rest of the skull by a joint on either side called the temporomandibular joint.
    (b) *Maxilla* (**Fig. 1.2**) refers to the upper jaw. Unlike the mandible, it is immovable. It acts like a cushion to shield the cranium from stress due to sudden trauma.
    (c) *Skull bones* (**Fig. 1.2**) include bones of the facial skeleton and the cranium (refer to Chapter 2 for a detailed description).
    (d) *Alveolus/alveolar process* (**Fig. 1.1**) is the part of the maxilla and mandible that supports the teeth.
2. **Dentition** (**Figs 1.2**, **1.5** and **1.8**): The term *dentition* refers to the natural teeth in the jaw bones whose function is to aid in digestion by breaking down ingested food into smaller fragments which can be acted upon by digestive enzymes in the stomach. It is of three types:
    (a) *Primary dentition* is the first set of teeth that erupt into the oral cavity. They are 20 in number and are also referred to as 'baby teeth' or 'deciduous teeth'.
    (b) *Permanent dentition* refers to the second set of succedaneous teeth that erupt after shedding of the primary dentition. They are 32 in number and are also called secondary or 'adult' teeth.
    (c) *Mixed dentition* occurs when both primary and permanent teeth are present, usually between the ages of 6 and 12 years.

The teeth vary in their shape, size and location in the jaws. The functions of the teeth vary according to their morphology:

1. *Incisors* are front, single-rooted teeth with a relatively sharp, thin edge designed to cut food. They are four in number in each arch—two centrals (front teeth) and two laterals (distal to the centrals).



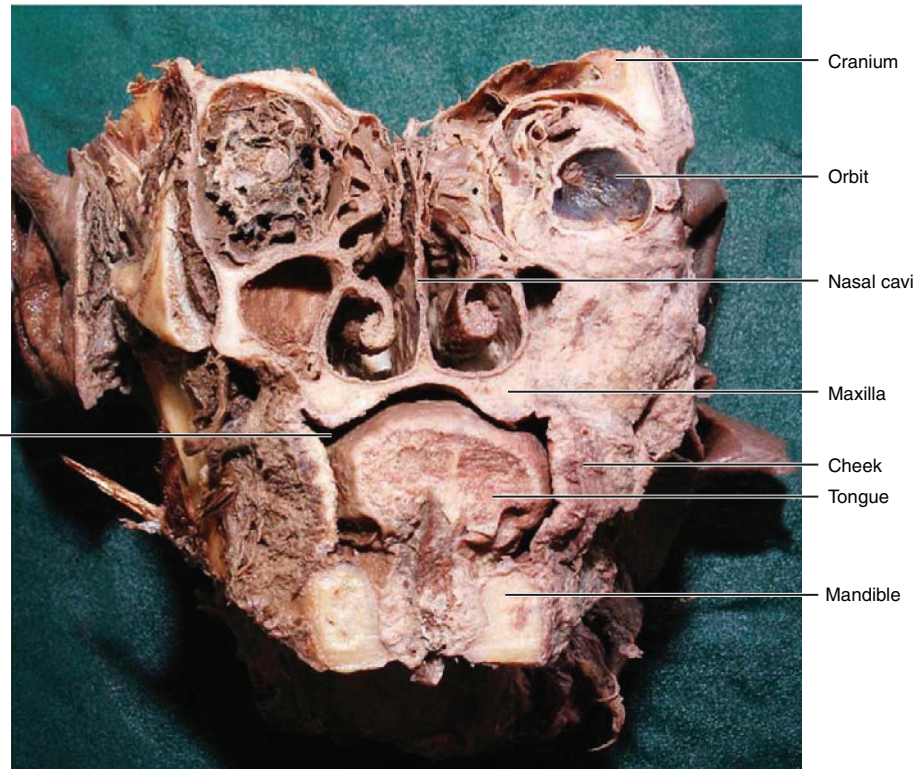
(i)



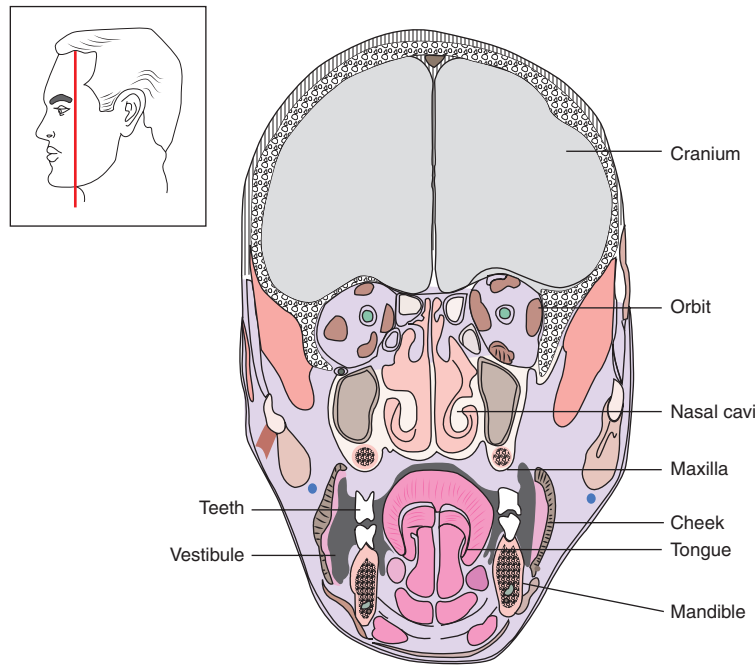
(ii)

(a)

Figure 1.10 (a) Sagittal section: (i) dissected specimen and (ii) schematic diagram. (*Continued*)



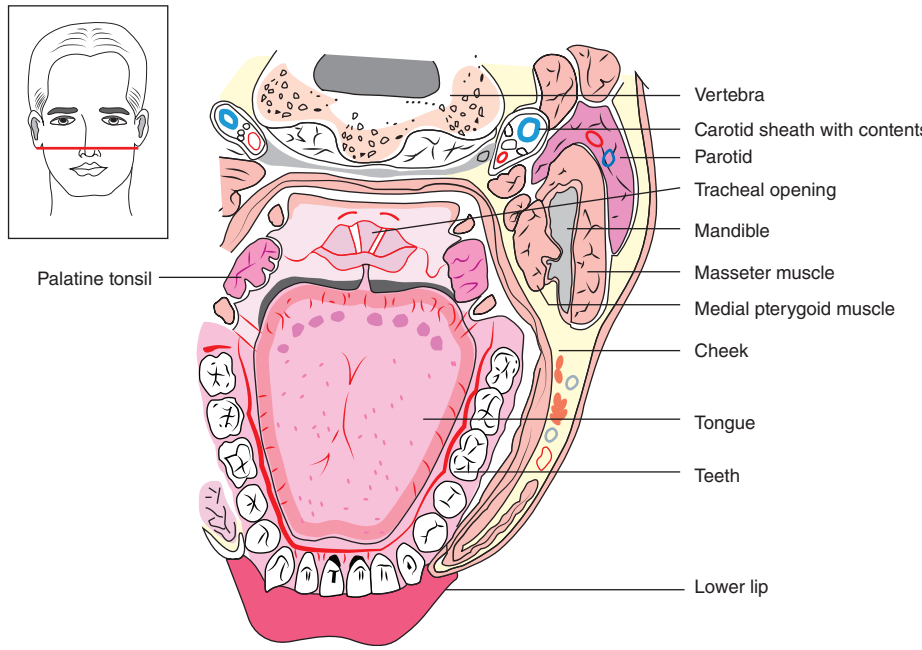
(i)



(ii)

(b)

Figure 1.10 (*Continued*) (b) Coronal section: (i) dissected specimen and (ii) schematic diagram.



(c)

Figure 1.10 (*Continued*) (c) Axial section.

2. *Canines* are corner teeth. They are also known as cuspids and are two in number, designed for cutting and tearing foods.
   (a) *Premolars* are also called bicuspids. They have cusps that hold and grind food. In every arch, there are four premolars in the permanent dentition. There are no premolars in the primary dentition.
   (b) *Molars* are larger teeth with more cusps than other teeth and are used to chew or grind food. In each arch, there are four molars in the primary dentition and six molars in the permanent dentition.

The morphology of every tooth in both the jaws is unique and numbered. This is discussed in detail under the section on Tooth Morphology.

Soft Tissues

The soft tissues of the oral cavity drape the skeletal components. They are comprised of the lips, cheeks, gums, tongue, salivary glands and soft palate.

1. **Lips** (*labia oris*) (**Fig. 1.1**) are the two fleshy linear structures (upper and lower) which encircle the orifice of the mouth and control the opening and closing of the oral cavity. Lips are composed of the orbicularis oris muscle, blood vessels, nerves, areolar tissue, fat and numerous minor salivary glands. They are covered externally by skin and internally by mucous membrane. The inner surface of each lip is connected to the corresponding gum by a fold of mucous membrane in the midline called the frenum (**Fig. 1.1**). Lips play an important role in deglutition and speech.
2. **Salivary glands** (**Fig. 1.3**) are organs that secrete saliva, which have a major role in various vital physiologic functions (discussed in Chapter 7). Three large pairs of salivary glands communicate with the mouth, pour their secretion into it and are responsible for maintaining the oral cavity moist. They are the parotid, submandibular and sublingual salivary glands. In addition, there are numerous minor salivary glands.
3. **Tongue** (*lingua*) (**Figs 1.1** and **1.6**) is a special sensory organ situated in the floor of the mouth, within the body of the mandible, containing many small papillae that hold the taste buds. It is firmly anchored to the floor of the

mouth by a fold of mucous membrane called the lingual frenum. It is the primary organ that helps in perceiving taste sensation and is also important for speech, mastication and deglutition of food.

4. **Cheeks** (*buccae*) (**Figs 1.1** and **1.10b**) are sheet-like structures that form the sides of the face and merge with the lips anteriorly. They are composed of muscle fibres, fat, areolar tissue, blood vessels and nerves and are lined by skin externally and mucous membrane internally.
5. **Gums** (*gingiva*) (**Fig. 1.1**) are tissues that cover the alveolar processes and encircle the necks of the teeth. They are composed of dense fibrous tissue and are adherent to the periosteum of the alveolar processes. They are covered by a firm mucous membrane. Gingivae extend as fine papillae into the interdental regions forming a healthy collar for the teeth and help in supporting them.
6. **Palate** (*palatum*) (**Figs 1.1** and **1.5**) is the anatomical unit that forms the roof of the mouth. It consists of two subunits: hard palate anteriorly and soft palate posteriorly.
   - The *hard palate* (*palatum durum*) (**Figs 1.4** and **1.5**) is the bony vault of the oral cavity bounded in front and the sides by the alveolar arches. It is continuous with the soft palate located behind it. It is covered by a firm lining formed by the adherence of the mucous membrane to the palatal periosteum and contains a few corrugations called rugae. It helps in the physical separation of the mouth from the nasal cavity and provides separate passages for the intake of air and food.
   - The *soft palate* (*palatum molle*) (**Figs 1.1** and **1.4**) is a movable soft tissue suspended from the posterior border of the hard palate and forms an incomplete barrier between the mouth and the pharynx. It is composed of mucous membrane overlying muscle fibres, palatine aponeurosis, blood vessels and nerves. It also contains mucous glands within its substance. The soft palate has a concave ventral surface and a convex dorsal surface which merges with the lining of the nasal cavities. Its anterior border is attached to the posterior aspect of the hard palate while the lower border is free. The sides of the soft palate blend with the pharyngeal wall. Along the posterior free end is a small midline conical process called the palatine uvula. Two curved folds of mucous membranes originate bilaterally from the base of the uvula and they are called the faucial pillars or arches.

SUBDIVISIONS OF ANATOMY (Fig. 1.11)

Anatomy can be broadly classified into macroscopic anatomy and microscopic anatomy. Macroscopic anatomy can further be subdivided into gross anatomy and surface anatomy while microscopic anatomy can be divided into cytology and histology.

Macroscopic Anatomy

Macroscopic anatomy is the study of structures that can be seen by the naked eye. It encompasses the following:

1. **Gross anatomy:** Study of the form/structure of the body parts as seen by naked eye/unaided vision. This can be done system-wise (e.g. vascular anatomy, neuroanatomy, osteology) or region-wise (e.g. head and neck, upper limb).
2. **Surface anatomy (superficial anatomy):** Study of the external surface of the body without dissection. It helps in identifying the inner configuration of anatomical structures with the aid of visible external landmarks.

Microscopic Anatomy

Microscopic anatomy is the study of structures in minute detail with microscopy. It consists of the following:

1. **Cytology**: Study of cells
2. **Histology**: Study of tissues

This also includes more specialized methods such as histochemistry and immunocytochemistry

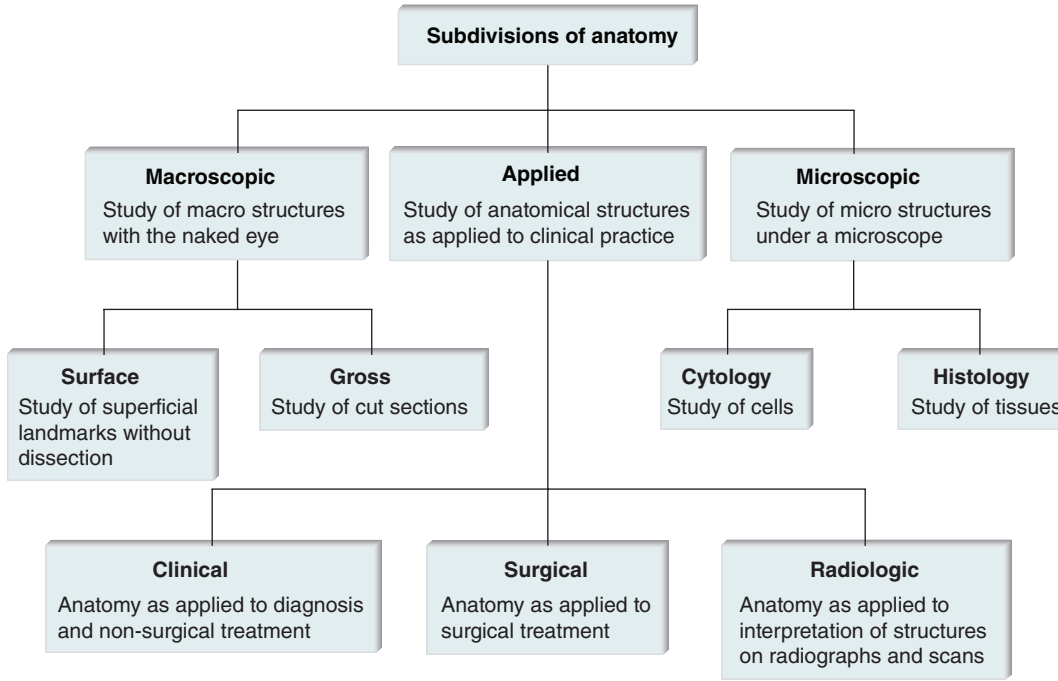


Figure 1.11 Subdivisions of anatomy.

where biochemical techniques are combined with histology.

Applied Anatomy

Applied anatomy is the study of the form and structure of different anatomical units as applied to diagnosis and treatment. It includes:

1. **Clinical anatomy:** It is the practical application of anatomy in diagnosis and treatment planning.
2. **Surgical anatomy:** It is the anatomy that facilitates planning and performing surgical procedures.
3. **Radiologic anatomy (also called imaging anatomy):** It is the study of anatomy in living subjects by interpretation of structures in radiographs and scans.

The evolution of the field of anatomy has led to creation of other specialized branches such as developmental anatomy (embryology) and comparative anatomy (comparative study of anatomy in different species).

APPROACHES TO STUDYING ANATOMY (Fig. 1.12)

The modes of studying anatomy are more than being confined to books. They have widened scope with the use of clinical material in the form of cadavers, live subjects, imaging methods and microscopy. Today, anatomy is learnt through diverse and novel approaches as mentioned below.

1. **Dissectional:** This includes the traditional study of gross anatomy of the deeper structures with the aid of scalpel dissection of cadavers and study during surgical dissection in live subjects.
2. **Clinical:** This is the study of anatomy practically in living subjects by inspection and palpation. It correlates clinical features with anatomical structures and helps in application of anatomy to diagnosis and treatment of patients.
3. **Radiologic:** This consists of a structural study in the living subject through real-time modes,

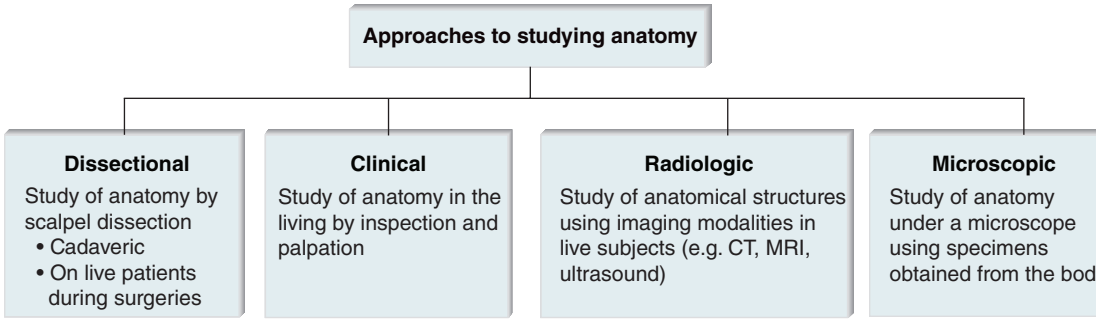


Figure 1.12 Modes of studying anatomy.

such as ultrasound, and cross-sectional modes, such as CT and MRI scans.

4. **Microscopic:** This is primarily an in-vitro specialization which involves the study of cells and tissues of specimens obtained from human body through microscopy.

IMPLICATIONS OF ORAL ANATOMY IN DENTISTRY

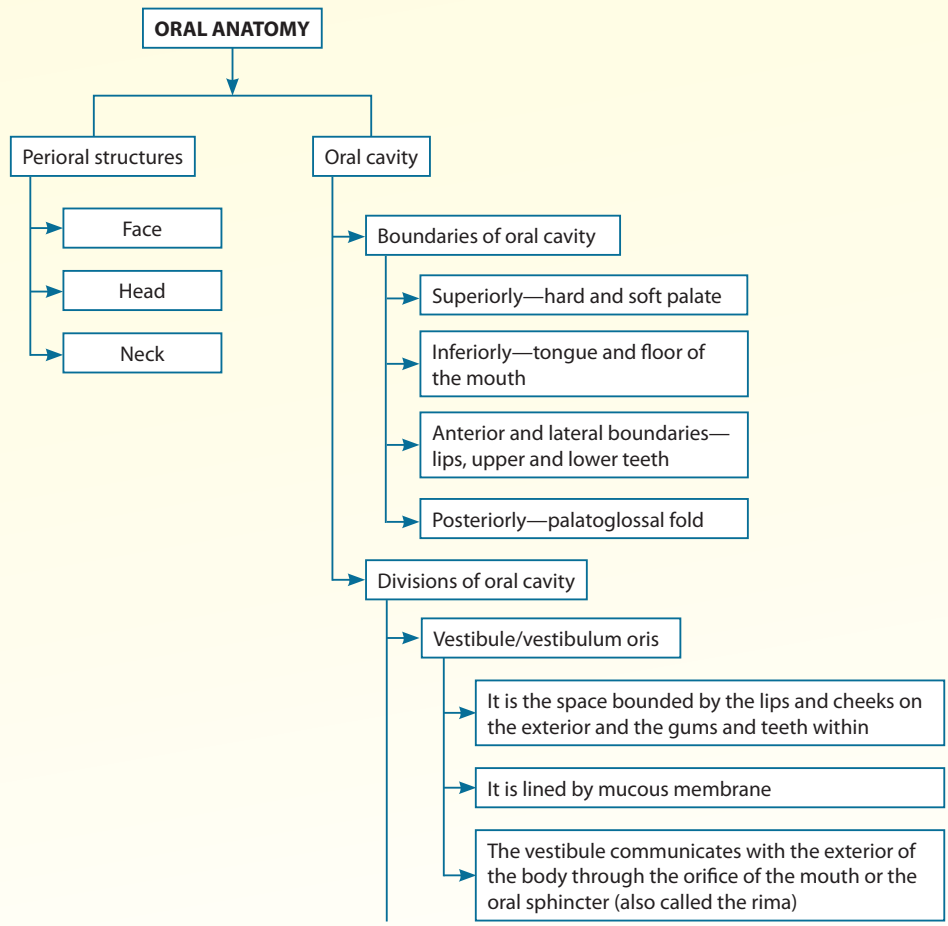
Dentistry is a specialized branch of health science dealing with the care and well-being of the teeth and the oral cavity. The study of oral anatomy has numerous implications in dentistry as highlighted below.

1. **Establishing harmony between anatomical parts and dentistry:** A dentist has the crucial role of restoring the form, function and aesthetics of the oral cavity and the face which are totally dependent on achieving ideal oral anatomy.
2. **Understanding the functional importance of the oral cavity:** The realm of the dentist is not only the teeth. It includes complex functions such as speech, respiration and facial expression which are influenced by the structures in his domain. A change in the anatomy and dynamics of the oral cavity has a direct influence on the above-mentioned functions. For example, a denture extending into the soft palate can not only affect mastication, which is the primary function for its fabrication, but may also significantly alter speech. A deficiency or abnormality in the jaws may affect a very important function such as respiration by creating an obstruction in the pharyngeal inlet.
3. **Diagnosing disease processes:** Knowledge of regional anatomy helps us to distinguish the abnormal from the normal, such as identification of a lingual thyroid or a syphilitic gumma. It provides us with an understanding of the channels and modes for the spread of disease process from the mouth to the body and vice versa, such as the occurrence of cavernous sinus thrombosis secondary to a perioral infection.
4. **Planning and performing treatment procedures:** Anatomical knowledge plays an important role in the planning and execution of surgical procedures in a precise manner.
5. **Maintaining oral care, restoration and rehabilitation:** Rehabilitation of oral structures, which is the primary role of a dentist, requires good working knowledge of the regional anatomy. Anatomy enables better application of biomechanical principles for an effective aesthetic and functional outcome.

Key Points

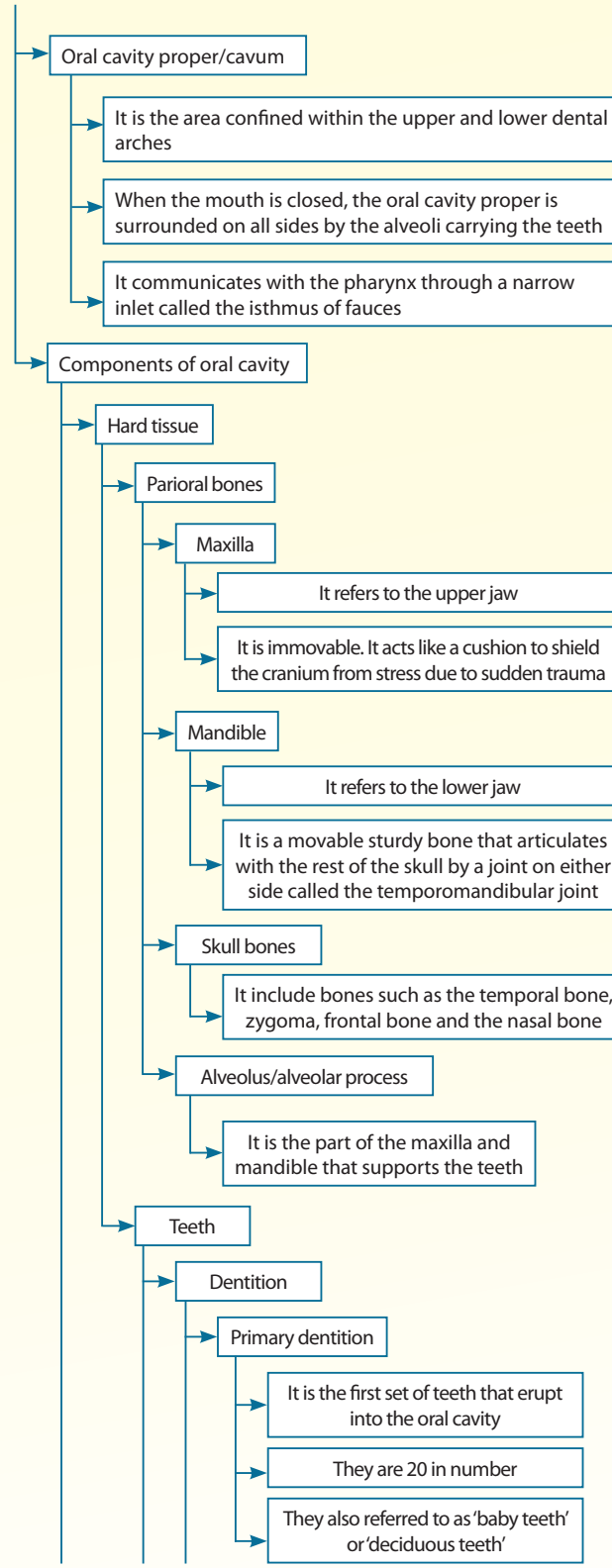
1. Oral anatomy is the study of structures related to the oral cavity (which is commonly referred to as the mouth) and/or the face.
2. The basic components of any anatomical unit are as follows: viscera (internal organs), skeleton (bone and joints), muscles, nerves, blood vessels and lymphatic system.
3. The major parts of oral cavity include the vestibule and oral cavity proper.
4. *Anatomical planes* are reference planes used to study deeper structures and their relationship to the adjacent anatomical units. The various planes are *sagittal*, *coronal*, *transverse/horizontal* and *axial*.
5. Anatomy can be broadly classified into macroscopic anatomy and microscopic anatomy. Macroscopic anatomy can further be subdivided into gross anatomy and surface anatomy while microscopic anatomy includes cytology and histology.
6. Applied anatomy is the study of the form and structure of different anatomical units as applied to diagnosis and treatment. It may be surgical, clinical or radiologic.
7. Alteration in anatomy leads to abnormalities in the form and function of organs which clinically present as diseases. The study of such diseases is called pathology.

Mind Map



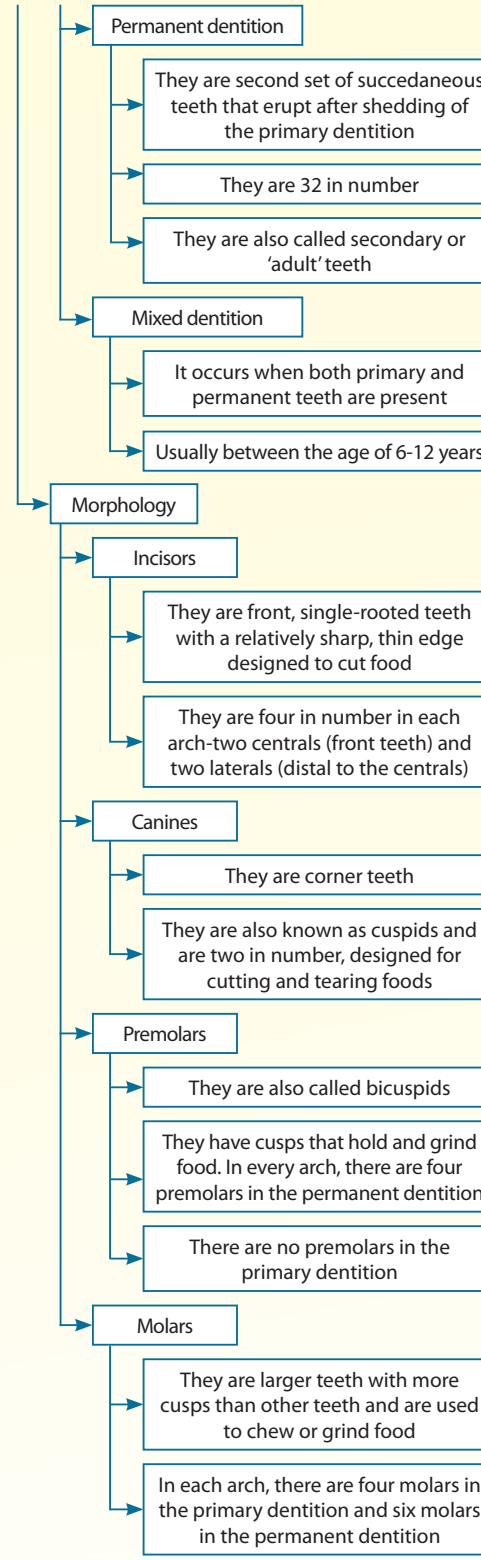
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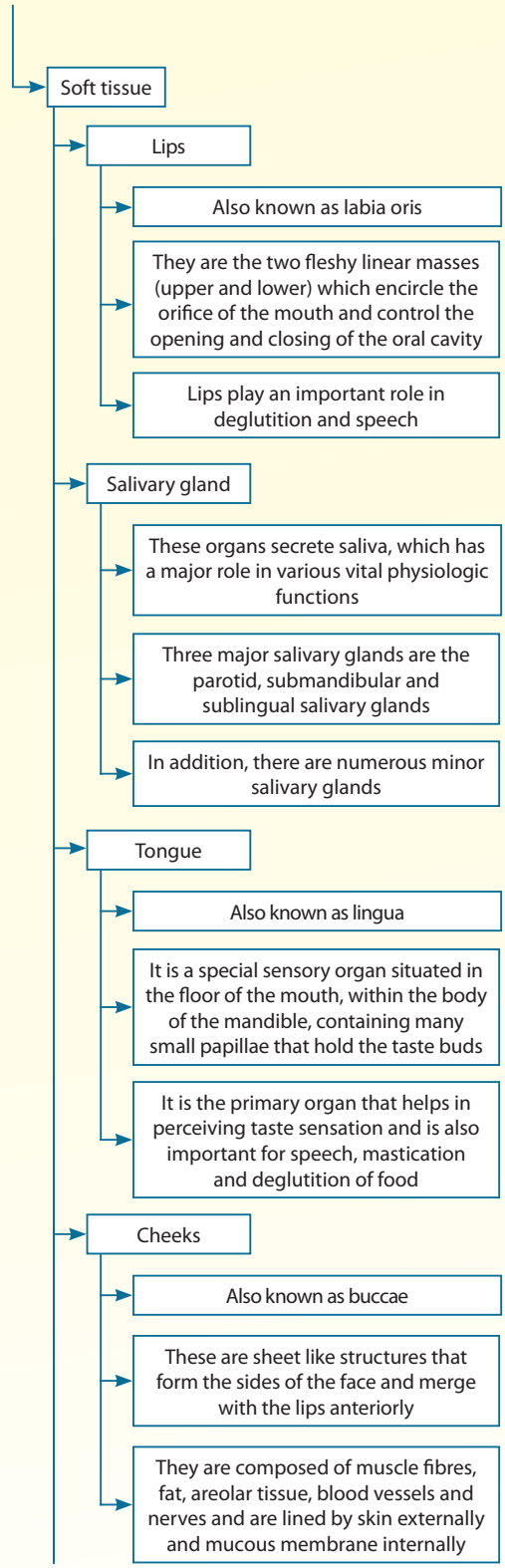
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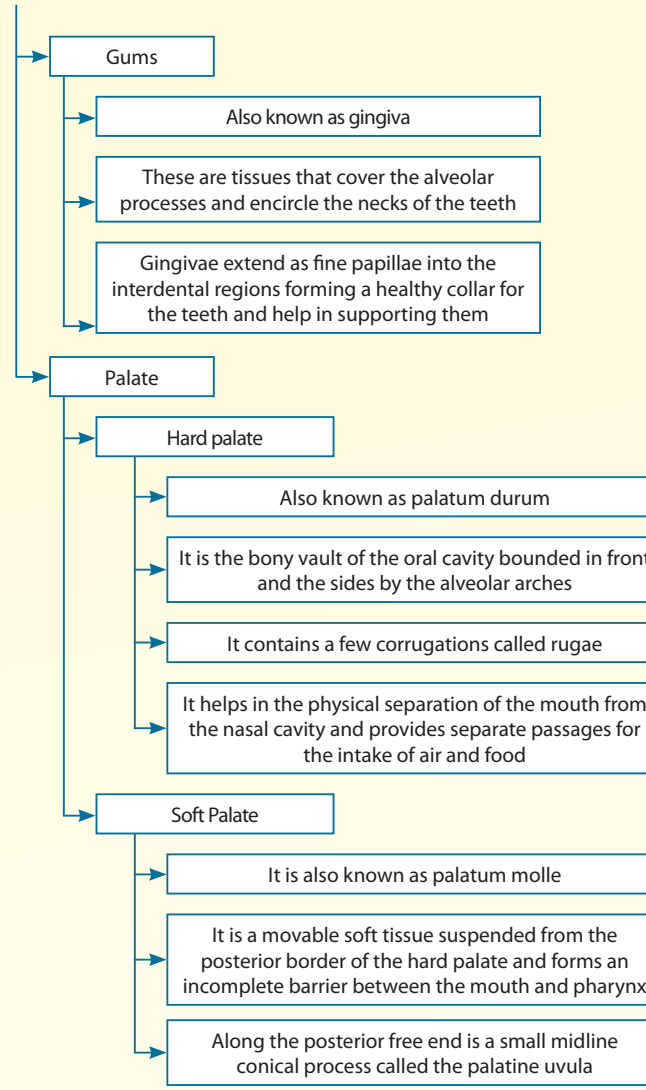
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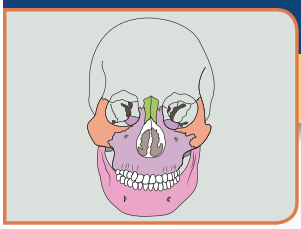
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Multiple Choice Questions

1. Buccal cavity refers to the
   (a) Oral cavity
   (b) Nasal cavity
   (c) Auditory cavity
   (d) Pituitary cavity
2. The term *viscera* refers to
   (a) Cheek
   (b) Internal organs
   (c) Soft palate
   (d) Mandible
3. The role of the lymphatic system is in
   (a) Maintaining body temperature
   (b) Respiration
   (c) Locoregional defence
   (d) Digestion
4. The posterior limit of the oral cavity is formed by the
   (a) Lips
   (b) Tongue
   (c) Palate
   (d) Palatoglossal fold
5. The term *medial* denotes
   (a) Towards midline
   (b) Towards cheek
   (c) Towards the sides
   (d) On the muscle
6. The term that refers to the surface on the back or the upper surface of an organ is
   (a) Ventral
   (b) Dorsal
   (c) Medial
   (d) Lateral
7. The relationship of the teeth of the mandibular and maxillary arches at rest or during various movements of the mandible is called
   (a) Articulation
   (b) Quadrant
   (c) Occlusion
   (d) Intercuspation
8. The sagittal plane divides the body into
   (a) Upper and lower parts
   (b) Superficial and deep parts
   (c) Front and back parts
   (d) Right and left parts
9. The maxilla is the
   (a) Upper jaw
   (b) Lower jaw
   (c) Lower joint
   (d) Lower tooth
10. The organ that helps in digestion is the
    (a) Lacrimal gland
    (b) Salivary gland
    (c) Pituitary gland
    (d) Lymph node



CHAPTER 2

Osteology of Skull

Overview

The human body is composed of 206 bones. Bones can be classified in general on the basis of location into axial and appendicular, on the basis of shape into flat, tubular and irregular bones, on the basis of size into long and short bones and on the basis of histology into compact and cancellous bones. The bones of the head can be grouped into cranial (8) and facial bones (14). Frontal, parietal, temporal, occipital, sphenoid and ethmoid constitute the cranial bones while nasal, zygomatic, palatine, lacrimal, vomer, maxilla and mandible constitute the facial bones. Bones possess rich vascularization via the endosteal and periosteal vessels. Thorough knowledge of the anatomy of cranial and facial bones is imperative for a dental surgeon.

INTRODUCTION

Osteology is the study of bones. The bone is a calcified connective tissue that forms the basic unit of the human skeletal system. It is of great importance for various physiological functions such as the following:

1. **Support:** Bones provide the hard structural framework to support the other structures of the body.
2. **Protection:** Bones protect the vital soft inner organs.
3. **Movement:** Bones, in co-ordination with the muscles, aid in locomotion.
4. **Electrolyte and acid–base balance:** Bones maintain the electrolyte and acid–base balance.
5. **Blood formation:** Bones contain red bone marrow which is the main site for synthesis of blood.
6. **Storage of minerals**: Minerals such as calcium and phosphorus which perform vital physiological functions in the body are stored in bones.
7. **Fat storage**: The yellow bone marrow in some bones is one of the sites of fat storage.

The terms generally used to describe bone structure are defined in **Box 2.1**.

Box 2.1 Osteology-Related Terminology

- **Canal:** A long passage within bone that transits blood vessels and nerves
- **Foramen:** A natural opening or perforation through bone that permits transit of blood vessels and nerves (*pl.* foramina)
- **Fossa:** A hollow or depressed area on the surface of bone (*pl.* fossae)
- **Notch:** A curved depression or indentation
- **Pit, groove and fissure:** Depressions that serve to increase the extent of surface for the attachment of ligaments and muscles (pit is circular but groove and fissure are linear)
- **Ridge, crest or line:** A narrow, rough elevation, extending to some distance along the surface
- **Spine:** A sharp, slender, pointed eminence
- **Sulcus:** A groove, crevice or furrow present on a bony surface meant for attachment of soft tissues or to house delicate structures (*pl.* sulci)
- **Tubercle:** A small, rough prominence
- **Tuberosity, protuberance or process:** A broad, rough, uneven elevation on bone

CLASSIFICATION OF BONES

Bones can be categorized on the basis of their location, shape, size and structure.

1. **On the basis of location**
   (a) *Axial skeleton:* Bones that occupy the central position of the skeletal system (e.g. bones of the skull, vertebral column, sternum and ribs)
   (b) *Appendicular skeleton:* Bones that occupy the lateral position of the skeletal system (e.g. bones of the pectoral girdle, pelvic girdle and limbs)
2. **On the basis of shape**
   (a) *Flat bone* (e.g. bones of the skull, sternum, pelvis and ribs)
   (b) *Tubular bone* (e.g. bones of the limbs)
   (c) *Irregular bone* (e.g. bones of the face and vertebral column)
3. **On the basis of size**
   (a) *Long bone:* Bones that are tubular in shape (e.g. bones of the limbs)
   (b) *Short bone:* Bones that are cuboidal in shape (e.g. tarsal bones in feet)
4. **On the basis of histology**
   (a) *Compact* (e.g. cortical part of long bones)
   (b) *Cancellous* (e.g. marrow of long bones)

The adult skeletal system comprises nearly 206 bones. It is less when compared with the actual number of bones present at birth, which is approximately 270. The reduction in number is due to the fusion and ossification that occur during the bone development phase since birth.

This chapter deals with the study of the bones that constitute the head. The bones of this region form part of the axial skeleton which supports and protects the organs of the head and neck. The skeletal unit of the head is called the skull and is made of 22 bones. It is anatomically and functionally subdivided into the following:

1. **Anatomical:** On the basis of the anatomical region involved, the bones of the head are classified into the following:
   (a) *Cranial bones:* These are bones that comprise the brain case and are eight in number (**Table 2.1**; **Figs 2.1–2.3**). In the figures, the cranial bones are not coloured whereas the facial bones are coloured.
   (b) *Facial bones:* These are bones that comprise the face and are 14 in number (**Table 2.1**).

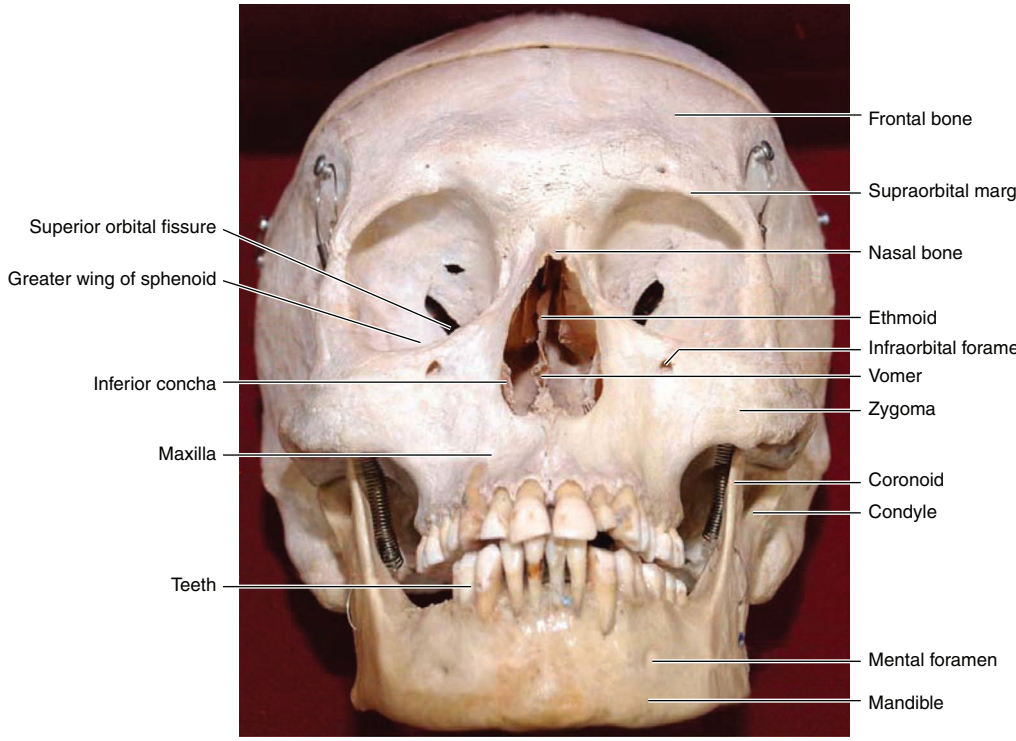
Table 2.1 Skull Bones (22 Bones)

Cranial Bones/ Neurocranium (8)	Facial Bones/ Viscerocranium (14)
Ethmoid bone (1)	Inferior nasal conchae (2)
Frontal bone (1)	Lacrimal bones (2)
Occipital bone (1)	Mandible (1)
Parietal bones (2)	Maxillae (2)
Sphenoid bone (1)	Nasal bones (2)
Temporal bones (2)	Palatine bones (2)
	Vomer (1)
	Zygomatic bones (2)

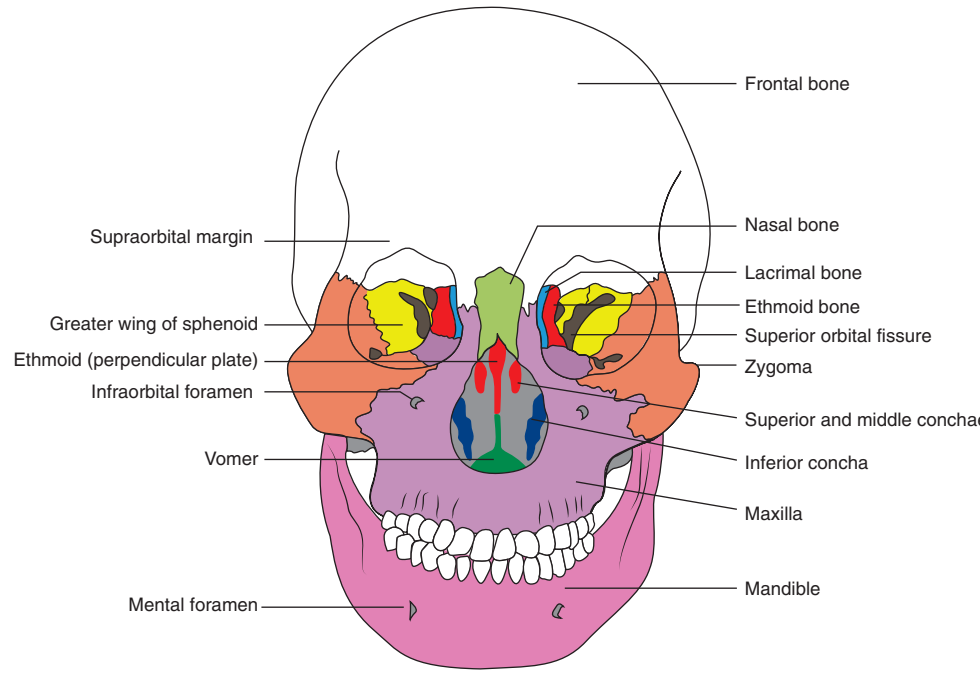
Applied Anatomy

Head injuries are a major cause of concern because they can lead to severe disability and even death. This is due to the involvement of the brain and the cranial nerves present within the cranium. The most common symptom of head injury is loss of consciousness. The convexity and thickness of the calvaria dissipate the shock due to trauma and thereby minimize the deleterious effects of a blow to the head.

2. **Functional:** Bones have specific functions individually or collectively and are classified into the following (**Fig. 2.4**):
   (a) *Neurocranium:* It is the bony covering of the brain and related structures, consisting of eight bones, namely the frontal bone, the parietal bones (paired), the occipital bone, the sphenoid bone, the ethmoid bone and parts of the temporal bones (paired) (**Fig. 2.5**). It is further divided into
      - *Roof/calvaria*: This comprises frontal, parietal, temporal and occipital bones (**Fig. 2.5**).
      - *Floor/basicranium*: This comprises the orbital process of the frontal bone, sphenoid, ethmoid, petrous temporal and occipital bones (**Fig. 2.6**).
   (b) *Viscerocranium or splanchnocranium:* This bony covering surrounds the oral cavity, pharynx and upper respiratory passages and is composed of 14 bones.

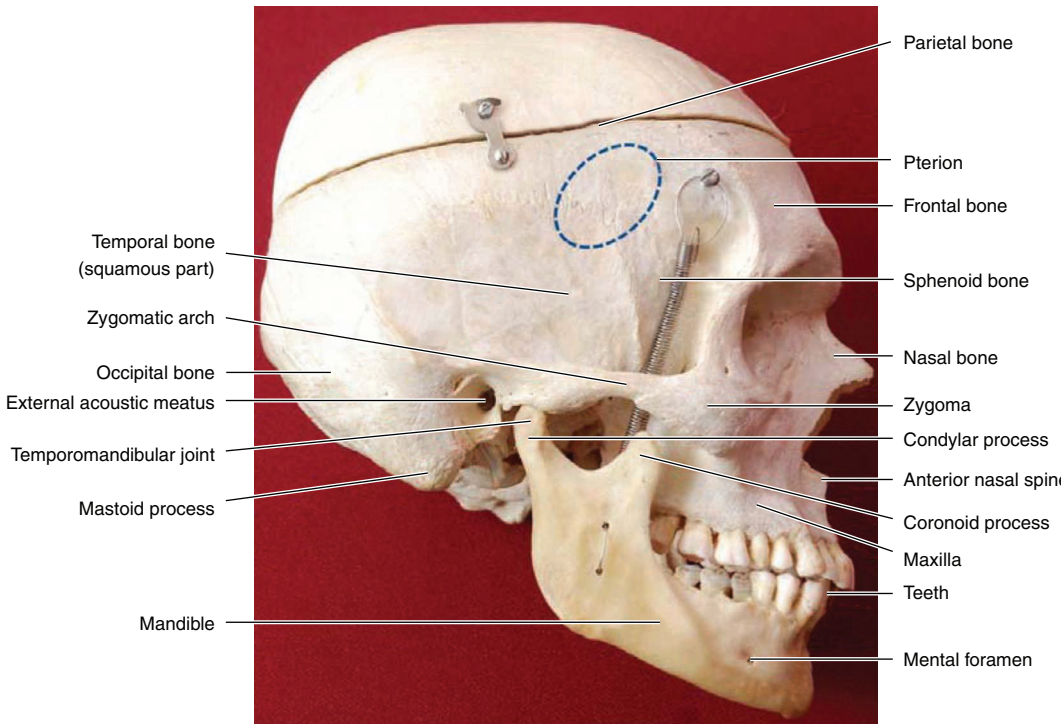


(a)

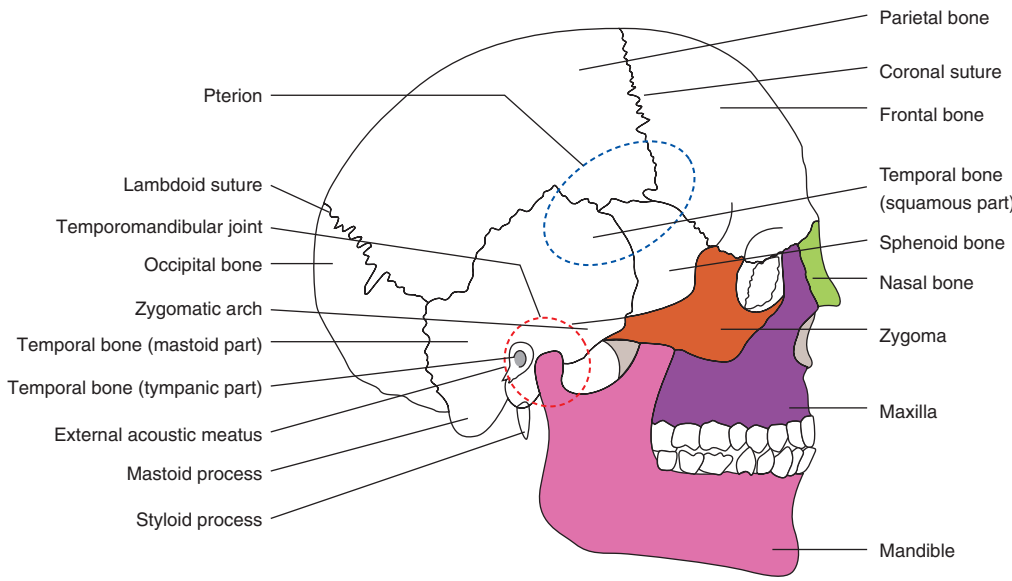


(b)

Figure 2.1 Skull—frontal view: (a) specimen of skull and (b) schematic diagram.



(a)



(b)

Figure 2.2 Skull—lateral view: (a) specimen of skull and (b) schematic diagram.

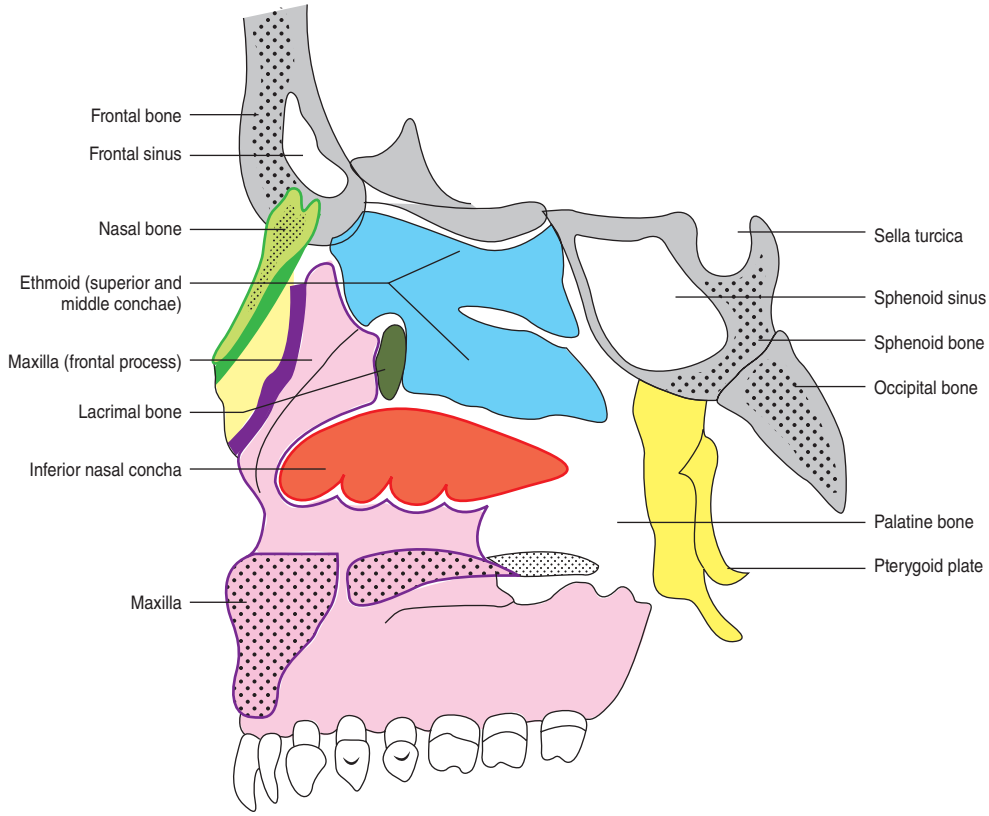


Figure 2.3 Skull—sagittal view.

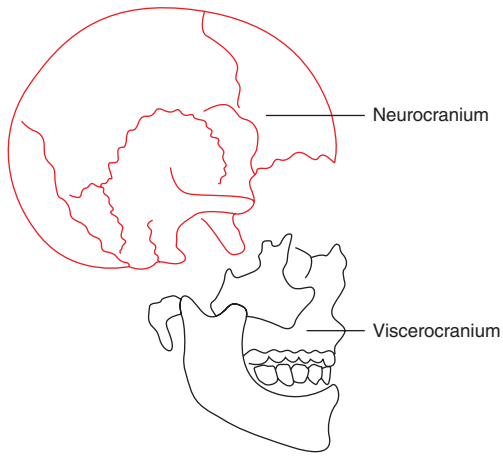
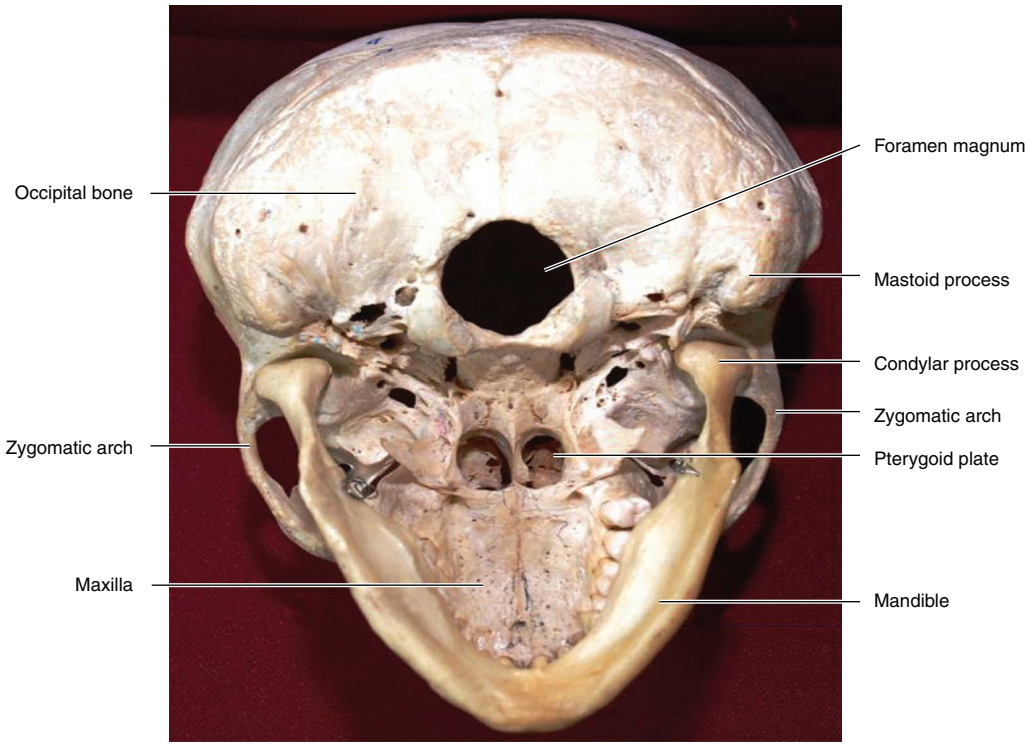


Figure 2.4 Bones of skull—functional classification.

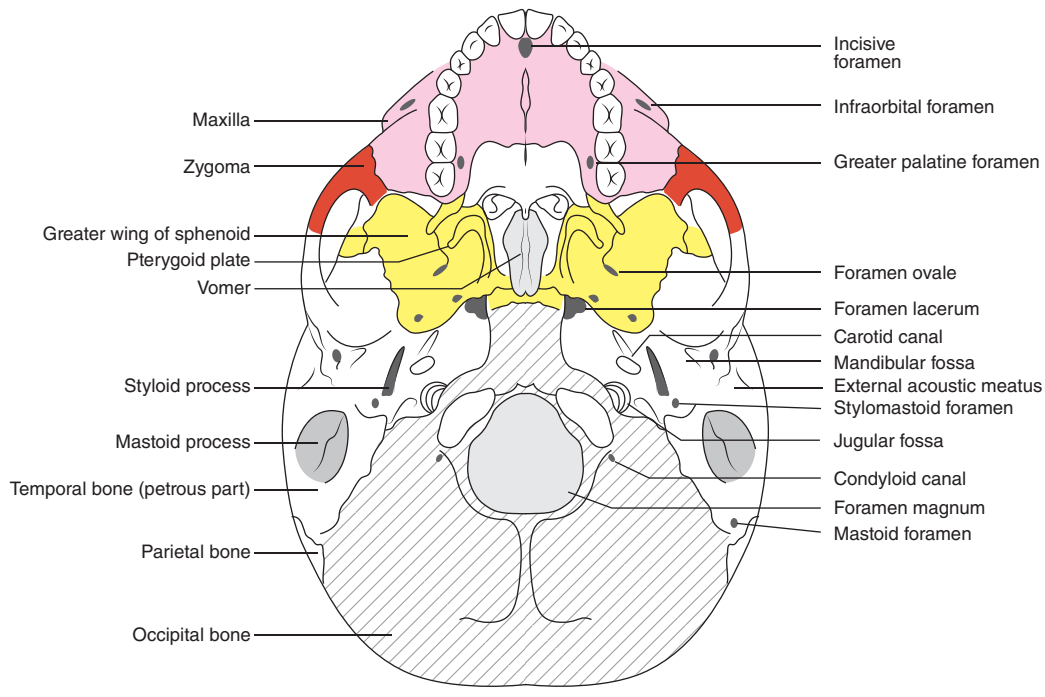
COMPONENTS OF THE SKELETAL SYSTEM

The features common to the skeletal system of any region of the body are the presence of the following:

1. **Solid bones:** Fused by sutures in skull (**Fig. 2.7**)
2. **Sinuses:** Air-filled cavities within bone (**Table 2.2**; **Fig. 2.8**)
3. **Cavities:** Hollow space communicating with the exterior cavity (**Table 2.3**; **Fig. 2.8**)
4. **Foramina** (*sing.* foramen): Perforations or holes for transit of vessels (**Table 2.4**; **Figs 2.6** and **2.9**)



(a)



(b)

Figure 2.5 Base of the skull: (a) specimen of the skull and (b) schematic diagram.

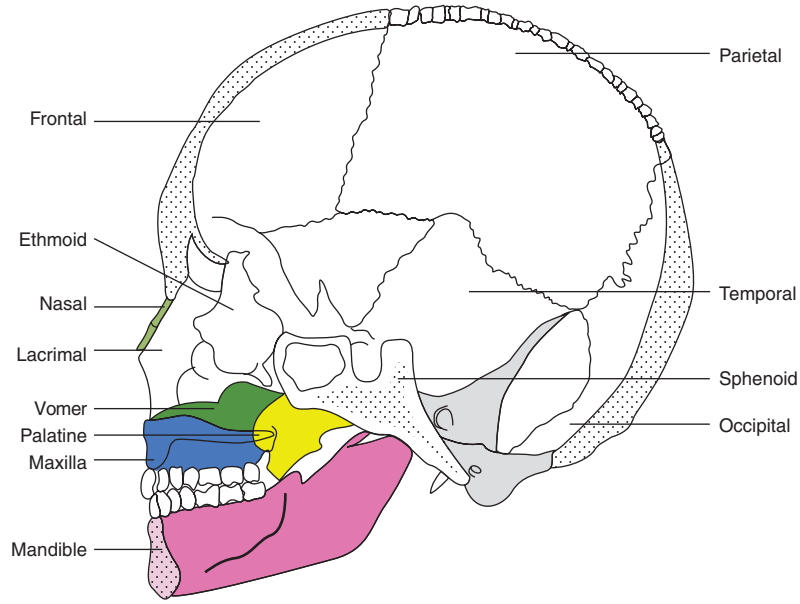


Figure 2.6 Bones forming the skull roof.

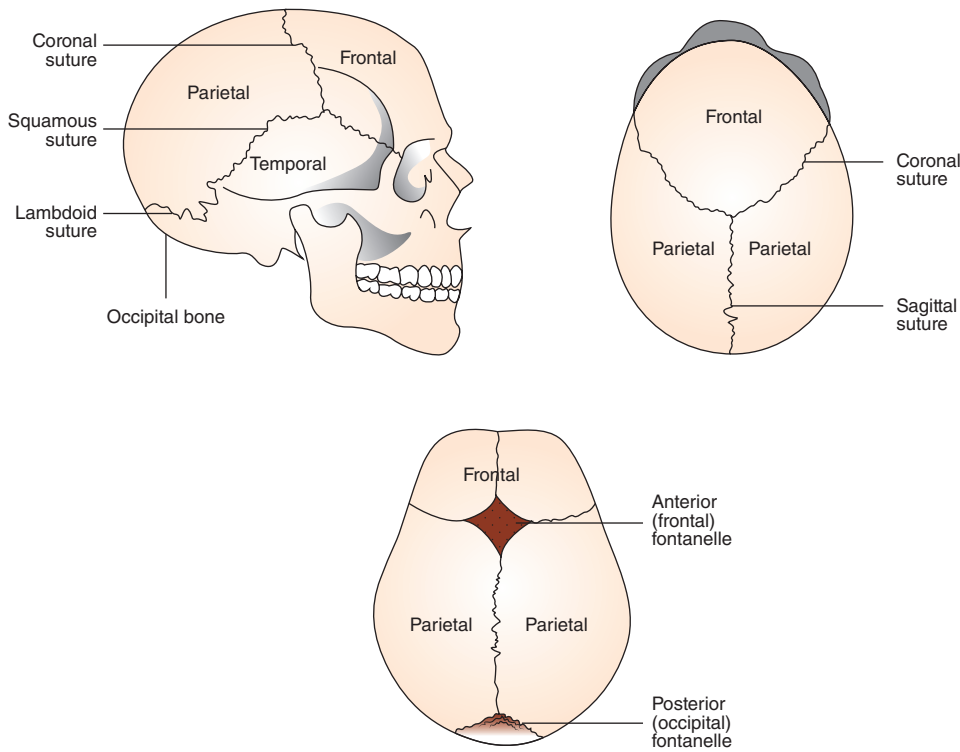


Figure 2.7 Sutures of the head.

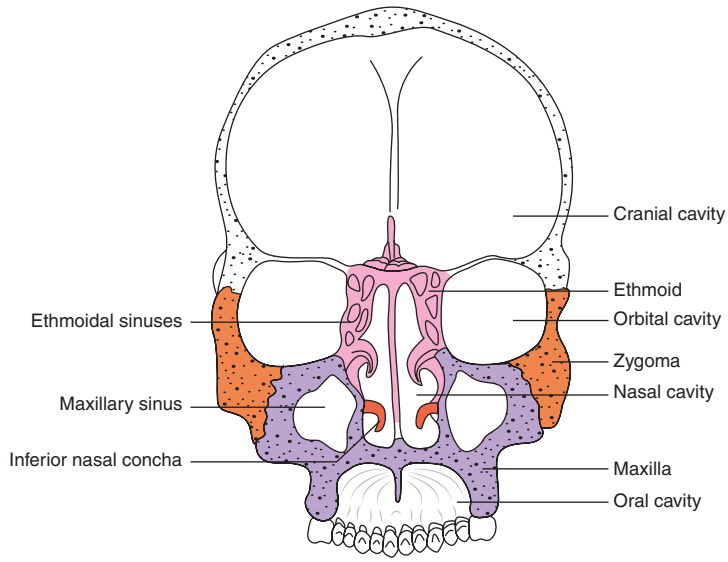


Figure 2.8 Cavities and sinuses of the head.

Table 2.2 Sinuses of the Head

Name of Sinus	Location
Maxillary sinus	Maxilla
Ethmoid sinus	Ethmoid bone
Sphenoid sinus	Sphenoid bone
Frontal sinus	Frontal bone

Table 2.3 Cavities of the Head

Cavity	Components
Orbit/orbital cavity	Eye and associated structures
Nasal cavity	Nose and associated structures
Oral/buccal cavity	Mouth and associated structures
Cranial cavity	Brain and related structures
Middle/inner ear cavity	Ear ossicles and semicircular canals

Table 2.4 Foramina of the Head

Name of Foramen	Location	Structures Transmitted
Greater palatine foramen	Palatine bone of the hard palate	Greater palatine nerve Descending palatine vessels
Lesser palatine foramen	Posterior to greater palatine foramen in the hard palate	Lesser palatine nerves
Incisive foramen	Anterior region of the hard palate, posterior to incisors	Branches of descending palatine vessels Nasopalatine nerve
Inferior orbital fissure	Between maxilla and greater wing of sphenoid bone	Maxillary nerve of the trigeminal cranial nerve Zygomatic nerve Infraorbital vessels
Superior orbital fissure	Between the greater and lesser wings of sphenoid bone	Oculomotor nerve Trochlear nerve Ophthalmic division of the trigeminal nerve Abducent nerve

(Continued)

Table 2.4 *(Continued)*

Name of Foramen	Location	Structures Transmitted
Optic foramen	Within orbit, in the lesser wing of sphenoid bone	Optic nerve Ophthalmic artery
Infraorbital foramen	In maxilla, below orbit	Infraorbital nerve and artery
Supraorbital foramen	Supraorbital ridge of orbit	Supraorbital nerve and artery
Nasolacrimal canal	Lacrimal bone	Nasolacrimal (tear) duct
Mental foramen	Below the second premolar on the lateral side of mandible	Mental nerve and vessels
Mandibular foramen	Medial surface of the ramus of mandible	Inferior alveolar nerve and vessels
Stylomastoid foramen	Between the styloid and mastoid processes of temporal bone	Facial nerve and stylomastoid artery
Zygomaticofacial foramen	Anterolateral surface of the zygomatic bone	Zygomaticofacial nerve and vessels
Foramen rotundum	Body of the sphenoid bone	Maxillary branch of the trigeminal nerve
Foramen ovale	Greater wing of the sphenoid bone	Mandibular branch of the trigeminal nerve
Foramen spinosum	Posterior aspect of the sphenoid bone	Middle meningeal vessels
Cribriform foramina	Cribriform plate of the ethmoid bone	Olfactory nerves
Foramen magnum	Occipital bone	Union of medulla oblongata and spinal cord Accessory nerves Vertebral and spinal arteries

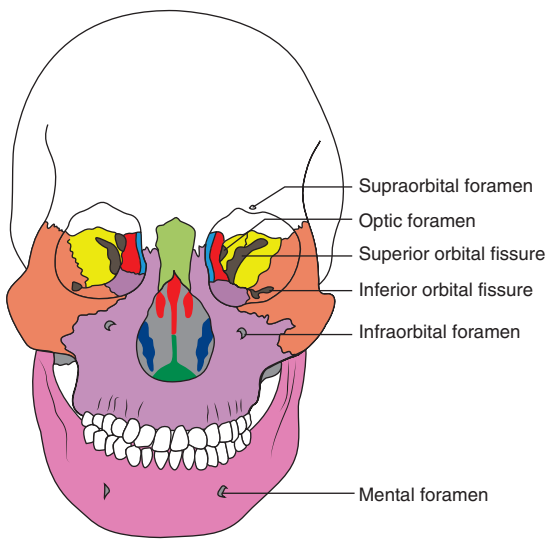


Figure 2.9 Foramina of the face.

Certain characteristics may be common to all bones, but every bone possesses some unique features in form and function, which are discussed in the subsequent paragraphs. Emphasis is laid on the facial bones more than the cranial bones, as the facial skeleton is the realm of a dentist.

Cranial Bones

Cranial bones perform the vital function of protecting the brain, which is the main centre for motor and sensory coordination. They also provide areas of attachment for muscles that move the head in different directions. The bones of skull roof are separated by regions of dense connective tissue called fontanelle during birth. They are six in number and are fibrous and moveable. With growth, the connective tissue of the fontanelles is gradually replaced

by bone. The interdigitation between the adjacent bones forms sutures. The five sutures of the cranium are two squamous, one coronal, one lambdoid and one sagittal. The posterior and the anterior fontanelles close by 8 weeks and 18 months, respectively, after birth (**Fig. 2.7**).

Applied Anatomy

Early closure of the cranial sutures is called *craniosynostosis*, which results in several abnormalities of the cranium. Premature closure of a suture causes more growth in a direction perpendicular to it. The incidence of primary craniosynostosis is approximately 1 per 2000 births. Premature closure of the sagittal suture results in a long, narrow, wedge-shaped cranium called *scaphocephaly*. Premature closure of the coronal or the lambdoid suture occurring on one side only leads to a cranium that is twisted and asymmetrical called *plagiocephaly*. Premature closure of the coronal suture results in a high, tower-like cranium called *oxycephaly* or *turricephaly*.

In some adults, additional bones called sutural (Wormian) bones are present within the sutures (joints) of the skull. Supplementary bones may also form as a reaction to stress, especially in tendons as they move continuously across a joint. Such bones are called *sesamoid bones*.

The fontanelles of the skull (i) allow it to flex and deform by a process called moulding to facilitate delivery of a child through the narrow birth canal and (ii) permit accommodation of the rapidly growing brain. They ossify completely by the age of 2 years.

Application of Structure of Bone in Forensics

Sexual dimorphism, or differences between sexes, exists in the morphological appearance of skull bones. In early life, less difference exists between male and female skulls. In adulthood, male skulls tend to be larger, heavier and tougher than female skulls; therefore, the cranial capacity of females is about 10% less than that of males.

Similar to fingerprints, the teeth, face and human skull are also unique and each varies between individuals. Its application in forensic medicine and archaeology is widespread. Bones play a vital role in the identification of an individual because they retain their features even after the soft tissues have perished.

Frontal Bone (Figs 2.1–2.3)

Frontal bone is the bone of the forehead, and it forms the anterior roof of the skull. It extends down anteriorly to form the upper margin of the orbit.

The frontal bone develops as halves which grow towards each other to fuse by the age of 5 or 6 years. The suture persistent beyond 6 years is called *metopic suture*. The frontal bone contributes to the supraorbital margin, a prominent bony ridge over the orbit. The *supraorbital foramen* lies medial to its midpoint. The frontal bone also lodges the frontal sinuses.

Applied Anatomy

The surface landmarks of the foramina of the face are used by dentists to locate the nerves that traverse them to inject local anaesthetic agents. For example, the mandibular teeth are anaesthetized by an injection near the mandibular foramen through which the inferior alveolar nerve that supplies the lower teeth passes. This technique is called *nerve block*.

Parietal Bone (Figs 2.2 and 2.5)

The parietal bones are paired and separated by the *sagittal suture* along the superior midline. They form the sides and roof of the cranium. The *coronal suture* separates the frontal bone from the parietal bones.

Temporal Bone (Figs 2.2, 2.5 and 2.6)

The temporal bones are also paired bones which form the lower sides of the cranium. The temporal bone articulates with the adjacent parietal bone by the *squamous suture*. Each temporal bone has four parts:

1. Squamous
2. Tympanic
3. Mastoid
4. Petrous

Occipital Bone (Figs 2.2, 2.3, 2.5 and 2.6)

The occipital bone forms most of the base of the skull. It articulates with the parietal bones at the *lambdoid suture*. The *foramen magnum* is the large opening in the occipital bone through which the

spinal cord passes to join the brainstem. On either sides, the foramen magnum presents the occipital condyles which articulate with the first vertebra of the vertebral column.

Sphenoid Bone

The sphenoid bone constitutes a part of the anterior cranial base (**Figs 2.3** and **2.6**). It consists of a central body and bilateral projections called the greater and lesser wings that form part of the orbit. The body contains the sphenoidal sinuses within and a superior saddle-like depression, the *sella tursica*, that houses the pituitary gland. A pair of pterygoid processes extend inferiorly from the sphenoid bone, contributing to the lateral walls of the nasal cavity (**Fig. 2.10**). The numerous foramina associated with the sphenoid bone (**Figs 2.6** and **2.10**) are as follows:

1. Optic canal
2. Superior orbital fissure
3. Foramen ovale
4. Foramen spinosum
5. Foramen rotundum
6. Foramen lacerum

The precise location of the foramina and the vital structures they transmit are mentioned in **Table 2.4**.

Ethmoid Bone

The ethmoid bone is a midline structure that constitutes the roof of the nasal cavity. It is situated in the anterior part of the cranial floor between the orbits (**Figs 2.3** and **2.5**). It exhibits the following extensions (**Fig. 2.11**):

1. **Perpendicular plate:** It is the downward extension that forms the upper part of the nasal septum. It divides the nasal cavity into two cavities referred to as the nasal fossae.
2. **Ethmoid sinus:** These are air-filled bone cells present on either side of the perpendicular plate.
3. **Crista galli:** It is the superior spine-like extension of the perpendicular plate protruding into the cranial cavity. It acts as an attachment for the meninges of the brain.

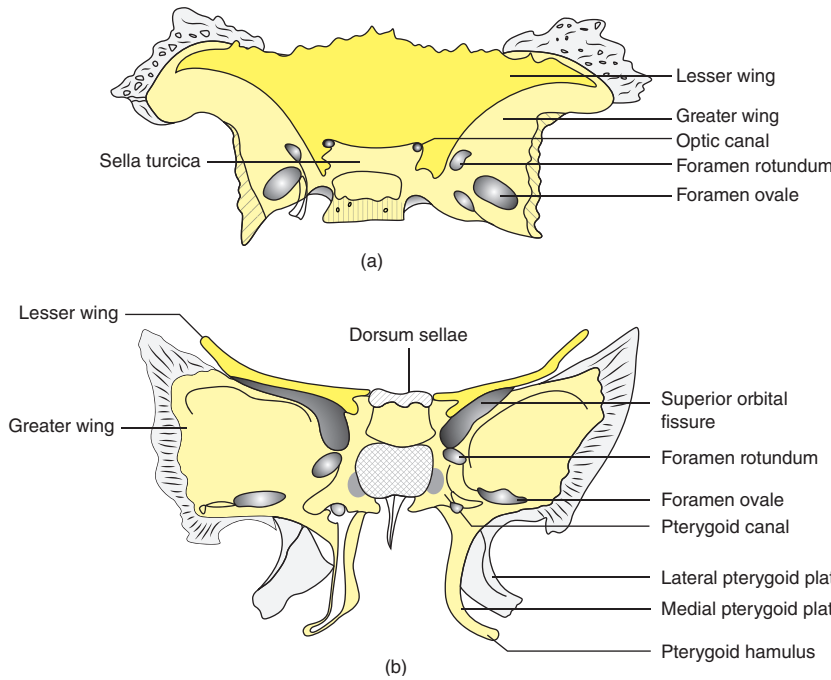


Figure 2.10 Sphenoid bone: (a) superior and (b) posterior views.

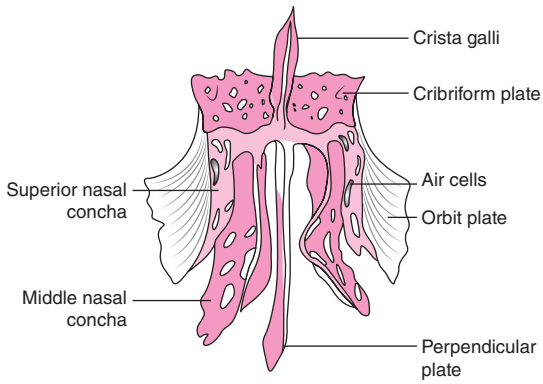


Figure 2.11 Ethmoid bone.

4. **Superior and middle nasal conchae:** These are two scroll-shaped plates related to the lateral walls of the nasal cavity (*sing.* concha). They are also called turbinates.
5. **Cribriform plate:** It is the perforated plate present in the cranial base at right angles to the perpendicular plate. The multiple holes through this plate are called cribriform foramina, which permit transit of olfactory nerves from the epithelial lining of the nasal cavity.

Facial Bones

The facial bones form the basic structural framework of the face. In addition to the normal functions of any bone, they also perform the following:

1. They protect and support the entry points of both the digestive and the respiratory systems.
2. They provide attachment for some muscles of facial expression.
3. They protect and support the organs for the senses of vision, taste, smell, hearing and equilibrium/balance.
4. They define a person's individuality

The facial bones are 14 in total. They are paired structures, with the mandible and vomer being the two exceptions. The following sections provide a detailed description of the individual facial bones along with their relationship to the adjacent structures.

Nasal Bones (Figs 2.1–2.3)

The nasal bones are two small, longitudinal bones which meet in the midline to form the prominence or bridge of the nose. The nasal bones protect the nares and support the pliable cartilaginous plates, which are a part of the nasal framework.

Applied Anatomy

Nasal bones are delicate structures that are unique and specific to races. These contribute greatly to facial aesthetics. Correction of nasal bone deformities is a sought-after procedure and is *called rhinoplasty*.

The nasal bone articulates with four bones: frontal, ethmoid, opposite nasal and maxilla.

Zygoma (Figs 2.1 and 2.8)

The zygomatic bone, also called the malar or cheekbone, is a paired rhomboidal bone and is located below each eye, thus forming the lower lateral margin of the orbital cavity. An extension of the zygomatic bone joins with a process of the temporal bone to form an arch-like strut called the zygomatic arch (Fig. 2.2).

Features The zygomatic bone has three surfaces, three processes and three foramina (Fig. 2.12).

1. **Surfaces**
   (a) *Facial:* Smooth, lateral aspect of the bone
   (b) *Temporal:* Curved, medial aspect
   (c) *Orbital:* Lateral and inferior orbital margins

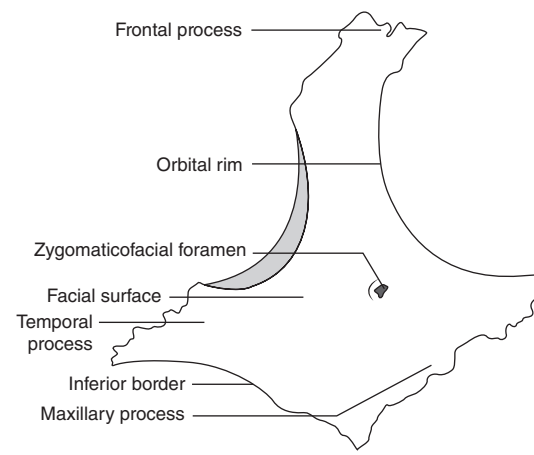


Figure 2.12 Zygoma.

2. **Processes**
   (a) *Frontal process:* Articulates superiorly with the frontal bone
   (b) *Maxillary process:* Articulates inferiorly with the maxillary bone
   (c) *Temporal process:* Articulates posteriorly with the temporal bone to form the zygomatic arch
3. **Foramina:** The zygomatic bone contains a Y-shaped canal to transmit the zygomatic nerve and vessels.
   (a) *Zygomatico-orbital foramen:* Present on the orbital surface of zygoma to transmit the zygomatic nerve
   (b) *Zygomaticofacial foramen:* Present on the facial surface of zygoma to allow the exit of zygomaticofacial nerve and artery
   (c) *Zygomaticotemporal foramen:* Present on the facial surface of zygoma to allow the exit of the zygomaticotemporal nerve and artery

Articulation The zygomatic bone articulates with a number of other facial bones including the maxilla, frontal bone, greater wing of sphenoid bone and temporal bone.

Applied Anatomy

Management of fractures involving the zygomatic bone may be complex because of the possibility of damage to the eye.

Maxilla (Figs 2.1–2.3)

Maxillae are paired bones which contribute to the formation of the upper face, orbital floor, lateral wall of the nasal cavity, floor of the nasal cavity and roof of the oral cavity. They are of great significance in dentistry as they carry the upper dental apparatus.

Features The maxilla is a hollow, pyramidal structure with the following features (**Fig. 2.13**). It consists of four surfaces, four processes, multiple foramina and a sinus.

1. **Surfaces**
   (a) *Anterior/facial:* This surface faces forwards and is angulated laterally. It displays the following features:
   - *Incisive fossa*: This is a small depression above the incisors from where the depressor septi muscle originates.
   - *Canine fossa*: This is a depression on the alveolar process, lateral to canine.
   - *Infraorbital foramen*: This is the foramen 7 mm below the inferior rim of the orbit that transmits the infraorbital nerve.
   - *Nasal notch*: This is a curved depression on the medial aspect of the maxilla bordering the nasal cavity. It meets the similar structure on the opposite side to form the anterior nasal spine.

Applied Anatomy

The orientation of the cranium in normal anatomical position is such that the inferior margin of the orbit and the superior margin of the external acoustic opening of the external acoustic meatus lie in the same horizontal plane. This craniometric reference is universal and is called the orbitomeatal plane or the Frankfort horizontal plane. It is of great importance in clinical dentistry.

   (b) *Posterior/infratemporal:* It is convex and curves posteriorly and laterally. The following features are characteristic:
   - *Alveolar canals*: These are foramen for the posterior superior alveolar nerve and vessels.
   - *Boundary of the infratemporal fossa*: The posterior surface of the maxilla forms the anterior wall of the infratemporal fossa.
   - *Boundary of the infrapterygopalatine fossa*: The posterior surface of the maxilla forms the anterior wall of the pterygopalatine fossa, which lodges the pterygopalatine ganglion.
   (c) *Superior/orbital*: It is concave and forms the floor of the orbit.
   (d) *Medial/nasal*: It forms the lateral wall of the nose and displays the following features:
   - *Maxillary hiatus*: It is a large irregular opening of the maxillary sinus.

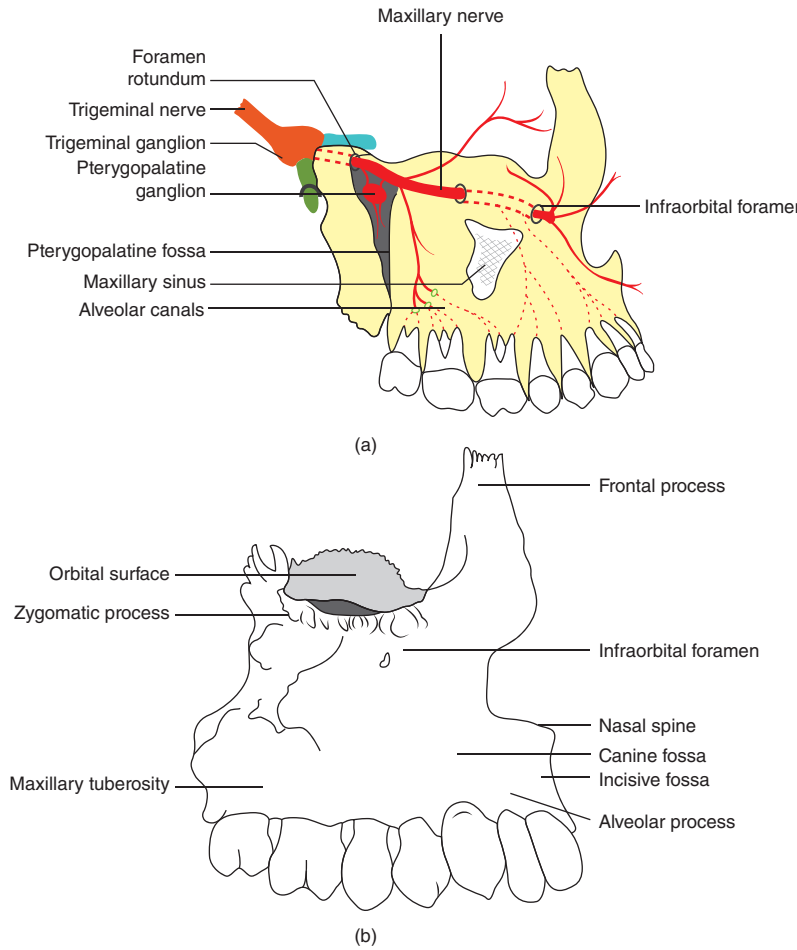


Figure 2.13 Maxilla: (a) medial and (b) lateral views.

- *Nasolacrimal groove*: It is a linear depression that becomes continuous with the nasolacrimal canal that lodges the nasolacrimal duct.

2. **Processes**
   (a) *Alveolar process:* It is part of the maxilla that supports the upper teeth.
   (b) *Palatal process:* It is medial extension towards the midline meeting the maxilla of the opposite side. It forms the floor of the nasal cavity and the roof of the oral cavity.
   (c) *Zygomatic process:* It is a lateral extension of the maxilla, forming the apex of the pyramidal structure.
   (d) *Frontal process:* It is upward projection of the bone that articulates with the frontal bone.
3. **Foramina**
   (a) *Incisive/nasopalatine foramen* (**Fig. 2.6**): This is located in the anterior region of the hard palate, behind the incisors, and transmits the nasopalatine nerve and the blood vessels.
   (b) *Infraorbital foramen* (**Figs 2.1** and **2.13**): This is located below the orbit to transmit the infraorbital nerve and artery.
   (c) *Inferior orbital fissure* (**Fig. 2.9**): This is located between the maxilla and the greater wing of the sphenoid and

transmits the infraorbital nerve and vessels, emissary veins, maxillary nerve and zygomatic nerve.

4. **Maxillary sinus** (Fig. 2.8)
   (a) Located within the maxilla, it is the largest of the four paranasal sinuses. It is also called *antrum of Highmore*. It helps to humidify air, lessen the weight of the skull and provide resonance to voice. It communicates with the nasal cavity through the middle meatus (see Chapter 46 for a detailed a description of the maxillary sinus).

Palatine Bone (Fig. 2.14)

The palatine bones contribute to the formation of the posterior third of the hard palate, orbit and a part of the nasal cavity. They are L shaped with horizontal and perpendicular plates. The palatine bone contains the large greater palatine foramen and two or more smaller lesser palatine foramina.

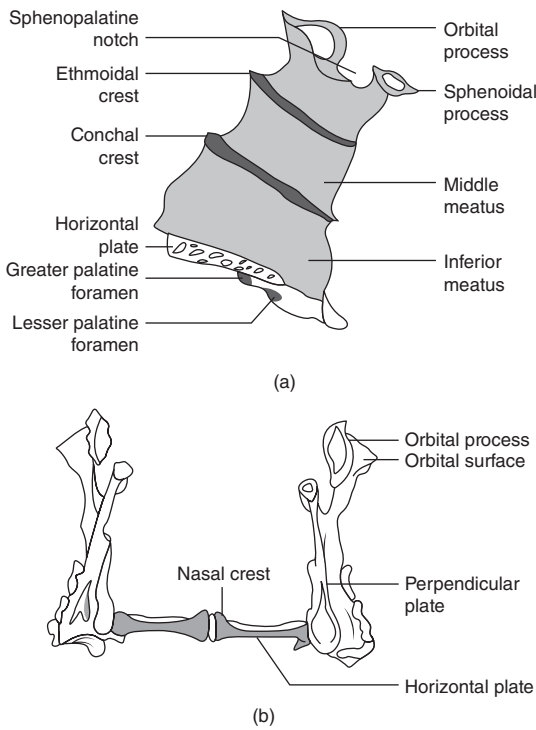


Figure 2.14 Palatine bone: (a) medial and (b) posterior views.

Applied Anatomy

When the two palatine processes do not unite during the early prenatal development (about 12 weeks), it is called *cleft palate*. It is difficult to feed a baby with such problems because of the inability to create the necessary suction within the oral cavity to swallow fluids. Cleft palate can be corrected surgically.

Lacrimal Bones (Fig. 2.3)

Lacrimal bones are the smallest of the facial bones. They form the anterior part of the medial wall of each orbit. Each bone has a lacrimal sulcus that forms the nasolacrimal canal.

Inferior Nasal Conchae (Figs 2.1 and 2.3)

Inferior nasal conchae are the largest of all the conchae. These are scroll-like paired bones that protrude medially from the lateral walls of the nasal cavity and lie below the superior and middle conchae. The bones are covered with a mucous membrane to humidify inhaled air.

Vomer (Fig. 2.5)

The vomer is a thin, flattened bone that forms the lower part of the nasal septum. It supports the septal cartilage that forms a part of the nasal septum.

Mandible

The mandible is a U-shaped bone forming the lower jaw of the face (Fig. 2.1), which is unique in numerous aspects. It is the largest, strongest bone of the face and the only movable bone of the skull. It articulates with the skull by paired temporomandibular joints (Fig. 2.2).

Features The features of the mandible are given in the following text (Fig. 2.15):

Anatomical Zones

1. **Body:** Part of mandible extending from the canine to the anterior border of the masseter muscle
2. **Ramus:** Broad, superior, vertical extension from the posterior part of the body

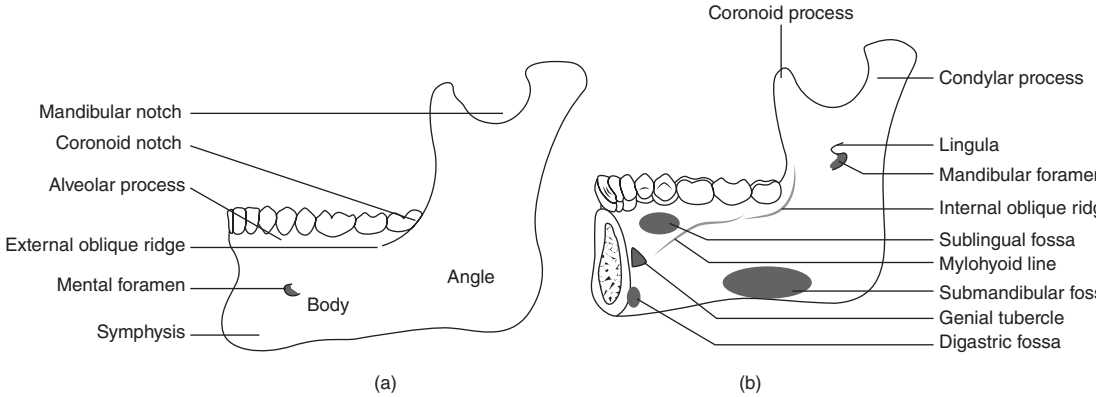


Figure 2.15 Mandible: (a) lateral/buccal and (b) medial/lingual views.

3. **Angle:** Junction formed by the ramus and the body of the mandible
4. **Symphysis:** Region corresponding to the mid-line of the mandible
5. **Parasymphysis:** Region adjacent to the symphysis

Applied Anatomy

In the mandible, the fracture of the angle region is common because of stress concentration due to the curvature and presence of impacted third molars.

Processes

1. **Condylar process:** Rounded projection from the upper border of the ramus which articulates with the temporal bone to form the temporomandibular joint
2. **Coronoid process:** Sharp triangular projection from the upper border of the ramus that provides attachment to muscles of mastication
3. **Alveolar process:** Part of the mandible that bears the teeth

Ridges

1. **External oblique ridge:** Linear bony elevation/crest on the lateral aspect of the mandible that extends from the first molar region and continues upwards as the anterior border of the ramus
2. **Internal oblique ridge:** Linear bony elevation/ crest on the medial aspect of the mandible

Notches

1. **Mandibular/sigmoid notch:** The curvature or depression between the condyle and the coronoid processes
2. **Coronoid notch:** Depression/concavity on the anterior border of ramus

Foramina

1. **Mental foramen:** Present on the anterolateral aspect of the body of the mandible between the two premolars. Mental nerve and vessels pass through the foramen.
2. **Mandibular foramen:** Present on the medial surface of the ramus. The inferior alveolar nerve and vessels are transmitted through the foramen.

Fossae

1. **Submandibular fossa:** Shallow depression present on the medial surface of the mandible to lodge the submandibular gland
2. **Sublingual fossa:** Shallow depression present on the medial surface of the mandible to lodge the sublingual gland
3. **Digastric fossa:** Depression on the lingual surface of the mandible near the symphysis menti from where the anterior belly of the digastric muscle originates

Tubercle

1. **Genial tubercles:** Small bony elevations that provide attachment to the geniohyoid and genioglossus muscles
2. **Lingula:** Lip-like projection on the medial surface of the mandible just above the mandibular foramen

Applied Anatomy

Maxilla and mandible are of great significance in dentistry as they carry the upper dental apparatus. Hence, it is imperative to understand the anatomy of maxillary bones since this plays a pivotal role in reconstruction surgeries, implant placement and prosthetic treatments.

Extraction of teeth causes the height of the alveolar bone to decrease in the affected region because of resorption. This brings the mental foramen, which transits the mental nerve, closer to the superior border of the body of the mandible and to possible pressure symptoms when dental prostheses are worn (e.g. a denture that rests on an exposed mental nerve may produce pain during eating). Loss of all the teeth leads to a decrease in the vertical facial dimension, thus providing an older appearance.

Bony excrescences found in the palate or the inner surface of the mandible are called palatal tori (torus palatinus) and mandibular tori (torus mandibularis), respectively. These are surgically excised if they cause any inconvenience during fabrication of dental prosthesis.

The size and alignment of jaws to each other may be modified for functional and aesthetic purposes by:

1. Use of myofunctional appliances during growth spurt in young children
2. Orthognathic surgeries in adults

Facial Buttresses

The facial skeleton consists of regions called buttresses which are localized areas of thick bone. They deserve special mention because they provide stability and strength to the adjacent relatively weaker bones and protect the surrounding soft tissues. There are three horizontal buttresses and two vertical buttresses. Horizontal buttresses are weaker than the vertical buttresses. The various buttresses are as follows:

1. **Horizontal**
   (a) Superior orbital rim and frontal bone
   (b) Inferior orbital rim and nasal bone
   (c) Maxillary alveolus
2. **Vertical**
   (a) Zygomaticomaxillary
   (b) Nasomaxillary

Applied Anatomy

The buttresses of the facial skeleton play a major role in protecting the important structures within the skull and the weaker bones around. It is essential to aim at restoration of the continuity of the buttresses of the facial skeleton during surgical procedures to treat fractures.

ARTICULATION

The cranial and facial bones articulate with each other to form various cavities such as the orbital and nasal cavities (**Tables 2.5** and **2.6**; **Fig. 2.1**)

Table 2.5 Bones Forming the Orbit

Orbital Part	Contributing Bones
Lateral wall	Zygomatic bone
Medial wall	Maxilla, ethmoid bone, lacrimal bone
Posterior wall	Greater wing of sphenoid bone
Roof	Frontal bone, lesser wing of sphenoid bone
Floor	Maxilla, zygomatic bone, palatine bone

Table 2.6 Bones Forming the Nasal Cavity

Nasal Part	Contributing Bones
Lateral wall	Maxilla, palatine bone
Nasal septum	Ethmoid bone (perpendicular plate), vomer, nasal bone
Roof	Ethmoid bone (cribriform plate), frontal bone
Floor	Maxilla, palatine bone
Bridge	Nasal bone
Conchae	Ethmoid bone (superior and middle conchae), inferior nasal concha

which protect important and delicate structures. The temporal bone and mandible together form a movable joint called the *temporomandibular joint* (**Fig. 2.2**), which is vital for jaw movements. Another significant landmark formed by the articulation of the greater wing of sphenoid, squamous temporal, parietal and frontal bones is called *pterion* (**Fig. 2.2**) over which the middle meningeal artery is located.

Applied Anatomy

The anatomy of bone in living beings is studied by using conventional radiographs and computed tomography. Bone is radiopaque and the opacity is directly proportional to the calcification level of bones.

BLOOD SUPPLY AND INNERVATION OF BONE (Fig. 2.16)

Bone is a viable tissue that requires constant blood supply for nutrition and growth. The bone that loses vascularity because of various reasons such as trauma or any pathology becomes non-vital and degenerates. Bone receives blood supply from two major sources:

1. **Endosteal vessels:** These are vessels that occupy the central portion of the bones. Also called nutrient vessels, these are the main source of blood supply for the bone and supply the medullary cavity, inner two-third of cortex and metaphyses (e.g. inferior alveolar artery in case of mandible).

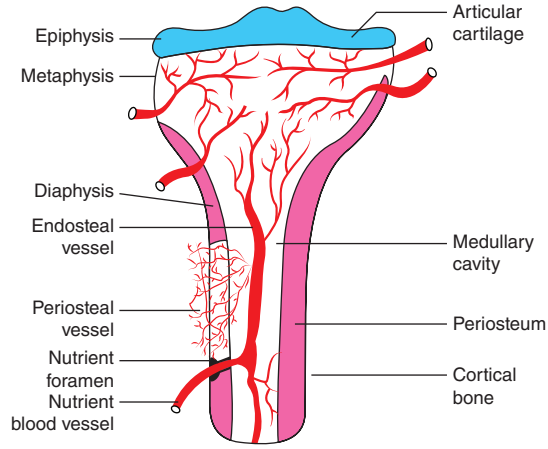


Figure 2.16 Bone vascularity.

2. **Periosteal vessels:** These are vessels that are present in the periosteum which send perforators to bone. They are numerous and supply blood to the periosteum and the outer one-third of the cortex.

Bones also receive blood supply from two minor sources:

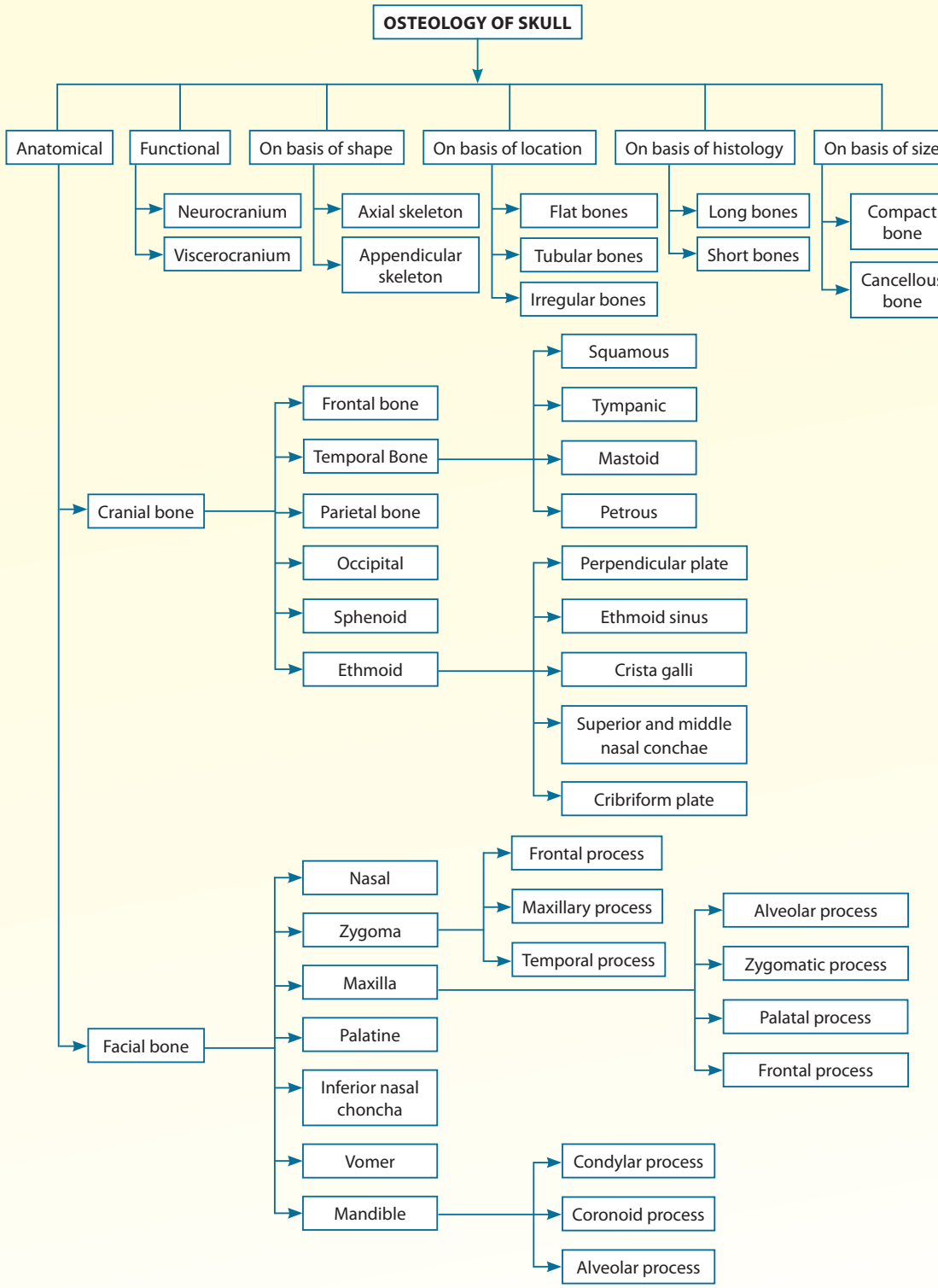
1. **Epiphyseal arteries:** These originate from the periarticular vascular plexus found on the non-articular bony surfaces and supply the epiphyses.
2. **Metaphyseal arteries:** These arise from the adjacent systemic arteries and supply the metaphyses.

The veins follow the course of the arteries and help in carrying waste products. They are distributed freely to the periosteum as well as accompany the nutrient arteries into the interior of the bone.

Key Points

1. The cranium consists of eight bones (two paired and four unpaired bones).
   (a) Unpaired bones are frontal, occipital, sphenoid and ethmoid.
   (b) Paired bones are parietal and temporal.
2. The facial skeleton consists of 14 bones (2 unpaired and 6 paired bones).
   (a) Unpaired bones are vomer and mandible.
   (b) Paired bones are inferior nasal conchae, lacrimal, maxillae, nasal, palatine and zygomatic bones.
3. Calvarium refers to the skull without the facial bone.
4. Each maxilla has four processes: frontal, zygomatic, alveolar and palatine.
5. The zygomatic bone is also called the cheekbone or the malar bone.
6. The only movable bone of the skull is the mandible.
7. The smallest bone of the face is the lacrimal bone and the largest is the mandible.
8. The hard palate is formed by two bones: the palatine process of maxilla and the horizontal plate of palatine bone.
9. Pterion is the junction of the greater wing of sphenoid, squamous temporal, parietal and frontal bone. It is an important landmark because the anterior division of the middle meningeal artery lies over this and can lead to serious consequences if injured.
10. Submandibular and sublingual fossae are present on the medial surface of the mandible to accommodate the submandibular and sublingual glands, respectively.
11. Mandible has two processes: coronoid and condylar processes. The condylar process articulates with the temporal bone of the cranium which is called the temporomandibular joint.
12. The nasal complex is partly bony and partly cartilaginous.
13. The bone of maxilla is cancellous and that of mandible is cortical.
14. The superior and middle conchae are parts of the ethmoid bone. Inferior concha is a separate bone.
15. Buttresses are structural pillars of bone that protect the facial skeleton by resisting and dissipating external forces. They are vertical and horizontal. Horizontal buttresses are weaker as compared to the vertical buttresses.

Mind Map


OSTEOLOGY OF SKULL
Anatomical
Functional
On basis of shape
On basis of location
On basis of histology
On basis of size
Neurocranium
Viscerocranium
Axial skeleton
Appendicular skeleton
Flat bones
Tubular bones
Irregular bones
Long bones
Short bones
Compact bone
Cancellous bone
Cranial bone
Frontal bone
Temporal Bone
Parietal bone
Occipital
Sphenoid
Ethmoid
Squamous
Tympanic
Mastoid
Petrous
Perpendicular plate
Ethmoid sinus
Crista galli
Superior and middle nasal conchae
Cribriform plate
Facial bone
Nasal
Zygoma
Maxilla
Palatine
Inferior nasal choncha
Vomer
Mandible
Frontal process
Maxillary process
Temporal process
Alveolar process
Zygomatic process
Palatal process
Frontal process
Condylar process
Coronoid process
Alveolar process

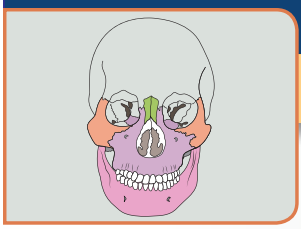
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Multiple Choice Questions

1. The study of bones is called
   (a) Osteology
   (b) Anthropology
   (c) Histology
   (d) Archaeology
2. Bones of the skull are
   (a) Sesamoid bones
   (b) Tubular bones
   (c) Short bones
   (d) Flat bones
3. The number of bones that make up the skull are
   (a) 22
   (b) 8
   (c) 14
   (d) 16
4. Air-filled cavities within bones are called
   (a) Sinuses
   (b) Ridges
   (c) Sulci
   (d) Fossae
5. The function of foramen is to
   (a) Transit blood vessel
   (b) Transit nerves
   (c) Help in muscle attachments
   (d) Both a and b
6. The orbital cavity houses one of the following structures:
   (a) Eyeball
   (b) Tongue
   (c) Maxillary sinus
   (d) Ear ossicles

7. The bone of the forehead is referred to as the
   (a) Frontal bone
   (b) Temporal bone
   (c) Parietal bone
   (d) Occipital bone
8. Infraorbital foramen is located on the following bone:
   (a) Maxilla
   (b) Zygoma
   (c) Sphenoid bone
   (d) Nasal bone
9. The bones of the facial skeleton are united by
   (a) Sutures
   (b) Cartilage
   (c) Muscles
   (d) Fissures
10. The bone that provides the prominence to the cheek is the
    (a) Mandible
    (b) Zygoma
    (c) Maxilla
    (d) Coronoid process
11. The movable bone of the face is the
    (a) Maxilla
    (b) Mandible
    (c) Zygoma
    (d) Frontal bone
12. Digastric fossa is present in the
    (a) Maxilla
    (b) Mandible
    (c) Zygoma
    (d) Orbit
13. The part of the maxilla or mandible that bears the teeth is called the
    (a) Axilla
    (b) Alveolus
    (c) Coronoid
    (d) Ramus
14. Lingula is a lip-like bony projection overlying the
    (a) Infraorbital foramen
    (b) Inferior meatus
    (c) Mandibular foramen
    (d) Nasopalatine foramen
15. The inferior alveolar canal is located in the
    (a) Maxilla
    (b) Mandible
    (c) Zygoma
    (d) Orbit



CHAPTER 3

Musculature of the Head and Neck

Overview

Myology is the study of muscles, their structure and function. Muscle is the contractile tissue of animals, derived from the mesodermal layer of embryonic germ cells. Muscles can be classified into skeletal, smooth and cardiac muscles based on histology and into voluntary and involuntary based on the action. The muscles of the head region include muscles of the eye, nose, mouth and ears. The major muscles of the eye are rectus muscles, oblique muscles and levator muscles. The major group of muscles in and around the mouth are the muscles of mastication and the muscles of facial expression. Each group of muscle possesses specific neural and vascular supply and also specific action which all play in synchrony to produce the desired effect that is controlled by the nervous system through the afferent and efferent pathways. To play its role in perfection, muscles are overflowed with rich vascularization

INTRODUCTION

Myology is the study of muscles, their structure and function. Muscle is the contractile tissue of animals, derived from the mesodermal layer of embryonic germ cells.

The anatomy of muscles is the basis for understanding the functions of muscles and the clinical correlation of muscle-related diseases. Muscle anatomy includes gross as well as microanatomy. Gross anatomy is the study of the overall muscle, its origin, insertion, actions and nerve supply whereas microanatomy is the study of a single muscle fibre. The basic terms and definitions a student has to be familiar with for good understanding of the anatomy and functions of muscles are defined in **Box 3.1**.

This chapter deals with the macroanatomy of the muscles of the facial region.

Box 3.1 Basic Terminology

- **Tendon**: Dense connective tissue that binds a muscle to the periosteum of a bone. Skeletal muscle is attached to the bone by the tendon.
- **Aponeurosis:** Flattened, sheet-like tendons.
- **Raphae:** A ridge or line where muscle fibres meet and partly interlace.
- **Fascia:** Fibrous connective tissue that drapes muscle and fuses to the skin; it has two components:
  - *Superficial fascia:* Attaches skin to deeper structures. The thickness of the superficial fascia varies depending on the region. It is thick over the abdominal wall whereas thin in the facial region.
  - *Deep fascia:* Deeper component of the superficial fascia. This merges with the epimysium of muscle.
- **Endomysium:** Thin sheath of connective tissue surrounding individual muscle fibres which binds muscle fibres together.
- **Perimysium:** Connective tissue that encompasses groups of muscle fibres together into bundles called fasciculi. The perimysium supports the neurovascular components which supply the various fasciculi.
- **Epimysium:** Covering of the entire muscle which is continuous with a tendon.

CLASSIFICATION OF MUSCLES

1. **On the basis of histology:** Muscles are of three types on the basis of histology:
   (a) *Skeletal muscles:* These are anchored by tendons or by aponeuroses to the bone.

They initiate skeletal movement such as locomotion and maintaining posture. Microscopically, they appear as alternating light and dark bands that give the characteristic striated appearance; therefore, they are also referred to as striated muscles. Facial muscles are skeletal muscles.

(b) *Smooth muscles:* These are found within the walls of organs and structures such as the oesophagus, intestines, bronchi and blood vessels. They are not striated. Striated muscles contract and relax in short, intense bursts whereas smooth muscles sustain longer contractions.

(c) *Cardiac muscle:* This is found only in the heart. It connects at branching, irregular angles.

2. **On the basis of movement:** Muscles are of two types on the basis of movement:
   (a) *Voluntary:* Muscles under conscious control, for example skeletal muscles
   (b) *Involuntary:* Muscles not under conscious control, for example smooth muscles and cardiac muscle
3. **On the basis of muscle architecture:** Variation in arrangement of muscle fibres renders characteristic functional features. The different types observed are parallel, convergent, sphincteric and pennate.

BLOOD AND NERVE SUPPLY TO SKELETAL MUSCLE

The high metabolic activity in the muscles demands rich vascularity to nourish the muscle cells with oxygen and nutrients and also to clear off the metabolic wastes. The capillary exchange of gases and nutrients between arteries and veins occurs at the endomysium level.

A skeletal muscle fibre contracts only when stimulated by a nerve impulse; therefore, an extensive network of nerves is present to initiate muscular action. Every muscle receives two types of nerves:

1. **Sensory (afferent) neuron:** Nerve cell that carries impulses from the muscle fibre to the central nervous system.
2. **Motor (efferent) neuron:** Nerve cell that carries impulses or commands from the CNS to the muscle fibre stimulating it to contract.

MUSCLES OF THE HEAD REGION

The muscles of the head region can be studied under the following groups which are based on their anatomical site and function:

1. Muscles of facial expression
2. Muscles of mastication
3. Muscles of soft palate
4. Muscles of tongue
5. Muscles of the eye
6. Muscles of the floor of the mouth

Applied Anatomy

Muscles and Bone Fracture

Fractured segments of the facial bones are displaced due to the pull of the muscles attached to them. Such fractures are termed *unfavourable, displaced fractures* because they are more difficult to treat than fractures which are not displaced by muscular pull.

Muscles of Facial Expression

Facial muscles (also called mimetic muscles) are subcutaneous, striated muscles that surround and regulate the function of four natural openings on the face, namely the oral cavity, the nasal cavity and the two orbits. They are of two types: compressors which close the opening and dilators which open the apertures.

The facial muscles play significant roles in:

1. Controlling the facial openings
2. Expressing varied emotions
3. Deglutition
4. Speech

The facial muscles are grouped according to their location (**Figs 3.1** and **3.2**):

1. **Muscles related to the eye**
   (a) Orbicularis oculi
   (b) Corrugator supercilii
   (c) Levator palpebrae superioris

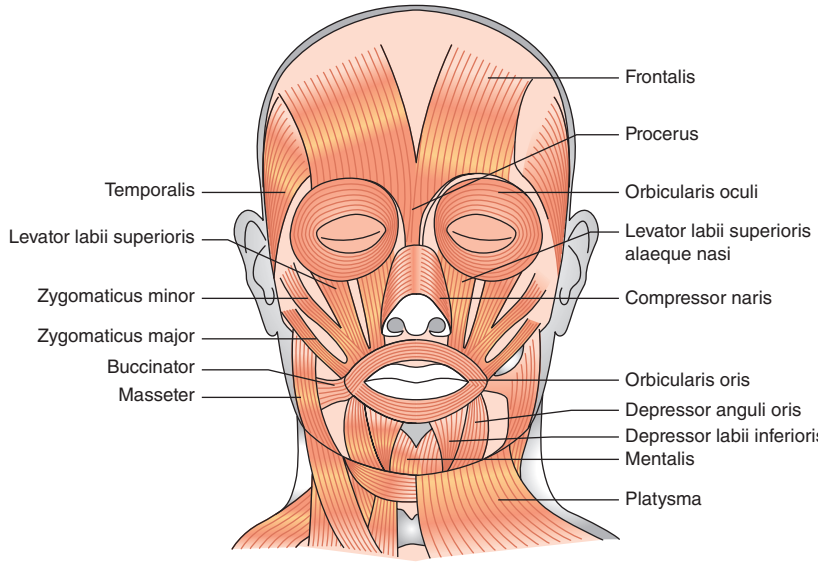


Figure 3.1 Muscles of the face—frontal view.

2. **Muscles related to the nose**
   (a) Procerus
   (b) Compressor naris
   (c) Dilator naris
   (d) Depressor septi

3. **Muscles related to the mouth**
   (a) Orbicularis oris
   (b) Buccinator
   (c) Zygomaticus major
   (d) Zygomaticus minor

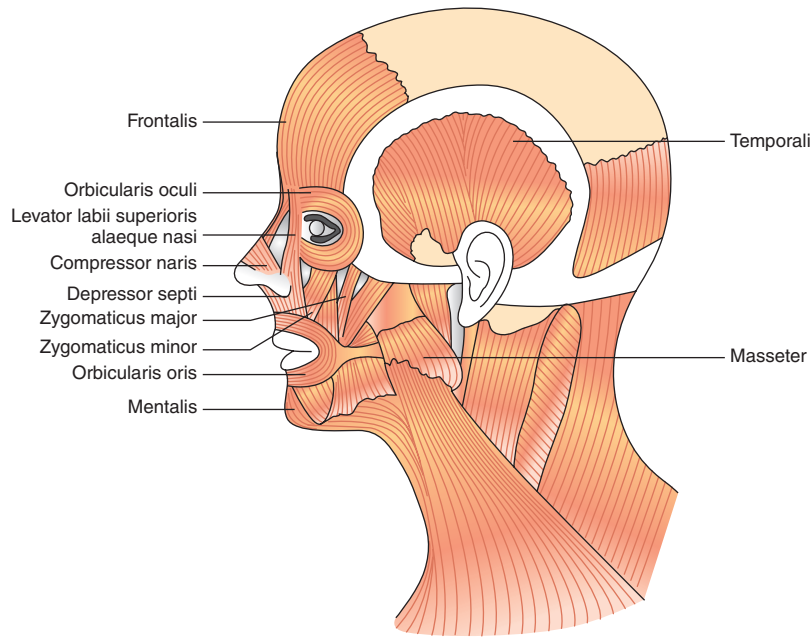


Figure 3.2 Muscles of the face—lateral view.

(e) Risorius
(f) Levator labii superioris
(g) Levator labii superioris alaeque nasi
(h) Depressor labii inferioris
(i) Levator anguli oris
(j) Mentalis
(k) Depressor anguli oris

4. **Muscles related to the ears**
   - Auricular muscles (anterior, superior, posterior)

The facial expressions evoked by the muscles are given in **Table 3.1**.

Table 3.1 Muscles and Facial Expressions

Muscle	Facial Expressions
Smiling, laughing	• Zygomaticus major
Doubt	• Mentalis
Sadness	• Levator labii superioris
Grinning	• Risorius
Grief	• Depressor anguli oris
Contempt	• Zygomaticus minor
Anger	• Dilator naris • Depressor septi
Closing mouth	• Orbicularis oris
Frowning	• Corrugator supercilii • Procerus
Horror, fright	• Platysma
Whistling	• Buccinator • Orbicularis oris
Surprise	• Frontalis

Origin and Insertion

The origin and insertion of some of the prominent muscles are given in the following text.

Orbicularis Oculi This is the sphincter muscle of the eye. It has three parts: orbital, palpebral and lacrimal.

The orbital part is present around the orbital margin. It originates from the medial part of the medial palpebral ligament and the adjoining bone, runs as a concentric circle and returns to the point of origin. The palpebral part starts from the lateral part of the medial palpebral ligament and inserts into the lateral palpebral raphae. The lacrimal part originates from the lacrimal fascia and the lacrimal bone and inserts into the upper and lower eyelids. It helps in dilating the lacrimal sac.

Orbicularis Oris This is the sphincter muscle of the mouth comprising two parts: intrinsic and extrinsic. The intrinsic part is derived from the superior incisivus of maxilla and the inferior incisivus of mandible. They become inserted into the angle of the mouth. The extrinsic part is derived from converging muscles such as the buccinator, elevators and depressors of lips and their angles. These are inserted into the lips and angles of the mouth.

Buccinator This is the muscle of the cheek. The muscle fibres are derived from three sources:

1. **Upper fibres:** These originate from the maxilla opposite the molar teeth and insert into the upper lip.
2. **Lower fibres:** These originate from mandible, opposite the molar teeth and insert into the lower lip.
3. **Middle fibres:** These originate from the pterygomandibular raphae, decussate and finally insert into the lip.

Innervation and Blood Supply

1. **Motor:** The facial muscles are derived from the second branchial arch; therefore, the motor supply to the facial muscles is by the branches of the facial nerve.
2. **Sensory:** Sensory innervation is by the branches of the trigeminal nerve.
3. **Vascularity:** Vascularity to the face is provided by the:
   (a) Facial artery
   (b) Transverse facial artery

Applied Anatomy

Electromyography of Facial Muscles

Facial electromyography refers to a technique that measures muscle activity by detecting and amplifying the tiny electrical impulses that are generated by muscle fibres when they contract. It is used to diagnose muscle disorders.

(Continued)

(Continued)

Facial Lines/Wrinkles

These are creases that develop due to the overactivity of the facial muscles and appear in a direction perpendicular to that of muscular activity. Any incision to be done on the face is placed along these lines to make scarring less prominent. The latest cosmetic management of wrinkles is the use of Botox injection which relaxes muscles. In addition, surgical procedures done to eliminate wrinkles are called rhytidectomy procedures.

Muscles of Mastication (Figs 3.3–3.7)

Muscles of mastication are related to the jaws and are responsible for the masticatory function and speech. They are four in number on either side (**Table 3.2**).

1. Masseter
2. Medial pterygoid
3. Lateral pterygoid
4. Temporalis

Masseter (Fig. 3.7)

Masseter is a quadrilateral-shaped muscle located on the lateral surface of ramus of mandible and originates as three different layers:

1. **Superficial layer:** It is the biggest layer and originates from the anterior two-third of the lower border of the zygomatic arch and the adjacent zygomatic process of maxilla. It runs downwards and posteriorly at 45° into the lower lateral surface of the mandibular ramus.
2. **Middle layer:** It begins from the deeper surface of the anterior two-third of the

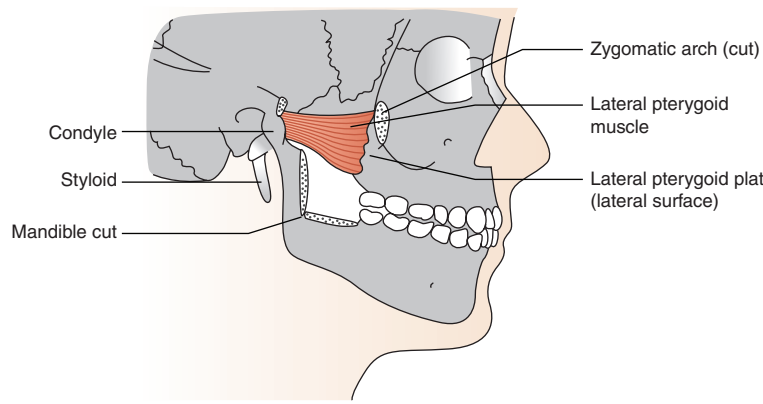


Figure 3.3 Lateral pterygoid.

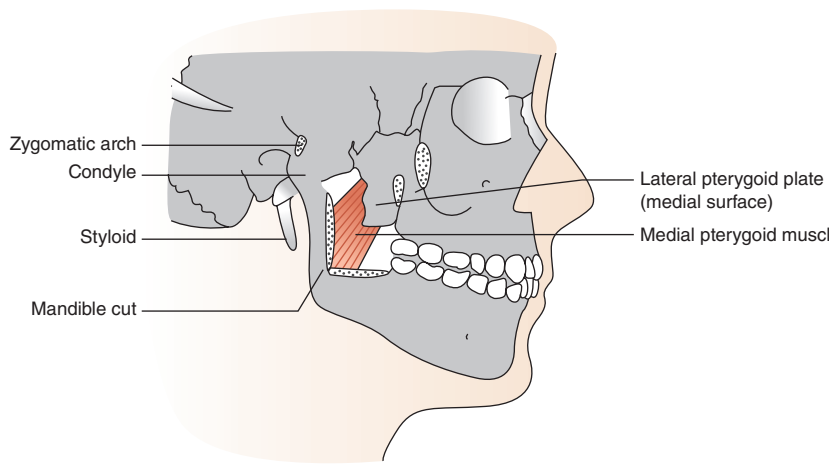


Figure 3.4 Medial pterygoid.

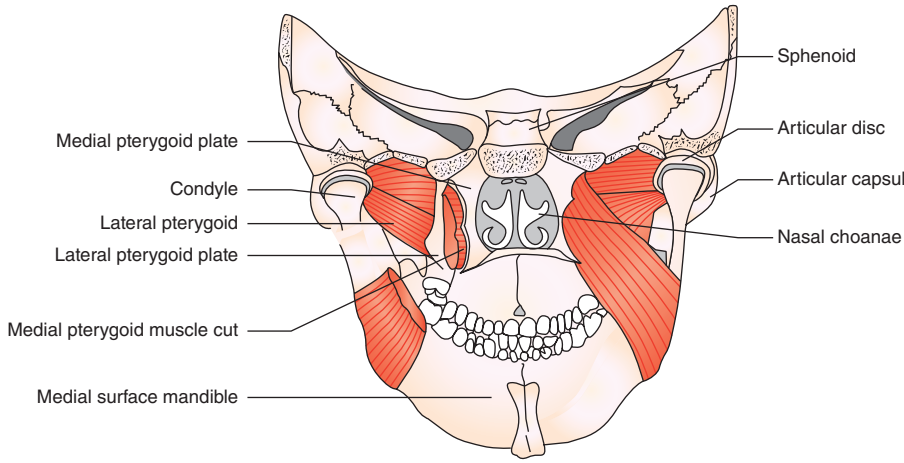


Figure 3.5 Pterygoids—posterior view.

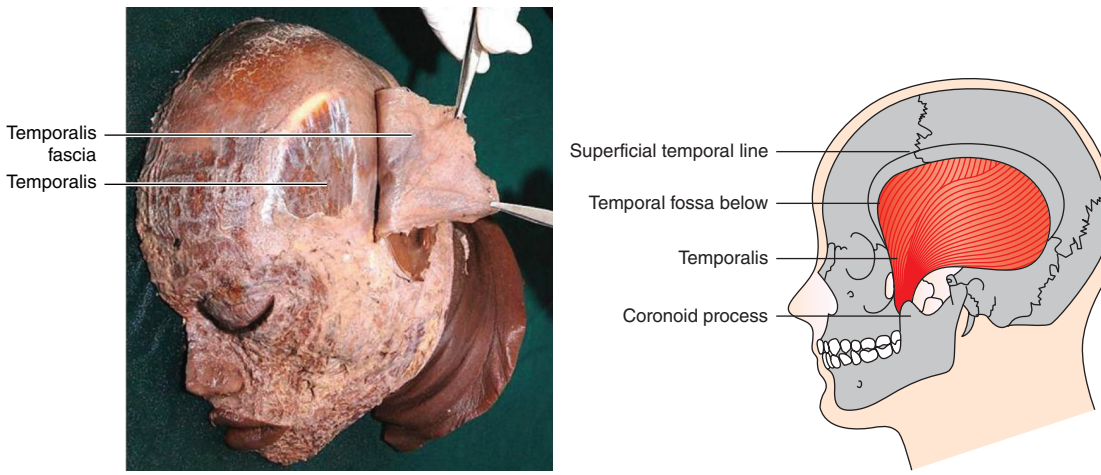


Figure 3.6 Temporalis: (a) dissected specimen and (b) schematic diagram.

zygomatic arch and the posterior one-third. These run vertically downwards to become inserted into the middle part of the ramus.

3. **Deep layer:** It originates from the deep surface of the zygomatic arch, descends vertically and inserts into the upper part of the ramus and the coronoid process.

Medial Pterygoid (Figs 3.4 and 3.5)

Medial pterygoid has a superficial and a deep head. The superficial head is small and arises from the maxillary tuberosity. The deep head is large and arises from the medial surface of the lateral pterygoid plate and the adjoining process of the palatine bone. All the fibres are inserted into a roughened area on the medial surface of the mandibular angle and the ramus.

Lateral Pterygoid (Figs 3.3 and 3.5)

Lateral pterygoid too has two heads:

1. **Upper head:** This arises from the infratemporal surface and the crest of the greater wing of the sphenoid.
2. **Lower head:** This arises from the lateral surface of the lateral pterygoid plate.

The fibres of both the heads converge and become inserted into the pterygoid fovea present at the neck of the mandible and the anterior

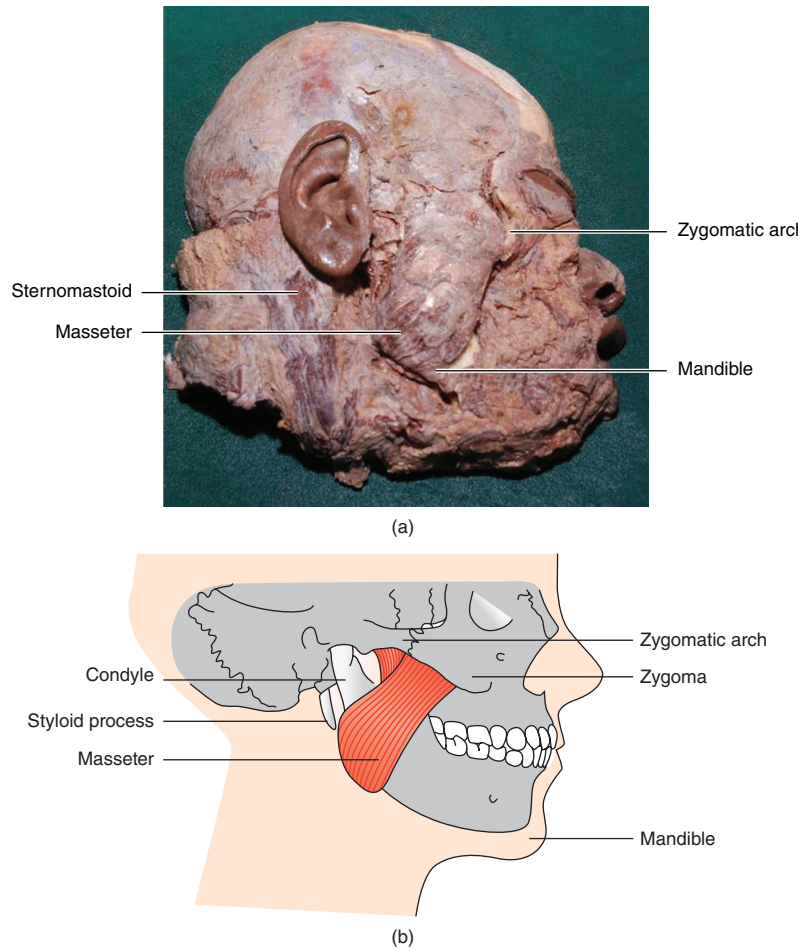


Figure 3.7 Masseter: (a) dissected specimen and (b) schematic diagram.

margin of the articular disc and capsule of the temporomandibular joint (TMJ).

Temporalis

The origin of this fan-shaped muscle is the temporal fossa and the temporal fascia. Fibres pass deep to the zygomatic arch and insert into the coronoid process and the anterior border of the ramus.

The actions of all the muscles of mastication are listed in **Table 3.2**.

Innervation and Blood Supply

1. **Motor:** Motor supply is provided by the muscular branches of the mandibular nerve (V_3 of the trigeminal nerve).
2. **Sensory:** Sensory supply is by the trigeminal nerve.
3. **Vascularity:** The vascularity of the muscles of mastication is maintained by the second part of the maxillary artery.

Applied Anatomy

Myofascial Pain Dysfunction Syndrome (MPDS)

It involves pain originating from the muscles of mastication, their sheaths, tendons or ligaments. Pain is referred to the face, head and neck regions. The common causes are improper dental occlusion and nocturnal bruxism. A close association has been found between stress and MPDS. Treatment includes analgesics and muscle relaxants

Teeth and Muscles

Malocclusion is the misalignment and improper relationship of upper and lower teeth. It can

(Continued)

(Continued)

induce strain on the adjoining bones and muscles, depending on the severity of the condition and vice versa. The muscles that move the jaw are very powerful, and they can produce major damage to the teeth when the occlusion is not normal. This can lead to severe attrition of teeth. Excessive muscle activity because of malocclusion often results in pain in the jaw muscle itself. Muscles of mastication can become tender, especially the temporal muscles.

Hypertrophy of Muscles

Muscle hypertrophy refers to the growth and increase in the size of muscle cells. The most common cause of hypertrophy is physical exercise. Of the facial muscles, masseteric hypertrophy is common due to overactivity such as chewing or clenching. Such a condition can be corrected for cosmetic reasons by surgical debulking.

Atrophy

It is wasting of muscles, which can be due to two causes: disuse atrophy, when there is lack of physical activity of muscles, or neurogenic atrophy, when there is lack of neural stimulation to muscles because of diseases of the nerves.

Table 3.2 Features of the Muscles of Mastication

Muscles		Origin	Insertion	Action	Motor Nerve Supply
Medial pterygoid	Superficial head	• Maximum tuberosity	• Ramus (medial surface angle and below mandibular foramen)	• Elevates mandible	• Branch from main trunk of mandibular nerve
	Deep head	• Lateral pterygoid plate (medial surface) • Palatine bone			
Temporalis		• Temporal fossa • Temporal fascia	• Coronoid process • Ramus, anterior border	• Elevates mandible	• Branch from anterior division of mandibular nerve
Masseter	Superficial layer	• Zygomatic arch—anterior two-thirds (lower border)	• Ramus, lateral surface (lower part)	• Elevates mandible	• Branch from anterior division of mandibular nerve
	Middle layer	• Zygomatic arch—anterior two-thirds (deep surface) • Zygomatic arch—posterior one-third (lower border)	• Ramus, lateral surface (middle part)		
	Deep layer	• Zygomatic arch (deep surface)	• Ramus, lateral surface (upper part) • Coronoid process		
Lateral pterygoid	Upper head	• Infratemporal surface and crest of greater wing of sphenoid	• Pterygoid fovea, at the neck of the mandible	• Depresses mandible; retracts mandible • Grinding movement	• Branch from anterior division of mandibular nerve
	Lower head	• Lateral pterygoid plate (lateral surface)	• Temporomandibular joint—articular disc and capsule		

Muscles of the Soft Palate

The soft palate (muscular palate) comprises muscles sheathed by the mucous membrane, which hangs down from the posterior aspect of the hard palate (**Fig. 3.8**). It acts as a movable gateway between the oropharynx and the nasopharynx, closing one during the usage of the other.

The muscles which constitute the soft palate are paired and are five in number (**Fig. 3.9**). The important functions of the muscles are (i) speech, (ii) deglutition, (iii) respiration and (iv) reflexes such as coughing and sneezing. The muscles of the soft palate are as follows:

1. Tensor palati (tensor veli palatini)
2. Levator palati (levator veli palatini)
3. Musculus uvulae
4. Palatoglossus
5. Palatopharyngeus

The individual muscles are described later and in **Table 3.3** (**Figs 3.8** and **3.9**).

Tensor Palati

Tensor palati is the primary muscle of the soft palate. It originates from the lateral side of the auditory tube and the adjoining region of the sphenoid bone. It runs down forming a narrow tendon that winds

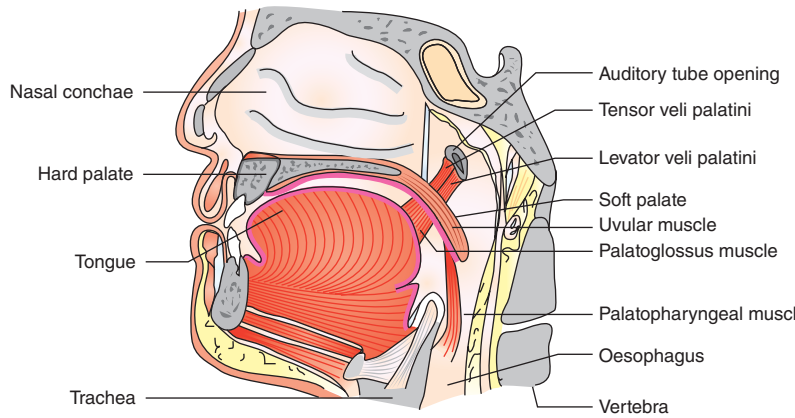


Figure 3.8 Soft palate—sagittal section.

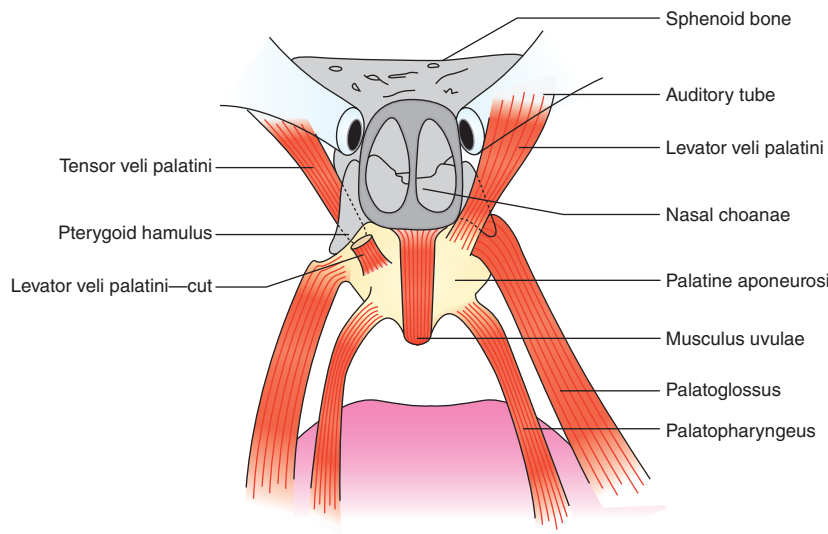


Figure 3.9 Muscles of the soft palate.

Table 3.3 Features of the Muscles of the Soft Palate

Muscles	Origin	Insertion	Action	Motor Supply
Palatopharyngeus	• Palatine aponeurosis • Posterior part of hard palate	• Pharyngeal wall • Thyroid cartilage	• Pulls up pharynx	• IX CN through X CN
Palatoglossus	• Palatine aponeurosis	• Tongue—lateral borders	• Pulls up tongue	• IX CN via X CN
Uvular	• Palatine aponeurosis • Postnasal spine	• Mucous membrane of uvula	• Pulls up uvula	• IX CN via X CN
Levator veli palatini	• Auditory tube—inferior aspect	• Palatine aponeurosis—upper part	• Elevates soft palate • Opens auditory tube	• IX CN via X CN
Tensor veli palatini	• Auditory tube—lateral aspect • Adjoining part of sphenoid	• Flattens to form the palatine aponeurosis and inserts into the posterior border of hard palate and inferior surface of palate at palatine crest	• Tightens soft palate • Opens auditory tube	• Mandibular nerve

CN, cranial nerve.

around the pterygoid hamulus. Later, it broadens out to form the palatine aponeurosis in the midline to join with the same of the opposite side. Anteriorly, it attaches to the posterior border of the hard palate. On contraction, it tightens the soft palate, especially the anterior part, and opens up the auditory tube.

Levator Palati

Levator palati originates from the inferior aspect of the auditory tube and the inferior surface of the adjoining part of petrous temporal bone. It is cylindrical in shape and lies deeper to the tensor palati. The muscle passes over the superior constrictor and inserts into the upper surface of the palatine aponeurosis. Its actions are elevation of the soft palate and opening up the auditory tube.

Musculus Uvulae

Musculus uvulae lies within the palatine aponeurosis. It starts from the posterior nasal spine and becomes inserted into the mucous membrane of uvula. It helps in pulling up the uvula.

Palatoglossus

Palatoglossus is discussed earlier along with the muscles of the tongue.

Palatopharyngeus

Palatopharyngeus consists of two fasciculi:

1. **Anterior fasciculus** originating at the posterior border of the hard palate
2. **Posterior fasciculus** originating from the palatine aponeurosis

These fasciculi descend into the palatopharyngeal arches and become inserted into the posterior border of the thyroid cartilage and pharyngeal wall. Some of the fibres of palatopharyngeus form a sphincter deep to the superior constrictor at the level of the hard palate. This constitutes Passavant's muscle. This muscle on contraction produces a ridge on the posterior wall of pharynx which encounters the elevated soft palate. This helps in the closure of the pharyngeal isthmus when necessary.

Innervation and Blood Supply

1. **Motor:** Motor supply to all the muscles except tensor palati is by the pharyngeal plexus derived from the cranial part of the accessory nerve through the vagus. Tensor palati is supplied by the mandibular nerve.
2. **Sensory:** Sensory innervation is of two types. The general sensation is provided by the middle and posterior lesser palatine nerves and the glossopharyngeal nerve. Gustatory sensation and secretomotor fibres are transmitted through the lesser palatine nerves.

The arterial supply of the soft palate is from three sources:

1. Greater palatine artery (branch of the maxillary artery)
2. Ascending palatine artery (branch of the facial artery)
3. Palatine artery (branch of the ascending pharyngeal artery)

Venous drainage is by the corresponding veins to the pterygoid and tonsillar plexus of veins.

Applied Anatomy

Soft Palate and Speech

Soft palate retracts and elevates during speech, thus separating the oral cavity from the nasal cavity which helps in producing speech sounds. Anatomical defect of the soft palate causes incomplete separation of the two cavities resulting in escape of air through the nose leading to nasal speech. This is called velopharyngeal incompetence.

Gag Reflex

It is also called the pharyngeal reflex. It is elicited by stimulating the soft palate or posterior pharynx; the response is a symmetric elevation of the palate, a retraction of the tongue and a contraction of the pharyngeal muscles. It is a protective mechanism that prevents any foreign body from choking the throat. The reflex is used as a test of the integrity of the vagus and glossopharyngeal nerves.

Cleft Soft Palate

It is the fissure in the midline of the soft palate. Also called bifid uvula, it arises following the non-fusion of the palatal shelves during the developmental phase. This creates a communication between the nose and the oral cavity, which leads to difficulties in sucking or nasal regurgitation of milk and food.

Muscles of the Tongue

The tongue is an important organ for speech and deglutition. A median fibrous septum divides the tongue into right and left halves. Each half has two types of muscles:

1. **Extrinsic muscles:** These are paired muscles, four in number on either side (**Fig. 3.10**). They protrude, retract, depress and elevate the tongue (**Table 3.4**). The description of individual muscles is as follows:
   (a) *Genioglossus:* It is the muscle which forms the major bulk of the tongue. It arises from the genial tubercles on the medial surface of the mandible, fans out and is divided

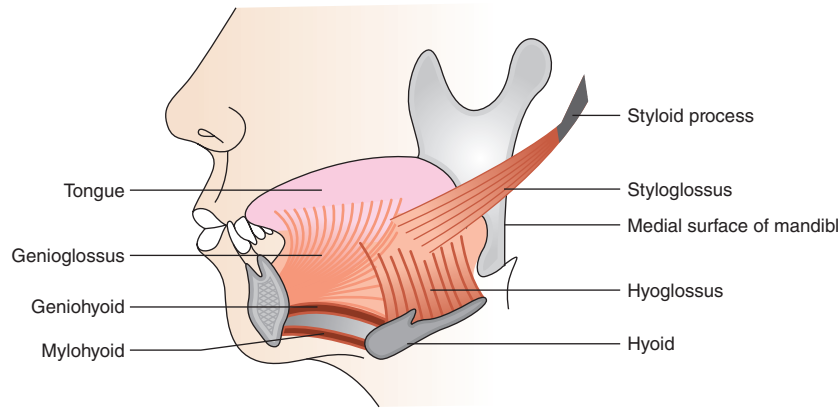


Figure 3.10 Extrinsic muscles of the tongue—sagittal section.

Table 3.4 Muscles of the Tongue and Their Action

	Muscle	Action
Extrinsic	Genioglossus	Causes protrusion of tongue
	Hyoglossus	Depresses tongue
	Styloglossus	Elevates, retracts tongue
	Palatoglossus	Elevates back of tongue
Intrinsic	Superior longitudinal	Shortens the tongue
	Inferior longitudinal	Shortens the tongue
	Vertical	Flattens and widens the tongue
	Transverse	Narrows and elongates the tongue

into three bundles of fibres to insert into the tongue at three different regions. The upper fibres are inserted into the tip, middle fibres into the dorsum and lower fibres into the hyoid bone. Each group has distinct functions. The upper fibres retract the tip, the middle fibres depress the tongue and the lower group helps in the protrusion of the tongue.

(b) *Hyoglossus:* It originates along the whole length of the greater cornu and the lateral part of the body of the hyoid bone. It ascends upwards and forwards to insert into the lateral aspect of the tongue between the styloglossus and the inferior longitudinal muscle. The actions of the muscle are depression and retraction of a protruded tongue.

(c) *Styloglossus:* It is a long strip of muscle originating from the tip and anterior border of the styloid process as well as the upper end of the stylohyoid ligament. It runs forwards and downwards to intersperse with the fibres of the hyoglossus. It is active during swallowing and it pulls the tongue upwards and backwards.

(d) *Palatoglossus:* This muscle starts from the oral surface of the palatine aponeurosis. It descends the palatoglossal arch to the lateral side of the tongue. It approximates the palatoglossal arches, thus helping in the closure of the oropharyngeal isthmus.

2. **Intrinsic muscles** (Fig. 3.11): Intrinsic muscles refer to muscles that lie entirely within the tongue whereas extrinsic muscles refer to those which attach the tongue to the adjacent structures. They originate from the adjacent bony structures and insert into the tongue. There are four pairs of intrinsic muscles that originate and insert within the tongue, running along its length.

The intrinsic muscles modify the shape of the tongue for various functions such as talking and swallowing whereas the extrinsic

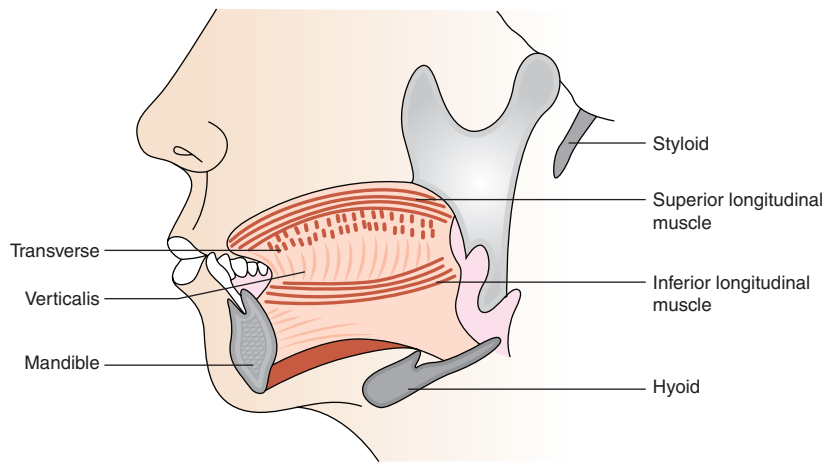


Figure 3.11 Intrinsic muscles of the tongue—sagittal section.

muscles alter the position of the tongue. The intrinsic muscles are as follows:

(a) Superior longitudinal
(b) Inferior longitudinal
(c) Vertical
(d) Transverse

These muscles lie in the upper part of the tongue and are attached to the submucous fibrous layer and the median septum. The transverse muscle fibres are seen only in cross-section as transverse dots running under the longitudinal muscles. The specific actions of the intrinsic muscles are depicted in **Table 3.4.**

Innervation and Blood Supply

1. **Motor:** Motor supply is through the hypoglossal nerve. All intrinsic and extrinsic muscles of the tongue are supplied by the hypoglossal nerve (CN XII), except the palatoglossus, which is innervated by the CN X through the pharyngeal plexus.
2. **Sensory:** Sensory supply is through different nerves. General sensation of the anterior two-third is supplied by the lingual nerve, which is a branch of V_3 (mandibular branch) of the trigeminal nerve CN V. The taste for the anterior two-third of the tongue is supplied by the facial nerve (chorda tympani, CN VII). Taste as well as general sensation for the posterior one-third is supplied by the glossopharyngeal nerve (CN IX).

The tongue receives blood supply from two sources:

1. **Primary source:** Lingual artery, branch of the external carotid artery
2. **Secondary source:** Tonsillar branch of the facial artery and ascending pharyngeal artery

Applied Anatomy

Paralysis of Genioglossus Muscle

This can lead to loss of the natural tone and position of the tongue. This can cause falling back of the tongue and obstruction of airway.

Muscles of the Eye (Figs 3.12–3.14)

The muscles of the eye play a number of vital functions such as movement of the eyeball, controlling the lacrimal apparatus and protecting the optic nerve.

The muscles of the orbital region are of two major types:

1. Voluntary muscles are the
   - *Four recti muscles:* Superior rectus, inferior rectus, medial rectus and the lateral rectus
   - *Two oblique muscles:* Superior oblique and inferior oblique
   - *Levator palpebrae superioris*
2. Involuntary muscles are the
   - Superior tarsal muscle
   - Inferior tarsal muscle and
   - Orbitalis muscle

Recti Muscles

Recti muscles originate from a common annular tendon which is attached to the orbital surface of apex of the orbit. They encircle the optic canal and

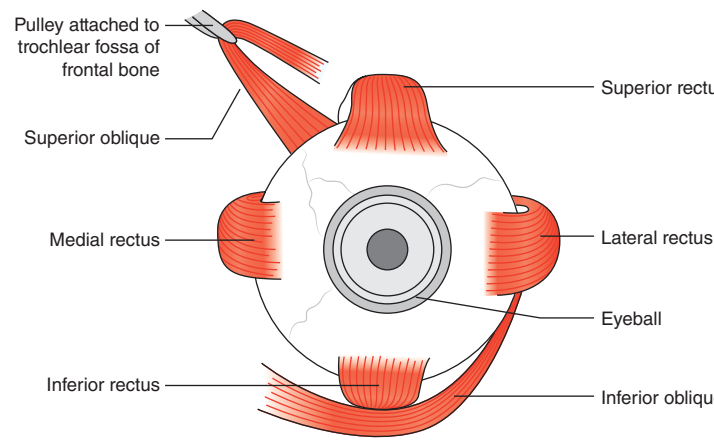


Figure 3.12 Extraocular muscles of the eye—frontal view.

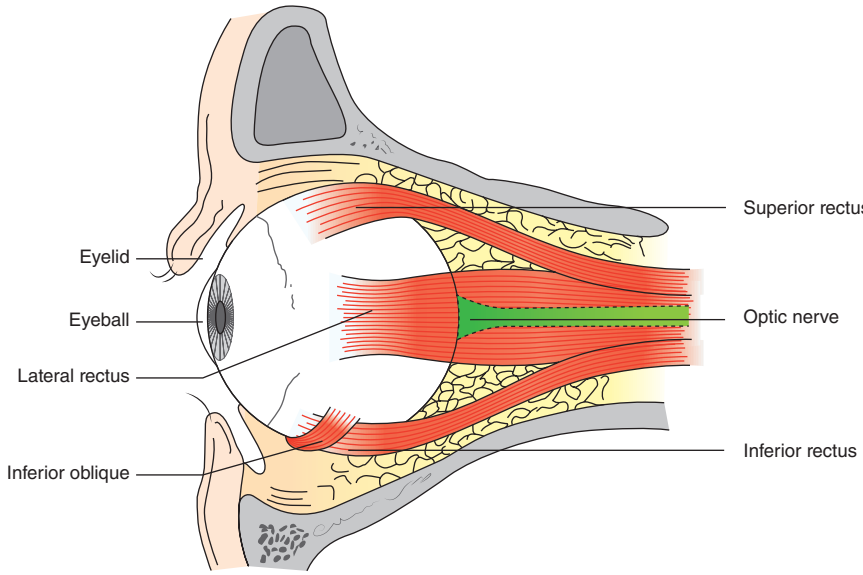


Figure 3.13 Extraocular muscles of the eye—sagittal view.

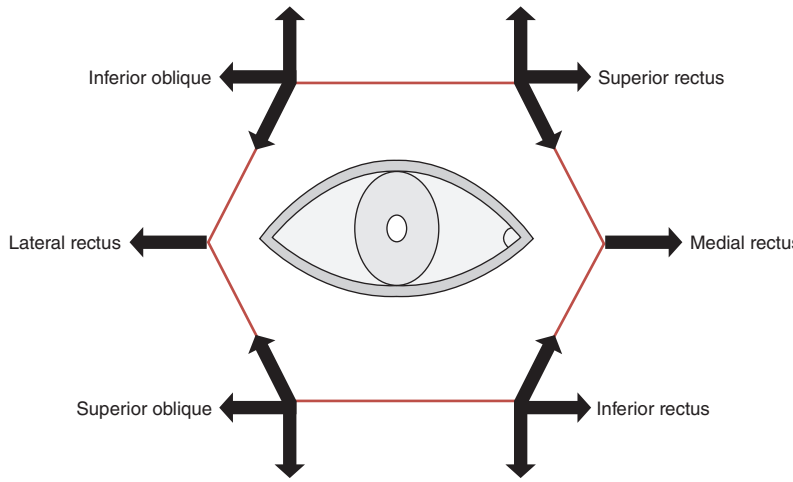


Figure 3.14 Muscles of the eye—movement.

the middle part of the superior orbital fissure. All the recti muscles insert into the sclera.

Superior Oblique

Superior oblique arises from the sphenoid body and passes through a fibrocartilaginous pulley attached to the trochlear fossa of the frontal bone. The muscle passes downwards below the superior rectus and inserts into the sclera behind the eyeball.

Inferior Oblique

Inferior oblique arises from the orbital surface of maxilla and inserts posterior to the insertion of the superior oblique.

Levator Palpebrae Superioris

Levator palpebrae superioris originates from the orbital surface of the lesser wing of the sphenoid and splits into two lamellae: superior and inferior. The superior lamella inserts into the superior

tarsus as well as the skin of the upper eyelid and the inferior tarsus inserts into the superior tarsus.

Actions of Muscles

The actions of muscles are depicted in **Figure 3.14**. The definitions of the basic movements of the eyeball are as follows:

1. **Upward movement:** Elevation
2. **Downward movement:** Depression
3. **Medial movement:** Adduction
4. **Lateral movement:** Abduction
5. **Inward movement:** Intorsion
6. **Outward movement:** Extortion

The movements of the eyeball may be due to the action of a single muscle or due to the combined action of many muscles.

Innervation and Blood Supply

1. **Motor:** The motor supply is through different nerves.
   - Superior rectus, inferior rectus, medial rectus, inferior oblique and levator palpebrae superioris by the oculomotor nerve
   - Superior oblique by the trochlear nerve
   - Lateral rectus by the abducent nerve
2. **Vascularity:** Vascularity is from the ophthalmic artery and the venous drainage is through the superior and inferior ophthalmic veins.

Muscles of the Floor of the Mouth

The main muscle which forms the floor of the mouth is the mylohyoid (**Fig. 3.15**).

Mylohyoid is a flat triangular muscle that occupies the floor of the mouth. Mylohyoid of both the sides originates from the mylohyoid line present on the medial surface of the mandible. They run medially and little inferiorly to meet in the midline. The anterior and the middle fibres meet in the median raphae and the posterior fibres insert into the body of the hyoid bone.

This muscle helps in the elevation of the floor of the mouth, the depression of the mandible and the elevation of the hyoid bone. The motor supply is by the nerve to the mylohyoid.

Applied Anatomy

Pirogov's Triangle

The triangle formed by the intermediate tendon of the digastric muscle, the posterior border of the mylohyoid muscle and the hypoglossal nerve is called Pirogov's, Pirogof's or Pirogov–Belclard's triangle. This is the ideal site to ligate lingual artery which is the major source of bleeding from the tongue.

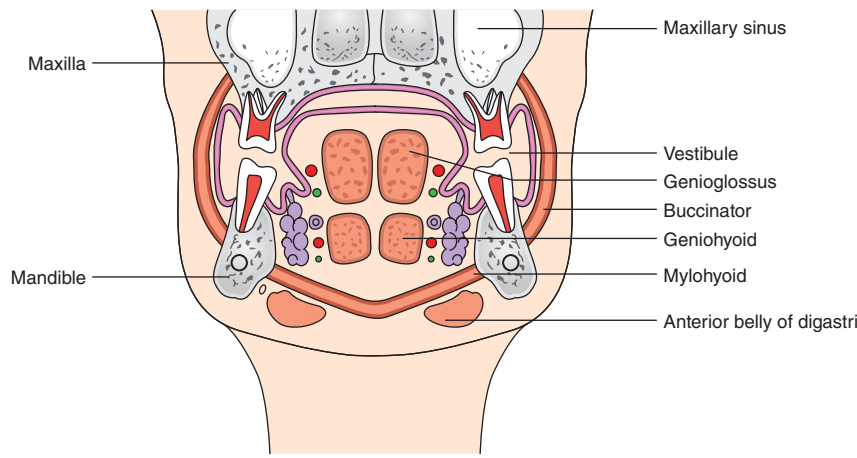
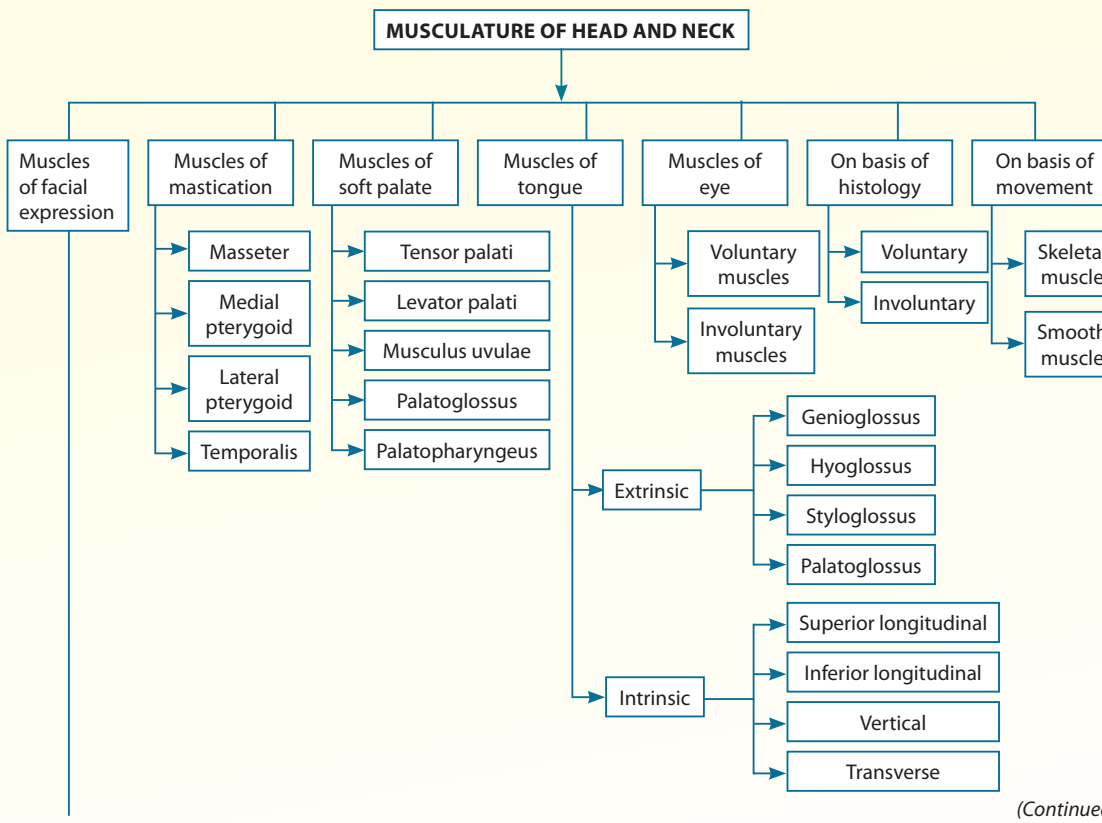


Figure 3.15 Floor of the mouth—coronal section.

Key Points

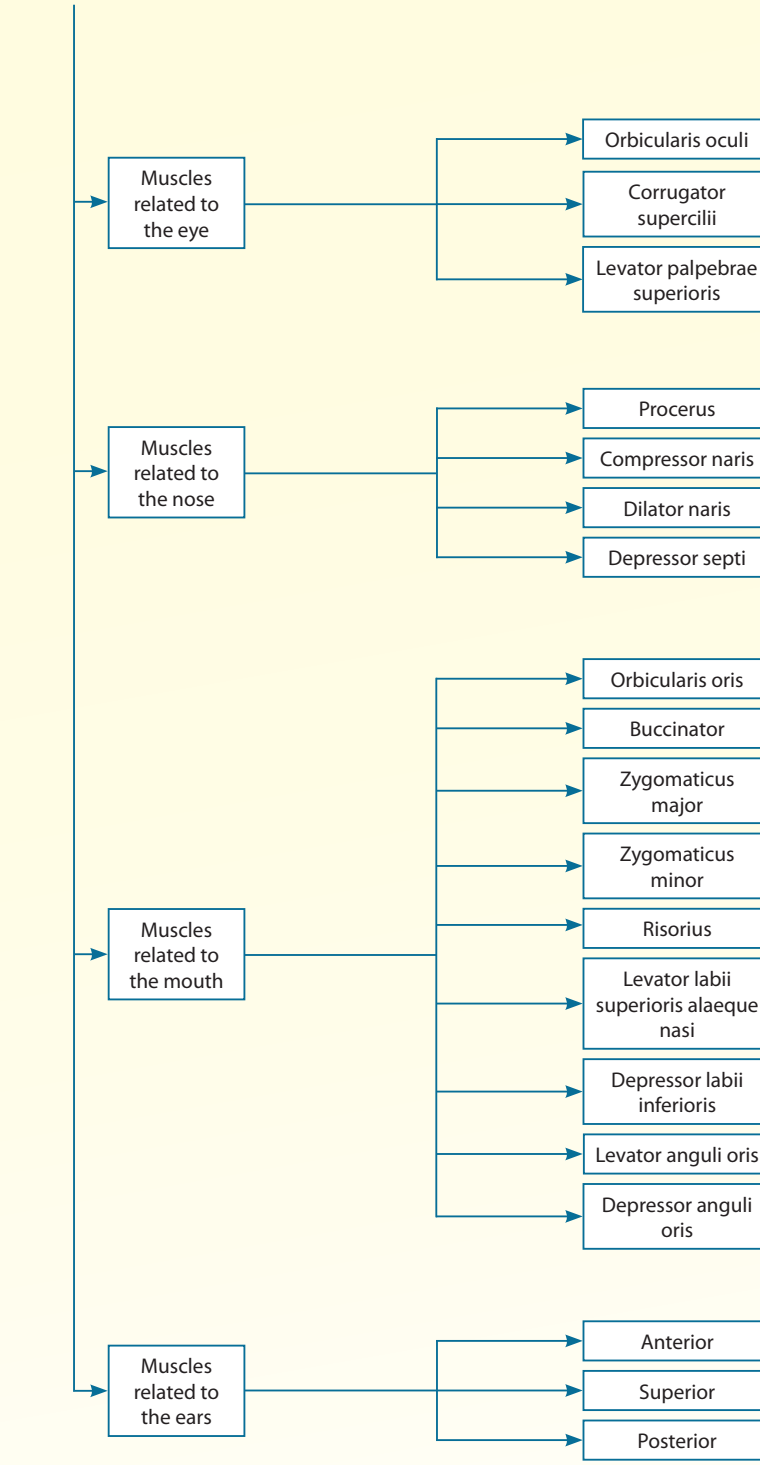
1. Facial muscles are (i) striated, (ii) voluntary and (iii) inserted into skin.
2. The motor nerve supply to the facial muscles is by the facial nerve.
3. The sphincters of the facial openings are as follows:
   (a) Orbicularis oculi that constricts the orbital opening
   (b) Orbicularis oris that closes the oral cavity
   (c) Compressor naris that compresses the nasal cavity
4. All the muscles of mastication help in elevating the mandible except the lateral pterygoid that helps in depressing the mandible.
5. The nerve supply to all the muscles of mastication is from the motor branch of the mandibular division of the trigeminal nerve and the arterial supply is from the second part of the maxillary artery.
6. The four recti muscles of the eye arise from a tendinous ring which is attached to the orbital surface of the apex of the orbit and insert into the sclera.
7. Mylohyoid muscle forms the floor of the mouth. It originates from the mylohyoid line on the medial surface of the mandible and inserts into the median raphae and hyoid bone.
8. The genioglossus muscle, a fan-shaped extrinsic muscle, forms the bulk of the tongue.
9. The chief blood supply of the tongue is the lingual artery.
10. The motor supply to the intrinsic and extrinsic muscles of the tongue is by the hypoglossal nerve, except the palatoglossus, which is supplied by the cranial root of the accessory nerve through the pharyngeal plexus.

Mind Map



(Continued)

(Continued)


Muscles related to the eye
Orbicularis oculi
Corrugator supercilii
Levator palpebrae superioris
Muscles related to the nose
Procerus
Compressor naris
Dilator naris
Depressor septi
Muscles related to the mouth
Orbicularis oris
Buccinator
Zygomaticus major
Zygomaticus minor
Risorius
Levator labii superioris alaeque nasi
Depressor labii inferioris
Levator anguli oris
Depressor anguli oris
Muscles related to the ears
Anterior
Superior
Posterior

Bibliography

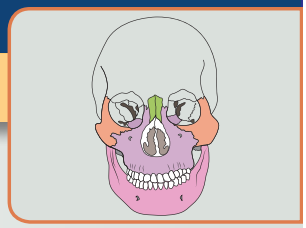
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Multiple Choice Questions

1. Striated muscles are
   (a) Skeletal muscles
   (b) Cardiac muscles
   (c) Smooth muscles
   (d) Skeletal and cardiac muscles
2. The dense connective tissue that binds a muscle to the periosteum of a bone is
   (a) Tendon
   (b) Fascia
   (c) Aponeuroses
   (d) Ligament
3. The zygomaticus major muscle is activated during
   (a) Smiling
   (b) Anger
   (c) Eating
   (d) Whistling
4. One of the following is a sphincter muscle:
   (a) Orbicularis oculi
   (b) Zygomaticus minor
   (c) Superior rectus
   (d) Frontalis
5. The muscle which prevents accumulation of food in the vestibule is the
   (a) Masseter
   (b) Buccinator
   (c) Orbicularis oris
   (d) Zygomaticus major
6. The muscle of mastication which has both an upper and lower head is the
   (a) Masseter
   (b) Temporalis
   (c) Medial pterygoid
   (d) Lateral pterygoid

7. The muscle which helps in opening the mouth or depressing the mandible is the
   (a) Masseter
   (b) Medial pterygoid
   (c) Lateral pterygoid
   (d) Temporalis
8. All the muscles of the soft palate are supplied by the cranial accessory nerve except the
   (a) Palatopharyngeal
   (b) Palatoglossal
   (c) Levator veli palatini
   (d) Tensor veli palatine
9. The muscle which opens the mouth of the auditory tube during swallowing and yawning is the
   (a) Tensor veli palatini
   (b) Palatoglossus
   (c) Palatopharyngeus
   (d) Superior rectus
10. Intrinsic muscles of the tongue
   (a) Alter the shape of the tongue
   (b) Alter the position of the tongue
   (c) Are attached to the bone
   (d) Help in the perception of taste
11. All the muscles of the orbit originate from a common tendinous ring except the
   (a) Superior rectus
   (b) Inferior rectus
   (c) Superior oblique
   (d) Inferior oblique
12. One of the following muscles of the eye is involuntary in action:
   (a) Superior rectus
   (b) Inferior rectus
   (c) Orbitalis
   (d) Superior oblique
13. The recti muscles of the eye are inserted into the
   (a) Zygoma
   (b) Frontal bone
   (c) Sphenoid bone
   (d) Sclera
14. The muscle which forms the floor of the mouth is the
   (a) Stylohyoid
   (b) Mylohyoid
   (c) Masseter
   (d) Inferior oblique
15. Gag reflex is elicited by the stimulation of the
   (a) Soft palate
   (b) Tongue
   (c) Nose
   (d) Floor of the mouth

CHAPTER 4



Nerves of the Head and Neck

Overview

The basic components of the nervous system are the neurons and the supporting connective tissue. Microscopically, the neuron is composed of nerve cell body (soma), axon and dendrite. Anatomically, the nervous system can be broadly classified into central and peripheral nervous systems. The central nervous system is constituted by the brain and the spinal cord while the peripheral nervous system is constituted by the somatic and autonomic nerves. Thirty-one pairs of spinal nerves and 12 pairs of cranial nerves comprise the somatic nerves while the sympathetic and parasympathetic nerve chains constitute the autonomic nerves. Each and every branch of any nerve possesses a specific area of supply and a specific area of representation in the brain.

INTRODUCTION

The nervous system is a complex and vital part of the human body that performs the following functions:

1. Senses the various internal and external stimuli
2. Integrates/coordinates the various systems of the body
3. Directs individual organs to perform specific functions at a specific time in response to stimuli

Importance of Neuroanatomy in Dentistry

Pain control is an essential and primary aspect of patient management in dentistry. Pain control before any dental procedure is achieved by anaesthetizing nerves using local anaesthetic (LA) solutions. Knowledge of anatomy of nerves and the various structures related to them is very important for practising different techniques of delivery of LA solutions and achieving site-specific action.

COMPONENTS OF THE NERVOUS SYSTEM

The nervous system consists of tissues that may be broadly divided into two components:

1. **Neurons:** The basic cells of the nervous system that receive, transmit and respond to external stimuli (which may be excitatory or stimulatory)
2. **Connective tissues:** Tissues that perform supportive functions such as providing nutrition and protection to the neurons; they are of two types:
   (a) Connective tissue of the central nervous system (CNS) called *neuroglia*
   (b) Connective tissue of the peripheral nervous system (PNS) constituting the *Schwann cells* and loose connective tissue

The terms commonly used to describe the structure and function of nerves are defined in **Box 4.1**.

Microanatomy of Neurons

Neurons are the fundamental, functional units of the nervous system. They conduct electrical impulses to various target organs and communicate with each other through intercellular junctions called *synapses*. The basic structure of

Box 4.1 Essential Terminologies

- **Afferent fibres:** Axons that carry impulses towards CNS; also called sensory fibres
- **Axon:** Long, cellular extension of nerve cell body that carries impulses away from the cell body of the neuron; also called nerve fibre
- **Dendrite:** Short cellular extension of the nerve cell body that conducts impulses towards the cell body of the neuron
- **Efferent fibres:** Axons that carry impulses away from the CNS; also called motor fibres
- **Ganglion:** Group of neuronal cell bodies sharing the same function, located outside the CNS (*pl*. ganglia)
- **Myelinated nerve/medullated nerve:** Nerve with a myelin sheath
- **Myelin sheath:** An envelope of myelin that helps in rapid conduction of impulses; formed by the cell membrane of the Schwann cells in the PNS and by oligodendroglia cells in the CNS
- **Nerve:** Bundles of neurons or nerve fibres
- **Nerve tract:** A bundle of myelinated nerve fibres that traverses the brain
- **Neuron:** Basic functional unit of the nervous system consisting of the nerve cell body with nucleus and cellular extensions called dendrites or axons
- **Non-myelinated nerve:** Nerve without a myelin sheath
- **Nucleus:** Group of neuronal cell bodies sharing the same function, located within the CNS (*pl.* nuclei)
- **Plexus:** A group of interconnected nerves or branches, or a network of nerves
- **Postganglionic neuron:** Neuron whose cell body lies in the autonomic ganglia and axon terminates in the target organs
- **Preganglionic neuron:** Neuron whose cell body lies in the CNS and axon terminates in a peripheral ganglion by synapsing with another nerve cell located in the same ganglion
- **Ramus:** Small branch-like structure of nerve extending from a larger one (*pl.* rami)
- **Synapse:** Junction between two neurons (axon-to-dendrite) or between a neuron and a muscle across which nerve impulses are transmitted

a neuron (**Fig. 4.1**) consists of a nerve cell body and cytoplasmic extensions (dendrite or axon).

1. **Nerve cell body/soma:** It is the central part of a neuron which forms the grey matter and nuclei in the CNS and the ganglia in the PNS.
2. **Axon:** It is a long, single, slender protoplasmic extension of a neuron which conducts electrical impulses away from the nerve cell body. Axons (axon = nerve fibre) communicate with other cells at junctions called synapses. Bundles of axons form the white matter/tract in the CNS and the nerve in the PNS.
3. **Dendrite:** It is a smaller protoplasmic extension, usually multiple in number, which conducts impulses towards the nerve cell body.

Applied Anatomy

Anaesthesia

The term *anaesthesia* refers to loss of sensation of pain. It can be generalized (general anaesthesia) or localized (local anaesthesia). Local anaesthesia is loss of pain sensation in a circumscribed area whereas general anaesthesia is associated with loss of pain as well as consciousness.

Local Anaesthetics in Dentistry

Local anaesthetic (LA) agents used in dentistry are compounds which act by reversibly blocking the conduction process of nerve impulses along sensory nerves. These agents may be in the form of gels, patches or injections.

Local anaesthetic techniques in dentistry are as follows:

1. *Infiltration*: It is a technique by which the LA solution is administered closer to the small terminal nerve endings.
2. *Block*: It is a technique by which the LA solution is injected close to the main nerve trunk.

Nerves

A nerve is defined as a cord-like structure of the PNS composed of bundles of axons which are covered by connective tissue. A bundle of axons is called a *fascicle*, and bundles of fasciculi constitute a *nerve*. Each component of a nerve has a connective-tissue covering as outlined below (**Fig. 4.2**):

1. **Endoneurium:** Loose connective tissue that surrounds an axon
2. **Perineurium:** Coarse connective tissue that covers a bundle of axons/fibres into fascicles
3. **Perilemma:** Innermost layer of perineurium

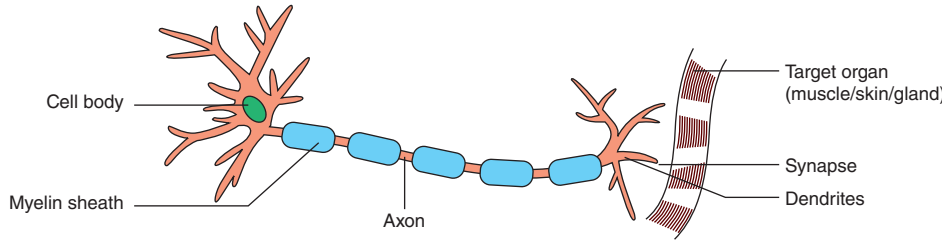


Figure 4.1 Neuron.

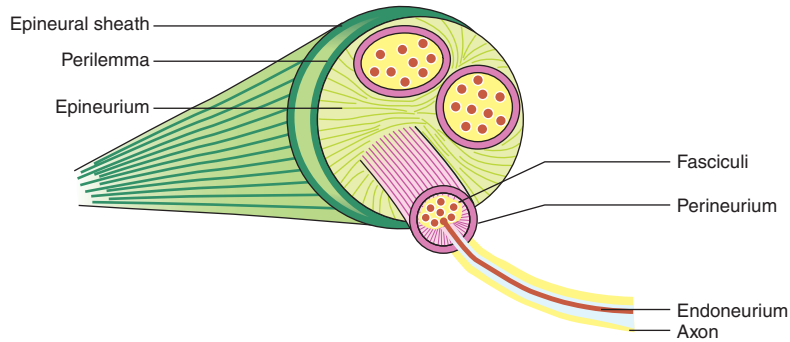


Figure 4.2 Coverings of a nerve.

4. **Epineurium:** Connective tissue with blood vessels that support the fascicule
5. **Epineural sheath:** Outermost tough fibrous sheath of a nerve

Applied Anatomy

Common Diseases Involving Nerves

1. **Neuritis:** It is inflammation of the nerve.
2. **Neuropathy:** It is a pathologic change in the PNS leading to functional deficits generally due to non-inflammatory lesions.
3. **Diabetic neuropathy:** It is a type of chronic peripheral polyneuropathy that occurs with diabetes mellitus; it generally affects the nerves of the lower limbs and frequently the autonomic nerves.
4. **Neuroma:** It is a tumour arising from a nerve and composed of nerve cells and nerve fibres.

Traumatic neuroma is a non-neoplastic, unorganised, nodular mass of nerve fibres and Schwann cells produced by the proliferation of nerve fibres and their supporting tissues following trauma.

Nerve Injuries

These may be classified as follows:

1. **Neuropraxia:** Temporary loss of nerve conduction following a blunt injury that leads to damage to the myelin sheath but leaves the nerve intact
2. **Axonotmesis:** Type of injury that occurs following a more severe crush or contusion which damages the axons and their myelin sheath but maintains the Schwann cells, the endoneurium, perineurium and epineurium intact
3. **Neurotmesis:** The most serious type of nerve injury in which both the nerve and the nerve sheath are disrupted; their recovery is incomplete

Types of Nerves

The nervous system of the body is categorized on the basis of the (i) anatomical location, (ii) function, (iii) control over systems, (iv) myelination, (v) diameter and (vi) functional components of nerves.

1. **On the basis of the anatomical location** (**Fig. 4.3**)
   (a) *Central nervous system (CNS)*: It involves the part of the nervous system that occupies the central region of the body. It includes the brain and the spinal cord.
   (b) *Peripheral nervous system (PNS)*: It constitutes extensions called nerves from the CNS. They are bundles of axons that carry impulses from the CNS to various parts of the body and vice versa. The PNS is broadly divided into two groups: somatic nerves and autonomic nerves, which are further subdivided as shown in **Figure 4.3a**.

Somatic nerves are of two types (**Fig. 4.3b**):

- Spinal nerves (31 pairs) arising from the spinal cord
- Cranial nerves (12 pairs) arising from the brain

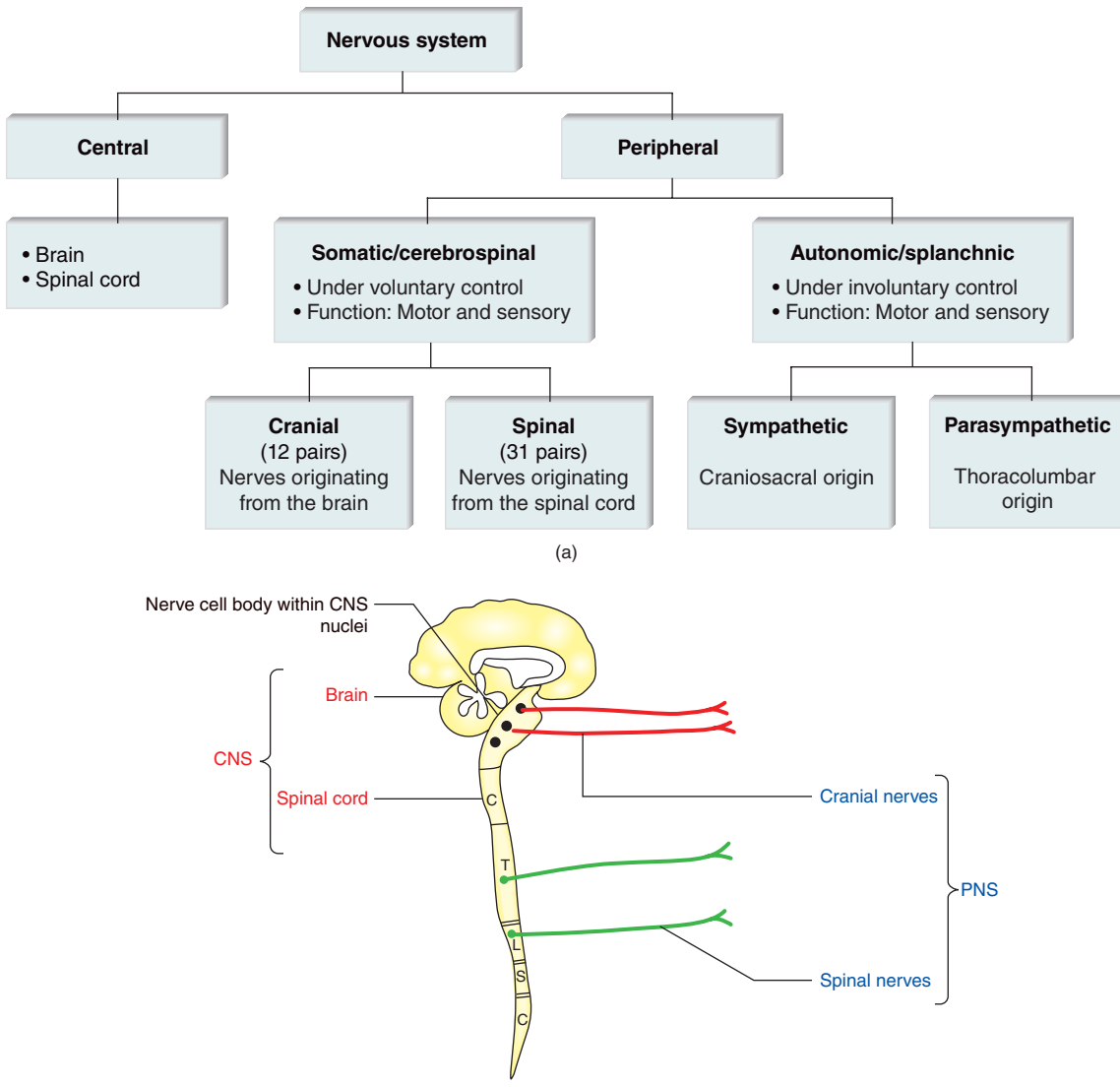


Figure 4.3 (a) Nervous system. (b) CNS versus PNS. *C*, cervical; *L*, lumbar; *S*, sacral; *T*, thoracic.

Table 4.1 Motor Versus Sensory Nerve

	Motor Nerve	Sensory Nerve
Function	Carry impulses from brain to organs	Carry impulses from organs to brain
Origin	Nuclei	Ganglia
Location of nuclei/ganglia of origin	Within brain	Outside brain
Pathway	Geniculate fibres	Lemniscus
Termination	Cerebral cortex (anterior)	Cerebral cortex (posterior)

Autonomic nerves are of two types:

- Sympathetic nerves
- Parasympathetic nerves

2. **On the basis of function** (Fig. 4.4; Table 4.1)
   (a) *Sensory/afferent nerves:* These nerves carry impulses from the peripheral regions to the brain and transmit the following two types of sensations:
   - General sensation, which refers to sensation of pain, touch and temperature.
   - Special sensation, which includes perception of vision, smell, hearing and taste.

   (b) *Motor/efferent nerves:* These nerves send impulses from the brain and spinal cord to all the muscles of the body which initiate muscular movement. The neuron involved can be either an upper or a lower motor neuron (Fig. 4.5):
   - Upper motor neuron refers to a nerve cell that connects the brain to the spinal cord. The cell body of an upper motor neuron is located in the motor area of the cerebral cortex and its processes connect with the lower motor neurons. Lesions of the upper motor neurons result in spasticity and very strong automatic reflex.
   - Lower motor neuron refers to a nerve cell that connects the spinal cord to a muscle. The cell body of a lower motor neuron is located in the spinal cord and its termination is in a skeletal muscle. Lesions of lower motor neurons result in weakness, twitching of muscle (fasciculation) and loss of muscle mass (muscle atrophy).

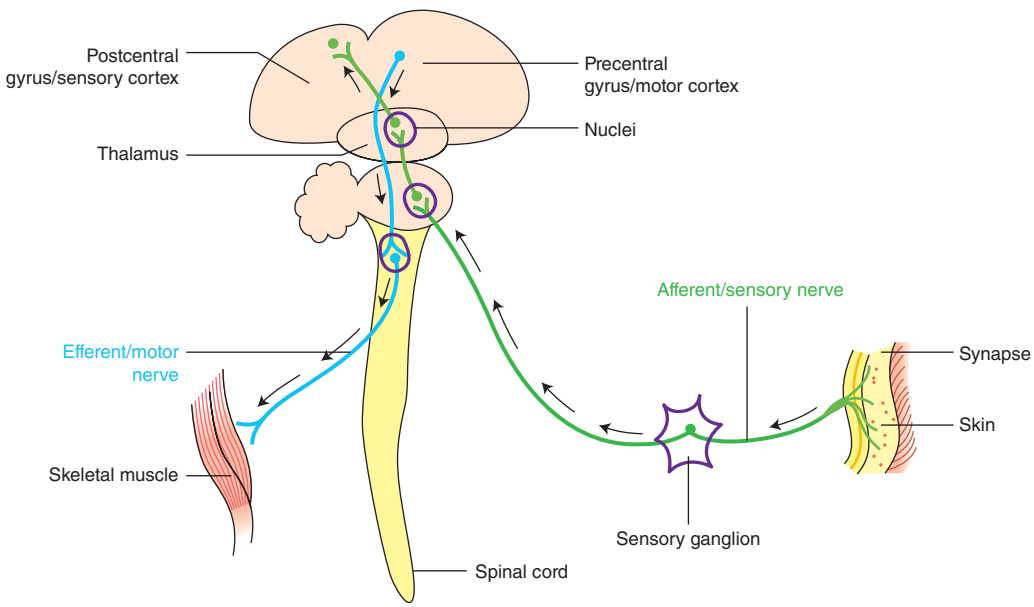


Figure 4.4 Sensory and motor nerves.

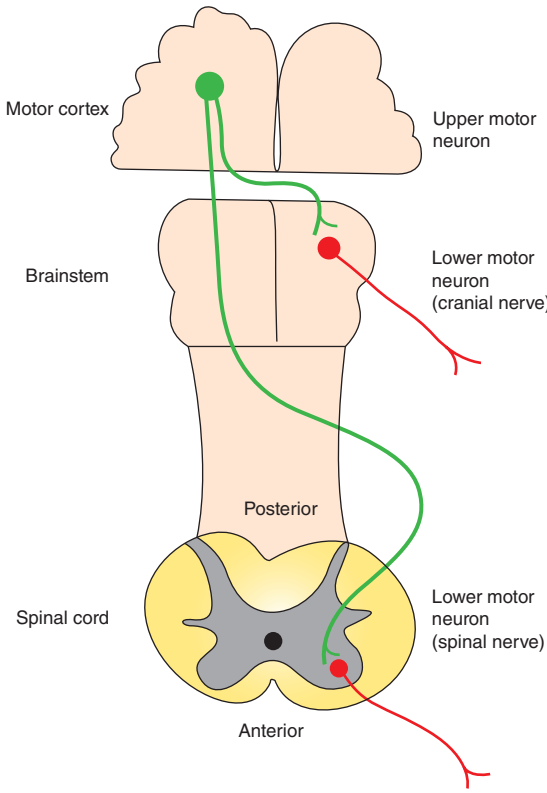


Figure 4.5 Motor neurons.

Table 4.2 Somatic Versus Autonomic

	Somatic Nerve	Autonomic Nerve
Action involved	Voluntary	Involuntary
Sensations carried	General and special sensations	Non-conscious sensations
Target muscles	Skeletal muscle	Smooth and cardiac muscles and glands
Number of functions	Single function (contraction of skeletal muscle)	Dual functions (excitation and inhibition)
Components of pathway	Single-neuron pathway	Two-neuron pathway

(c) *Mixed nerves*: These nerves carry both sensory and motor fibres.

(d) *Secretomotor nerves*: These are efferent nerves with the ability to induce a gland to secrete a substance. For example, the lacrimal branch of the maxillary nerve supplies secretomotor innervation to the lacrimal gland, stimulating its secretion of tears.

3. **On the basis of control over systems** (Table 4.2)

(a) *Somatic nervous system*: It is the part of the nervous system that perceives stimuli from external environment and controls voluntary activities of the body (Fig. 4.6a), for example movement of limbs by the action of skeletal muscles.

(b) *Autonomic nervous system (ANS)*: It is the part of the nervous system that controls involuntary action (Fig. 4.6b), for example functioning of internal organs such as the heart and intestines. It is subdivided into the sympathetic nervous system and the parasympathetic nervous system; the actions of these two systems oppose each other.

- The sympathetic nervous system is the part of the ANS that emerges from the thoracic and lumbar regions of the spinal cord. Actions are varied depending on the organs involved. It is active during emergency situations.
- The parasympathetic nervous system is the part of the ANS that arises from the brainstem and sacral part of the spinal cord. The actions of this system oppose the actions of the sympathetic system.

Both somatic and autonomic nervous systems have sensory as well as motor components.

4. **On the basis of the presence of myelin sheath** (Fig. 4.7; Table 4.3)

(a) *Myelinated nerves*: These are nerves with myelin sheath, and their conduction velocity is faster than that of non-myelinated nerves. Myelin is formed by Schwann cells in the PNS and oligodendrocytes in the CNS.

(b) *Non-myelinated nerves*: These are nerves without myelin sheath.

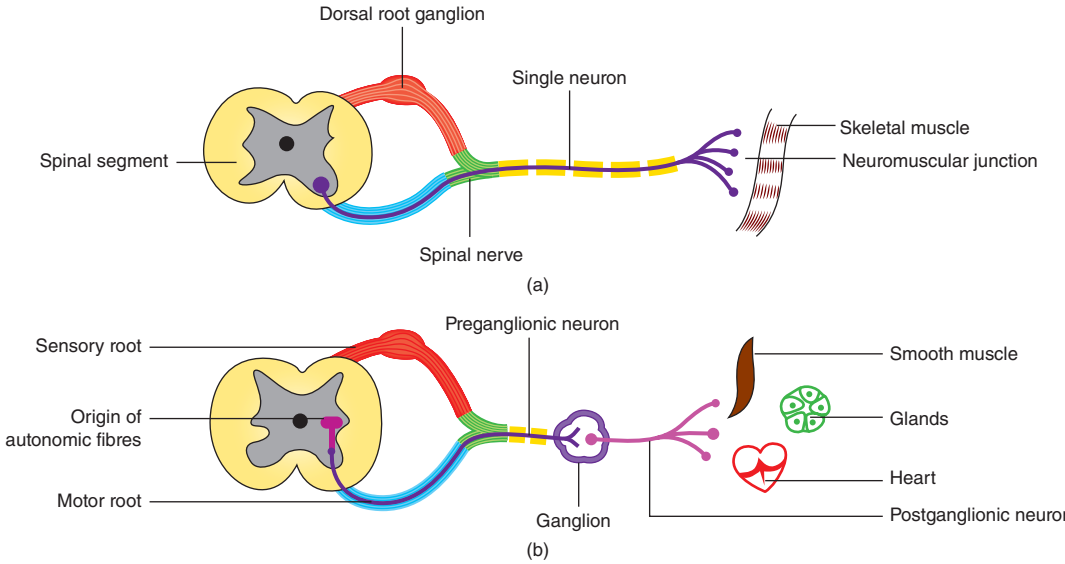


Figure 4.6 (a) Somatic system. (b) Autonomic system.

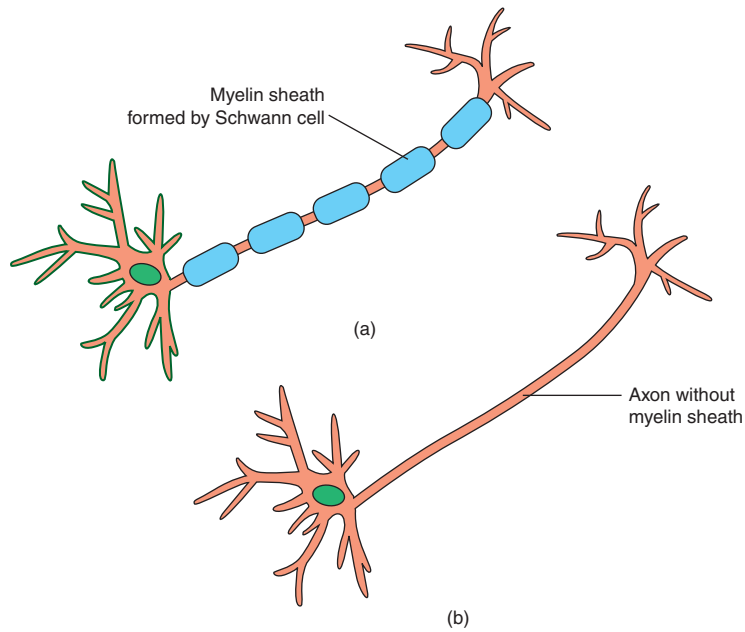


Figure 4.7 (a) Myelinated and (b) non-myelinated nerves.

Table 4.3 Myelinated Versus Non-Myelinated Nerve

	Myelinated Nerve	Non-Myelinated Nerve
Presence of myelin	Present	Not present
Colour	White	Grey
Diameter	Thicker	Thinner
Conduction velocity	Rapid conduction	Slow

Table 4.4 Types of Nerves Based on Diameter

Type	Erlanger–Gasser Classification	Diameter (μm)	Myelin Presence (√)/ Absence (×)	Conduction Velocity (m/sec)	Location of Nerve Fibres	Impulse Carried
La	Aα	13–20	√√√	80–120	Muscles and joints	Motor, proprioception
II	Aβ	6–12	√√	33–75	Muscles and joints	Motor, proprioception
	Ar	3–6	√	15–35	Muscles and joints	Motor, proprioception
III	Aδ	1–5	√	3–30	Sensory fibres	Pain, temperature and touch
	B	<3	√	3–15	Preganglionic sympathetic	Autonomic functions
IV	C	0.2–1.5	×	0.5–2.0	Postganglionic sympathetic	Autonomic functions

Table 4.5 Functional Components of Cranial Nerves

	Components	Type	Function
Afferent	Somatic afferent	Sensory	General sensation from body
	Visceral afferent	Sensory	General sensation from glands and viscera
	Special afferent	Sensory	Special sensation like smell, taste, hearing, sight and balance
Efferent	Somatic efferent	Motor	Motor supply to muscles derived from somites
	Visceral efferent	Motor	Motor supply to muscles derived from branchial arches
	Branchial efferent	Motor	Autonomic motor to smooth muscle and glands

5. **On the basis of the diameter of the nerves:** Nerves may be classified on the basis of their diameter, which varies according to the degree of myelination. The thickness of the nerve affects the conduction velocity as shown in **Table 4.4.**
6. **On the basis of the functional components of nerves** (**Table 4.5**)
   (a) *Somatic efferent nerve fibres (SE)*: These are fibres which transmit motor impulses from the spinal cord to the skeletal muscles.
   (b) *Visceral efferent nerve fibres (VE)*: These are fibres which transmit motor impulses from the spinal cord to the smooth muscles, cardiac muscle and glands.
   (c) *Somatic afferent nerve fibres (SA)*: These are fibres which transmit exteroceptive and proprioceptive impulses from the body to the spinal cord.
   (d) *Visceral afferent nerve fibres (VA)*: These are fibres which transmit interoceptive impulses from the viscera to the spinal cord.

AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system (ANS) controls involuntary actions of the body. It has two main components, the sympathetic and parasympathetic systems, which work in opposition to each other to maintain the homeostasis of the body (**Fig. 4.8**). Their actions, whether excitatory or inhibitory, depend on the organ involved. The differences between the two components of ANS in origin and functions are shown in **Tables 4.6(a)** and **(b)**.

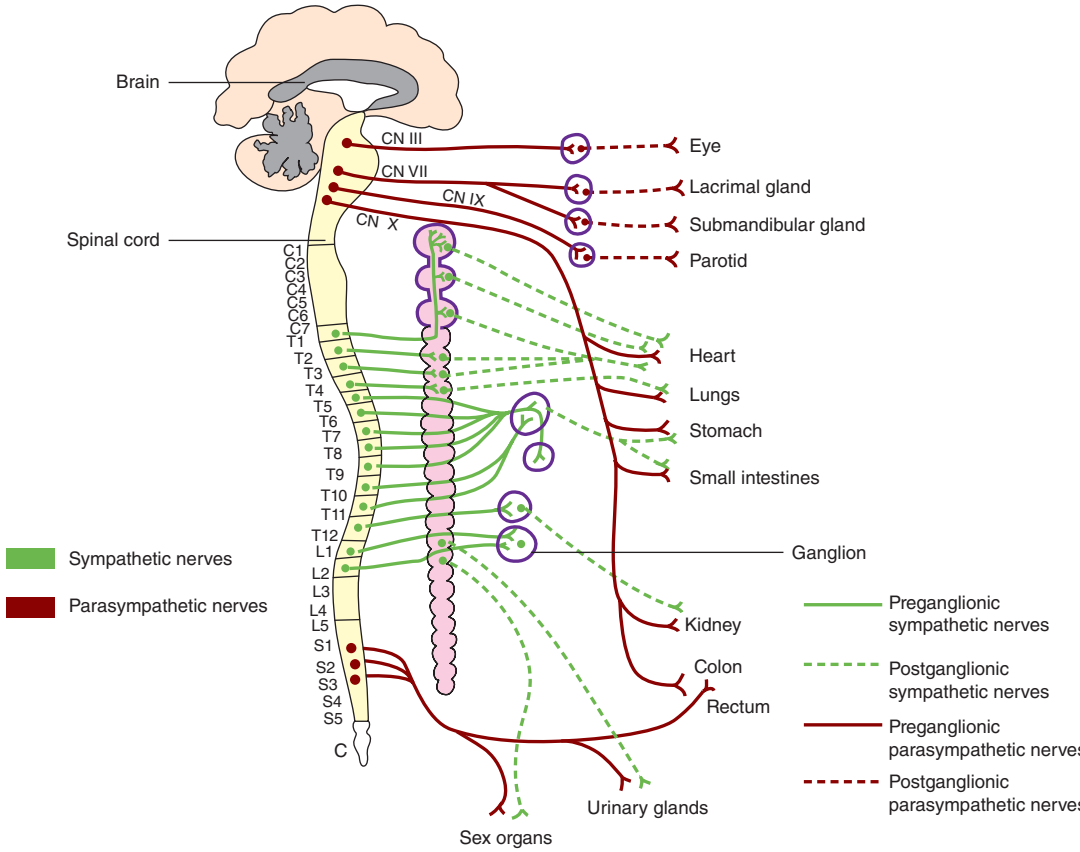


Figure 4.8 Sympathetic and parasympathetic systems—schematic diagram. *C*, cervical; *L*, lumbar; *S*, sacral; *T*, thoracic.

Table 4.6a Sympathetic Versus Parasympathetic

	Sympathetic Nerve	Parasympathetic Nerve
Function	Flight/fight	Rest/digest
Origin	Thoracolumbar outflow	Craniosacral outflow
Location of nuclei of origin	Prevertebral and paravertebral	Adjacent or within target organs
Preganglionic fibres	Shorter	Longer
Postganglionic fibres	Longer	Shorter

Table 4.6b Comparison of Functions—Sympathetic Versus Parasympathetic

Organ	Sympathetic Effect	Parasympathetic Effect
Eye	Dilates pupil	Constricts pupil
Heart	Increases the rate and force of contraction	Reduces the rate and force of contraction
Lungs	Dilates bronchioles	Constrict bronchioles
Digestive tract	Inhibits peristalsis	Promotes peristalsis
Kidney	Increases renin secretion	Reduces renin secretion
Penis	Promotes ejaculation	Reduces ejaculation
Sweat glands	Promotes sweating	Reduces sweating

Sympathetic Nerves of the Head

The sympathetic system is the part of the ANS that is concerned with involuntary initiation of the functioning of internal organs.

Characteristic Features

The sympathetic system plays a significant role in the following:

1. The sympathetic system remains subtly active throughout the day as well as night to be prepared for the fight-or-flight response to manage emergency and stressful situations of the body.
2. It opposes the action of the parasympathetic nervous system to maintain homeostasis.

Origin

The sympathetic fibres originate from the thoracolumbar region of the spinal cord (intermediolateral horn of T1–L2 levels, in particular).

Structure

1. Two types of neurons are involved in the transmission of impulses through the sympathetic system:
   (a) Preganglionic neurons
   (b) Postganglionic neurons (**Fig. 4.9a**)
2. Preganglionic neurons arise from the intermediolateral horn of the thoracolumbar region of the spinal cord (levels T1–L2) to reach a ganglion (one of the paravertebral ganglia) and to synapse with a postganglionic neuron present in the ganglion.
3. Sympathetic ganglia are centres where the preganglionic neuron synapses with the post-ganglionic neuron. The sympathetic ganglia of the head and neck are the *cervical ganglia* (**Fig. 4.9b** and **c**).
4. The cell bodies of the postganglionic neurons are present in the ganglion and their axons extend to target organs such as viscera and blood vessels or glands. Characteristically, the post-ganglionic axons are longer than the preganglionic axons.
5. Axons of sympathetic nerves exit the spinal cord through the anterior root. They run adjacent to the spinal (sensory) ganglion and enter the anterior rami of the spinal nerves (**Fig. 4.9a**). Later, they join either the paravertebral or the prevertebral ganglia through the communicating rami.

Neurotransmitter

Adrenaline and noradrenaline are the neurotransmitters involved with the nerve endings of the sympathetic nerves.

Action

Stimulation of the sympathetic nervous system results in a number of responses that are varied systemwise. They are as follows:

1. Constriction of blood vessels supplying the skin
2. Dilation of blood vessels supplying the heart and skeletal muscles
3. Bronchial dilation
4. Release of glucose from the liver

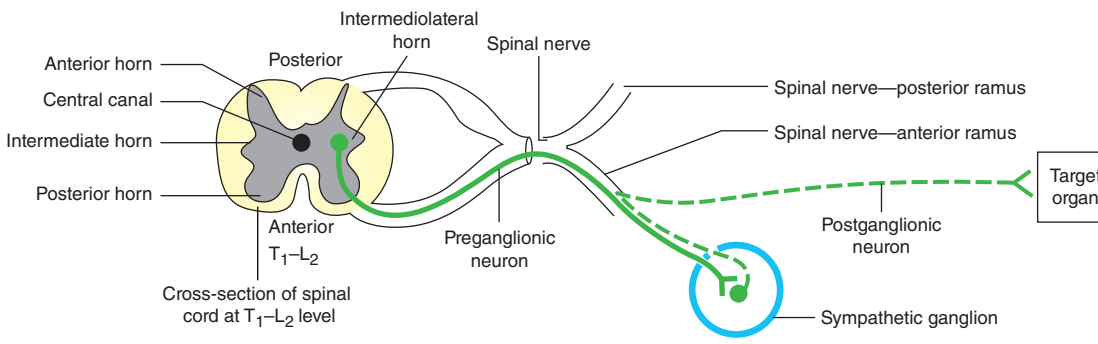


Figure 4.9 (a) Sympathetic nerves—origin and structure. *(Continued)*

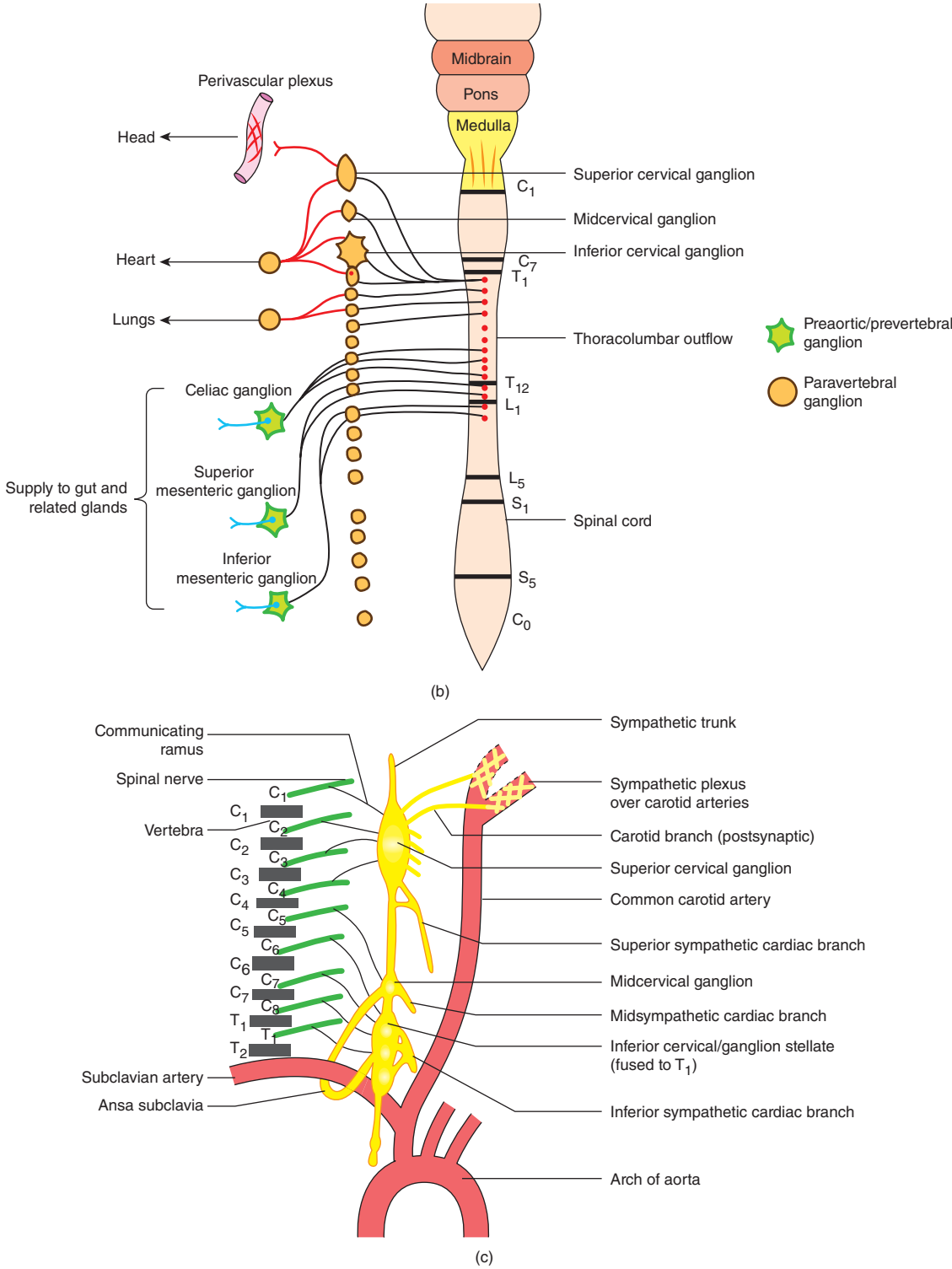


Figure 4.9 *(Continued)* (b) Sympathetic nerves and ganglia. (c) Cervical sympathetic ganglia. *C*, cervical; *L*, lumbar; *S*, sacral; *T*, thoracic.

Sympathetic Ganglia

Ganglia of the sympathetic nervous system are called sympathetic ganglia. Two groups of ganglia are identified on the basis of their location within the body: paravertebral and prevertebral ganglia (**Fig. 4.9b**).

1. **Paravertebral ganglia:** These are located on either side of the vertebrae (para = adjacent) and are united to form the sympathetic chain or trunk. Normally, 21 or 22 pairs of these ganglia constitute the sympathetic trunk and are found along the entire length of the vertebral column:
   (a) Three in the cervical region
   (b) 10–11 in the thoracic region
   (c) Four in the lumbar region
   (d) Four in the sacral region
   (e) A single, unpaired ganglion in front of the coccyx (*ganglion impar*)

   The ganglia and their respective innervation regions are given in **Table 4.7**.
2. **Prevertebral (preaortic) ganglia:** These lie in front of the aorta and are three in number:
   (a) Celiac
   (b) Superior mesenteric
   (c) Inferior mesenteric

Applied Anatomy

Horner Syndrome

This is a clinical abnormality involving the cervical sympathetic trunk. The syndrome includes the following signs involving the ipsilateral side of face: constriction of the pupil (miosis), drooping of the superior eyelid (ptosis), redness and increased temperature of the skin (vasodilatation) and absence of sweating (anhydrosis).

Parasympathetic Nerves of the Head

The parasympathetic system is responsible for the functions of the body at rest such as digestion, salivation, sexual arousal, lacrimation, urination and defaecation.

Characteristic Features

1. The parasympathetic system exerts its effects predominantly during non-emergency situations (i.e. basal activities of the body) such as digestion and rest.
2. In general, its functions oppose the actions of the sympathetic system.

Table 4.7 Sympathetic Ganglia Nerve Supply of the Head and Neck

Ganglionic Group	Ganglion	Areas Innervated
Paravertebral	Superior cervical ganglion: In front of second and third cervical vertebrae	Viscera of the head
	Middle cervical ganglion: In front of sixth cervical vertebrae	Viscera of the neck, thorax (i.e. the bronchi and heart) and upper limb
	Inferior/cervicothoracic/stellate ganglion: In front of sixth cervical vertebrae	
	Thoracic	Trunk region
	Lumbar	Pelvic floor and lower limb
	Sacral	
Preaortic	Celiac	Stomach, liver, pancreas, duodenum and the first part of the small intestine
	Superior mesenteric	Small intestine
	Inferior mesenteric	Descending colon, sigmoid colon, rectum, urinary bladder and sexual organs

Origin (Fig. 4.10a)

The parasympathetic fibres arise from a source called *craniosacral outflow*:

1. **Cranial nerves:** Third, seventh and ninth (**Fig. 4.8**)
2. **Sacral segment of the spinal cord:** S2, S3 and S4 spinal nerves, especially the ventral horn (**Fig. 4.10b**)

These parasympathetic nerves which originate from the S2, S3 and S4 spinal nerves are called the *pelvic splanchnic nerves* or the *nervierigentes*.

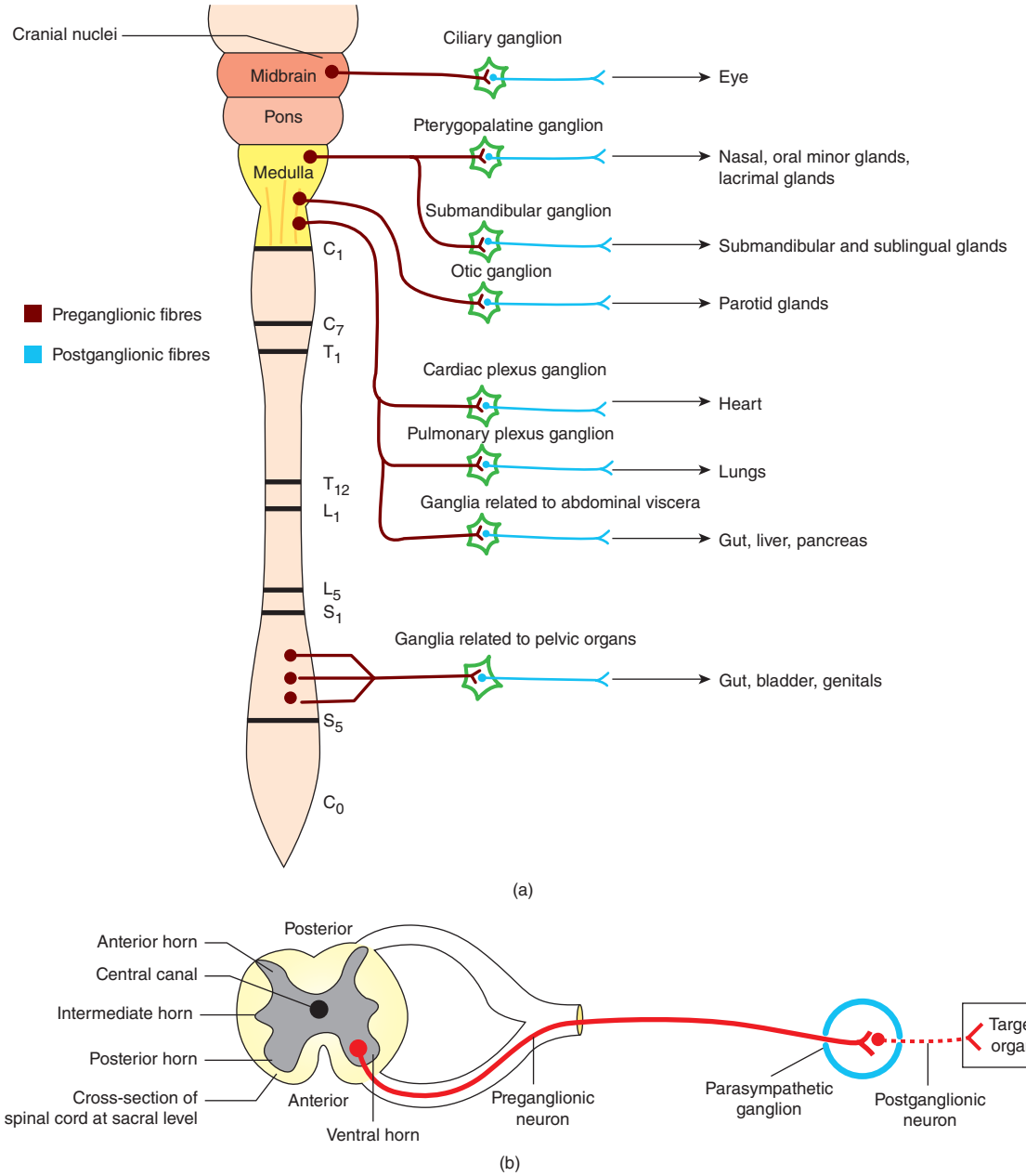
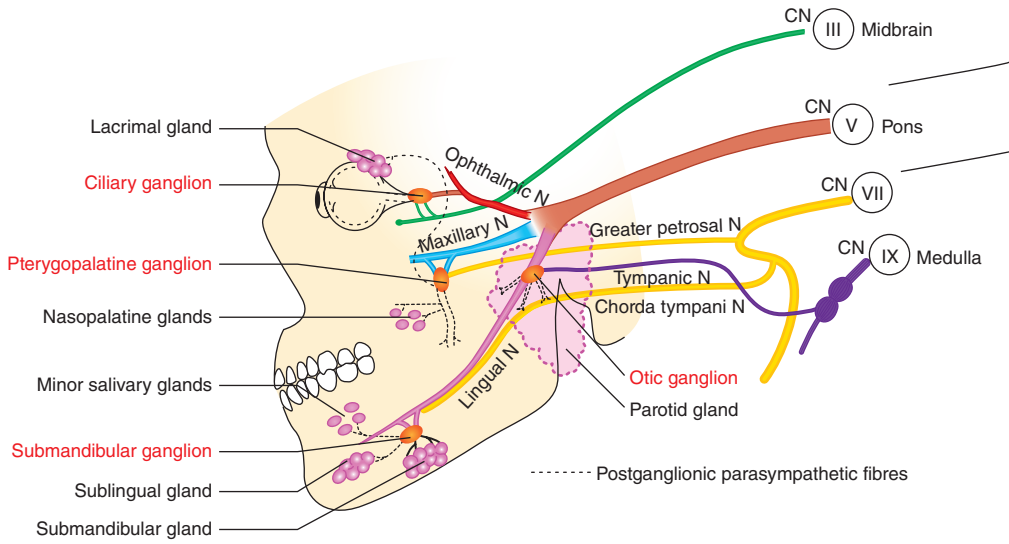


Figure 4.10 (a) Parasympathetic nerves and ganglia of the body. (b) Parasympathetic nerves—origin and structure. *C*, cervical; *L*, lumbar; *S*, sacral; *T*, thoracic. *(Continued)*



(c)

Figure 4.10 *(Continued)* (c) Parasympathetic nerves and ganglia of the head. *N*, nerve.

Neurotransmitter

Acetylcholine is the neurotransmitter at the parasympathetic nerve endings.

Parasympathetic Ganglia (Fig. 4.10c)

Parasympathetic ganglia are the autonomic ganglia of the parasympathetic nervous system. They lie close to or within the organs they innervate and hence are called *intramural ganglia*. The parasympathetic ganglia of the head and neck region, however, are exceptions to this. Four paired ganglia supply all the essential parasympathetic innervation to the head and neck area. The parasympathetic ganglia and their innervation are as follows:

1. Ciliary ganglion (sphincter pupillae, ciliary muscle)
2. Pterygopalatine ganglion (lacrimal gland, glands of nasal cavity)
3. Submandibular ganglion (submandibular and sublingual glands)
4. Otic ganglion (parotid gland)

Structure of a Ganglion (Fig. 4.10b)

Every parasympathetic ganglion consists of three roots which enter the ganglion and have multiple exiting branches. The three roots are as follows:

1. **Motor root:** This carries presynaptic parasympathetic nerve fibres (general visceral efferent [GVE]). These fibres terminate in the ganglion and synapse with the postsynaptic fibres travelling to target organs.
2. **Sensory root:** This carries general sensory fibres (general somatic afferent [GSA]). These fibres do not synapse in the ganglion.
3. **Sympathetic root:** This carries postsynaptic sympathetic fibres (GVE). These fibres also pass through the ganglion without synapsing.

Some ganglia also carry special sensory fibres that transmit the taste sensation. All the four parasympathetic ganglia of the head receive sensory filaments from the trigeminal nerve and motor and sympathetic filaments from various sources.

The parasympathetic ganglia of the head and neck and their preganglionic and postganglionic fibres are mentioned in **Table 4.8** along with their target organs.

SPINAL NERVES

The nerves which emerge from segments of the spinal cord are called spinal nerves (**Fig. 4.11**). Spinal nerves form part of the PNS. In humans, there are 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal. It is to be

Table 4.8 Parasympathetic Ganglia in the Head Region

Ganglia	Location	Preganglionic Fibres	Postganglionic Fibres	Target Organ
Ciliary	Near apex of orbit	CN III	• PS: Short ciliary nerve • S: Superior cervical ganglion, long ciliary nerve	Eye
Pterygopalatine	Pterygopalatine fossa	Greater petrosal nerve	• PS: Zygomaticotemporal nerve (V_2), lacrimal nerve (V_1) • S: Superior cervical ganglion, deep petrosal nerve	Lacrimal gland
Submandibular	On hyoglossus, inferior to submandibular duct	CN VII—chorda tympani, lingual nerve	• PS • S: Superior cervical ganglion	Submandibular and sublingual glands
Otic	Inferior to foramen ovale	CN IX—tympanic nerve, lesser petrosal nerve	• PS: Auriculotemporal • S: Superior cervical ganglion	Parotid gland

PS, parasympathetic fibres; *S*, sympathetic fibres.

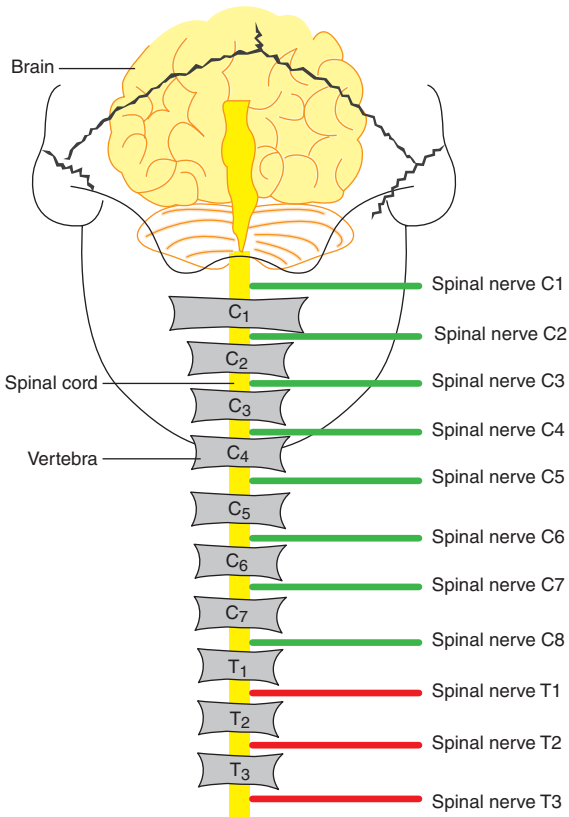


Figure 4.11 Numbering of spinal nerves. *C*, cervical; *T*, thoracic.

remembered that the number of vertebrae at every level are as follows: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral (fused) and 1 coccygeal (**Fig. 4.11**).

The number of spinal nerves generally corresponds to the number of vertebrae except in the cervical region. This is because in the cervical region, the spinal nerve roots come out above the corresponding vertebrae. Therefore, the spinal nerve that arises between the skull and the first cervical vertebra is the first spinal nerve. From the thoracic to coccygeal region, the spinal nerve roots emerge below the corresponding vertebrae. For example, the spinal nerve T1 arises below the thoracic vertebra T1.

Formation

A spinal nerve is formed at the intervertebral foramen by the union of the anterior and posterior roots that arise from the spinal cord (**Fig. 4.12**).

1. The anterior root contains the following structures:
   (a) Motor fibres for skeletal muscles
   (b) Sympathetic fibres (in fibres originating from T1 to L2)
   (c) Parasympathetic fibres (in fibres originating from S2 to S4)
2. The posterior root contains sensory fibres whose cell bodies are in the spinal ganglion.

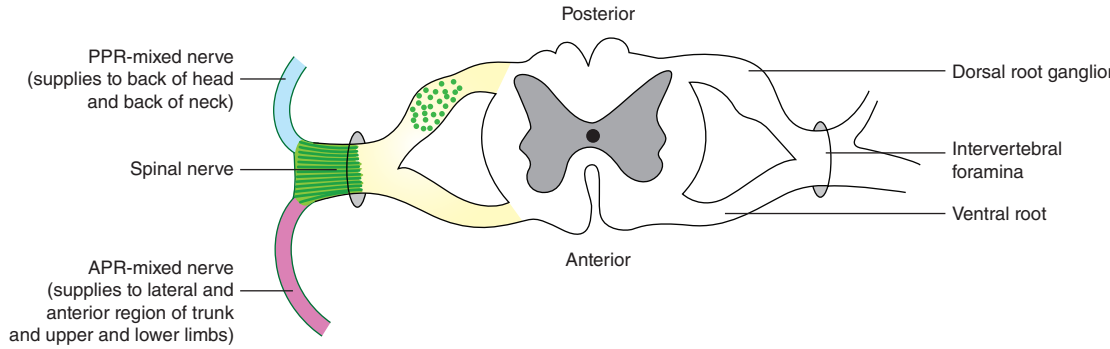


Figure 4.12 Spinal nerves—formation. *APR*, anterior primary ramus; *PPR*, posterior primary ramus.

Branches of Spinal Nerves

After its formation, the spinal nerve subdivides to give rise to the following branches. These branches are also called *rami* (*sing.* ramus) (**Fig. 4.12**).

1. **Anterior branch/anterior primary ramus:** This is larger than the other branches. It innervates the anterior as well as the lateral part of the body and limbs. The great nerve plexuses, namely the cervical, brachial, lumbar and sacral plexuses, are formed by anterior rami. The cervical plexus is of relevance to the face.
2. **Posterior branch/posterior primary ramus:** This innervates the back of the trunk.
3. **Communicating branch:** This connects the spinal nerve to the sympathetic trunk.
4. **Meningeal branch:** This branch supplies the dura mater by re-entering the vertebral canal through the intervertebral foramen.

Cervical Spinal Nerves (C1–C4)

Cervical Plexus (Fig. 4.13)

The cervical plexus is formed by the first four cervical spinal nerves, C1, C2, C3 and C4. This network divides and recombines to create a variety of nerves that supply the skin and muscles of the neck and back of the head.

Origin The plexus is formed by the anterior rami of C1–C4 spinal nerves.

Location The plexus lies anterior to the origin of *levator scapulae* and *scalenus medius* muscles and deep to the superior part of the sternocleidomastoid muscle.

Branches Various branches arise from the cervical plexus (**Fig. 4.14**):

1. **Cutaneous branches:** These branches provide sensory innervation to the skin. They arise at the level of the middle third of the sternocleidomastoid at the posterior border to innervate the skin of neck and scalp between auricle and external occipital protuberance. The branches and the regions innervated by them are as follows:
   (a) *Lesser occipital nerve (C2 and C3):* Skin of occipital region behind ear
   (b) *Great auricular nerve (C2 and C3):* Skin over mastoid, auricle, angle of jaw over parotid and masseteric area

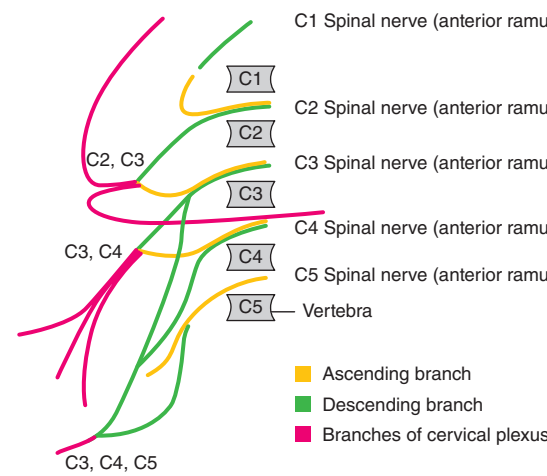


Figure 4.13 Cervical plexus—formation. *C*, cervical.

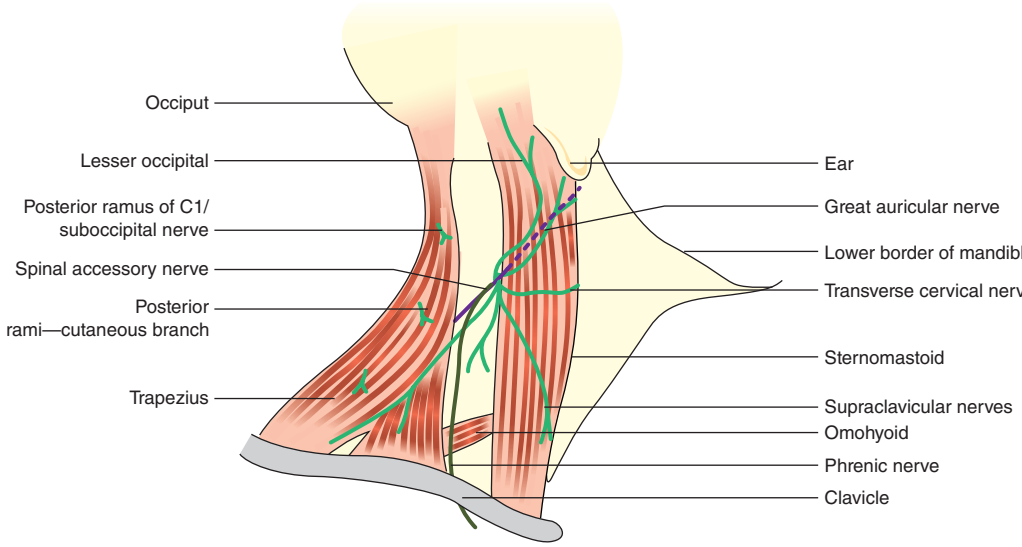


Figure 4.14 Spinal nerves—branches of the cervical plexus.

(c) *Transverse nerve of neck (C2 and C3):* Skin over the anterior aspect of neck

(d) *Supraclavicular nerves (C2 and C3):* Skin over acromion and deltoid/pectoral region

2. **Muscular branches**

(a) *Suboccipital nerve (C1):* Supplies the deep muscles of neck

(b) *Phrenic nerve (anterior rami of C3–C5):* Supplies the diaphragm (motor and sensory)

3. **Brachial plexus (C5–T1):** This plexus is formed by the last four cervical spinal nerves, C5, C6, C7 and C8, and the first thoracic spinal nerve, T1. This network forms the nerves which innervate the arm and the upper back.

CRANIAL NERVES

Cranial nerves originate directly from the brain. They reach the head and neck region by traversing through the numerous foramina present in the base of the cranium (**Fig. 4.15**). There are 12 pairs of cranial nerves in all, each designated by a Roman numeral (I–XII). The numbers indicate the arrangement of the nerves from the anterior to the posterior direction. The first and the second pair arise from the cerebrum whereas the remaining 10 pairs originate from the brainstem. The cranial nerves may be motor, sensory or mixed.

Origin of Cranial Nerves (Fig. 4.16; Table 4.9)

In general, the fibres of the motor nerves originate from a group of nerve cells in the brain called nuclei, and the fibres of the sensory nerves originate from a group of nerve cells outside the brain. The nerves are named as follows:

1. I: Olfactory
2. II: Optic
3. III: Oculomotor
4. IV: Trochlear
5. V: Trigeminal
6. VI: Abducent
7. VII: Facial
8. VIII: Acoustic
9. IX: Glossopharyngeal
10. X: Vagus
11. XI: Accessory
12. XII: Hypoglossal

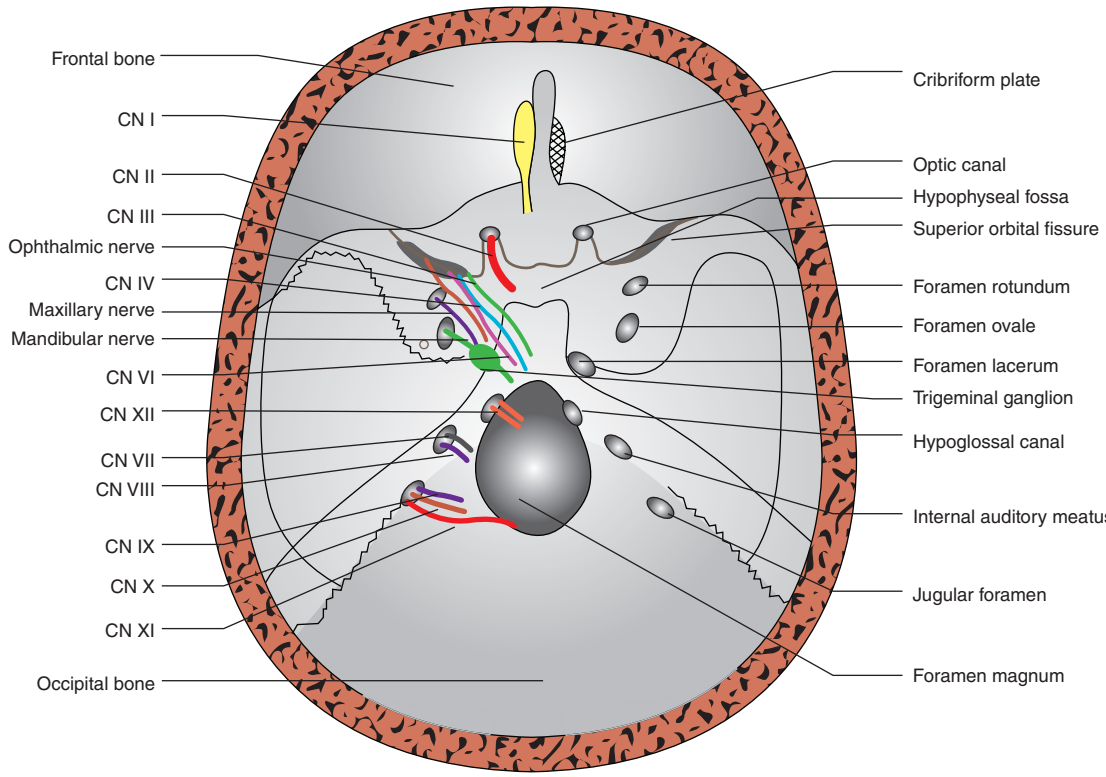


Figure 4.15 Cranial nerve—related foramina.

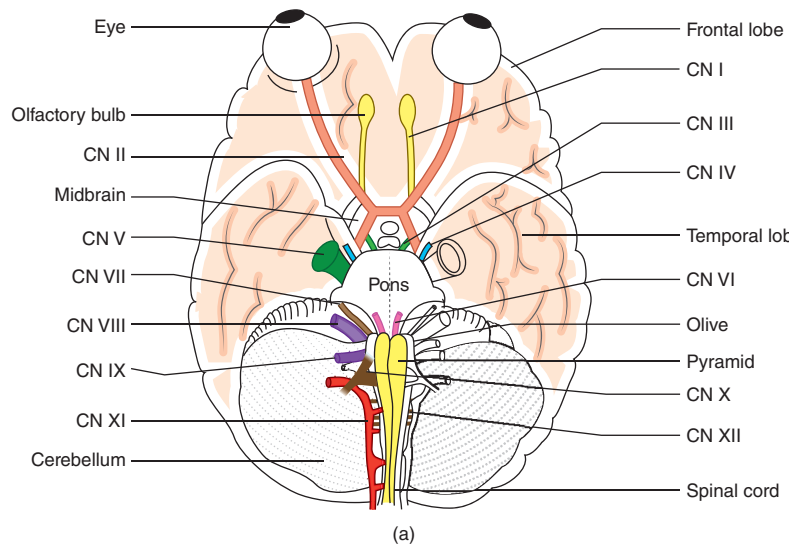


Figure 4.16 (a) Cranial origin of cranial nerves. *(Continued)*

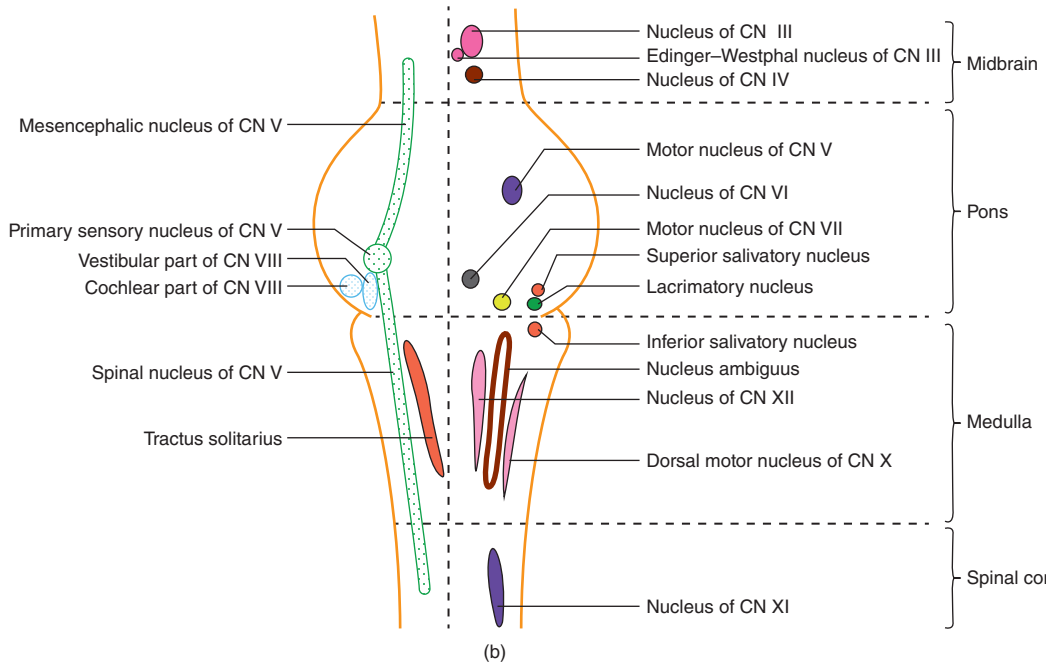


Figure 4.16 *(Continued)* (b) Nuclei of origin of cranial nerves—section from behind.

Table 4.9 Cranial Nerves and Their Origin

Cranial Nerve	Origin
I	Olfactory bulb
II	Retina
III and IV	Midbrain
V, VI and VII	Pons
VIII	Ear
IX, X, XI, XII	Medulla

The functions of the cranial nerves have been summarized in **Table 4.10**.

This chapter does not discuss the cranial course of the nerves in detail. Emphasis has been laid on the orofacial course of the cranial nerves which is of greater clinical significance to dentistry.

Olfactory Nerve (CN I)

The olfactory nerve is the *first cranial nerve*. It carries functional components which are *purely sensory*. It consists of fibres which transmit the sensation of smell to the brain.

Origin

The axons of olfactory nerve originate as a network from the olfactory cells which are located in the nasal mucous membrane, particularly in the superior and posterior region of the lateral nasal wall and septum (**Fig. 4.17**). The central processes of the olfactory cells continue as axons and group themselves into 15–20 bundles. Later on, they pierce the cribriform plate of the ethmoid bone and terminate in the glomeruli of the olfactory bulb present in the anterior cranial fossa (**Fig. 4.16a**). The olfactory bulb leads into the olfactory tract, which finally ends in the sensory cortex. Characteristically, the olfactory nerves are non-myelinated. Diseases of the olfactory nerve lead to loss of smell known as *anosmia*.

Optic Nerve (CN II)

The optic nerve is the *second cranial nerve*. This nerve is also *purely sensory* in function, carrying fibres of vision from the eye to the brain. This nerve is unique because it is a tract of nerve fibres with meningeal sheaths but with no neurilemmal sheath. Therefore, it does not regenerate once injured.

Table 4.10 Cranial Nerves

Cranial Nerve	Name	Type of Nerve	Function
I	Olfactory	Sensory	• Perception of smell
II	Optic	Sensory	• Perception of sight
III	Oculomotor	Motor	• Innervation of eye muscles
IV	Trochlear	Motor	• Innervation of superior oblique muscle supplying eye
V	Trigeminal	Mixed	• Perception of pain, temperature and touch • Ophthalmic branch to orbit • Maxillary branch to maxilla (upper jaw) • Mandibular branch to mandible (lower jaw)
VI	Abducent	Motor	• Innervation of lateral rectus muscle that abducts the eye
VII	Facial	Mixed	• Innervation of muscles of facial expression
VIII	Vestibulocochlear/ statoacoustic	Sensory	• Vestibular branch for equilibrium • Cochlear branch for hearing
IX	Glossopharyngeal	Mixed	• Taste from the posterior one-third of the tongue, secretomotor to the parotid gland and motor innervation to pharynx
X	Vagus	Mixed	• Special sensation from larynx • General sensation from part of the external ear • Sensory from pharynx, larynx, bronchial tree and heart • Motor to thoracic and abdominal viscera
XI	Spinal accessory cranial	Motor	• Sternocleidomastoid, trapezius, larynx, pharynx and soft palate
XII	Hypoglossal	Motor	• Innervation of tongue

Origin

The optic fibres originate from the ganglionic cells of the retina. The central processes of these specialized cells unite to extend posteriorly as the optic nerve. The fibres arising from the lateral half of the eye are called temporal fibres and those arising from the medial part are called nasal fibres (**Fig. 4.18a**). These exit the orbit through the optic canal to reach the middle cranial fossa. The fibres from the right and left sides meet at the optic chiasma which lies above the tuberculum sellae. Here, the nasal fibres decussate (cross to the opposite side) while the temporal fibres remain uncrossed (**Fig. 4.18**). The bundle of mixed fibres proceeding from this point is called the optic tract (**Fig. 4.16a**). The tract then proceeds backwards to terminate and synapse at the lateral geniculate body present in the thalamus. Postsynaptic fibres from the thalamus reach the visual cortex.

Applied Anatomy

The optic nerve is considered as an extension of the brain because of its development and structure. The covering of the nerve is derived from the cerebral membranes—perineural sheath from pia mater, intermediate sheath from arachnoid mater and outermost sheath from dura mater. The dura mater merges with the periosteum of the orbit. The spaces between these coverings lead to the subdural and subarachnoid spaces of the cranium and therefore spread of infections. Damage of optic nerve leads to complete blindness.

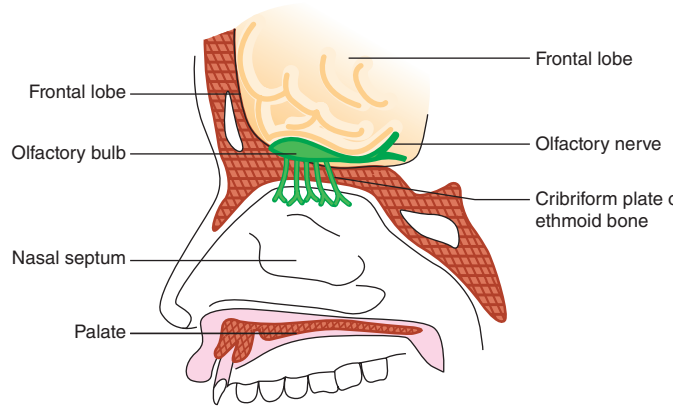


Figure 4.17 Olfactory nerve.

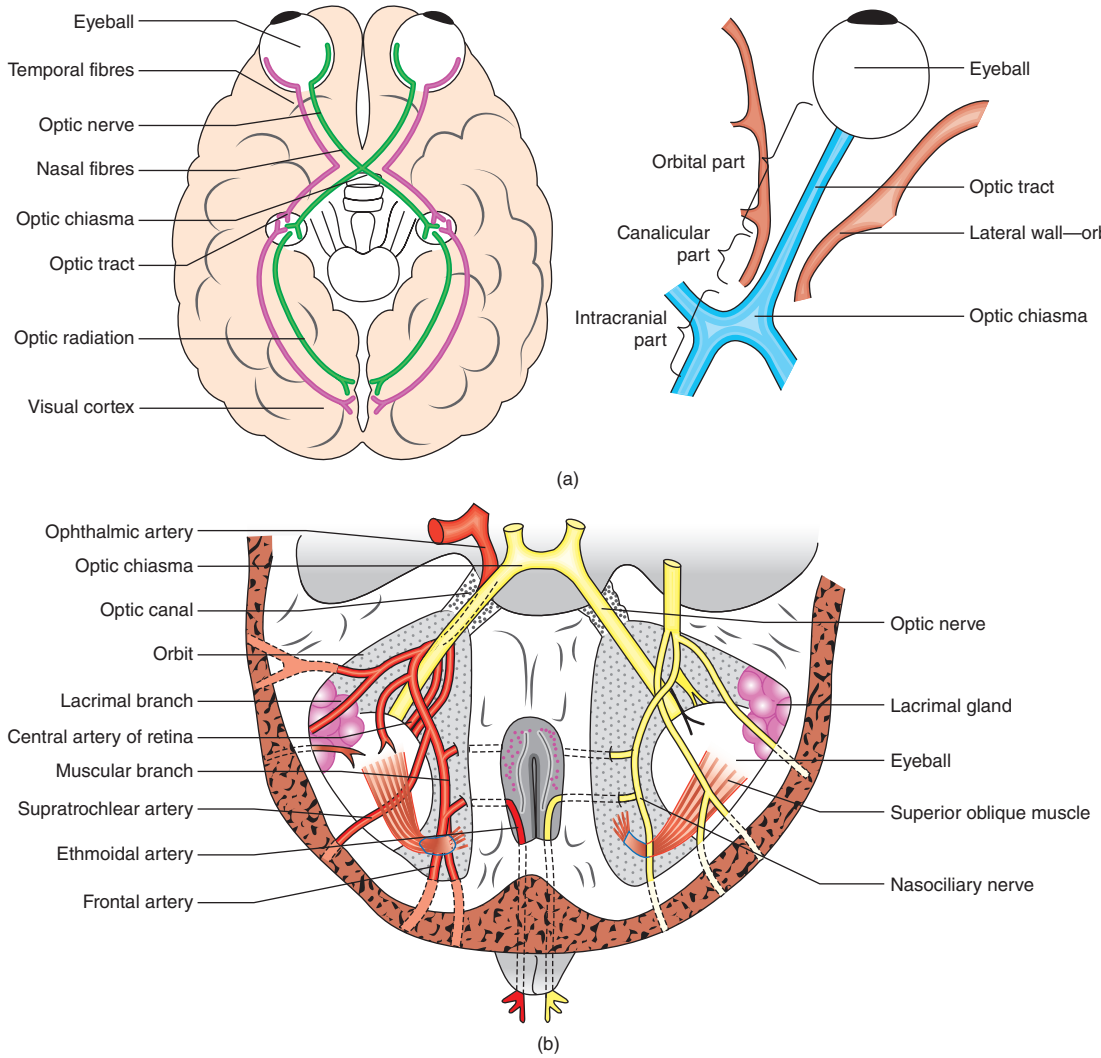


Figure 4.18 (a) Optic nerve. (b) Optic nerve—relations.

Oculomotor Nerve (CN III)

The oculomotor nerve is the *third cranial nerve*. It is motor in function and supplies the muscles of the eye.

Functional Components

The oculomotor nerve comprises three types of fibres:

1. **General somatic efferent fibres:** These supply the extraocular muscles except the superior oblique and lateral rectus; the *levator palpebrae superioris* help in movement of the eyeball.
2. **General visceral efferent/parasympathetic fibres:** These fibres innervate the intraocular muscles, sphincter pupillae and ciliaris muscle to perform functions such as contraction of pupil and accommodation.
3. **General somatic afferent fibres:** These fibres carry proprioceptive impulses of eye muscles to be relayed to the brain. These neurons originating from the eye are relayed at the mesencephalic nucleus.

Origin

The nuclei from which the fibres of the oculomotor nerve arise are as follows (**Fig. 4.16b**):

1. **Oculomotor nucleus:** It is an aggregation of a number of smaller nuclei present in the midbrain at the level of the superior colliculus and gives rise to general SE fibres.
2. **Edinger–Westphal nucleus:** This nucleus is located in the midbrain. It contributes parasympathetic fibres for the constriction of pupil. Fibres from the nucleus are preganglionic and synapse in the ciliary ganglion. Postganglionic fibres supply the ciliary and sphincter pupillae muscles of the eyeball.

Applied Anatomy

Oculomotor Nerve (CN III) Injury

This causes paralysis of the *levator palpebrae superioris* muscle, and the upper eyelid droops. This condition is called ptosis. Also, paralysis of one or more extraocular muscles can lead to double vision called diplopia.

Trochlear Nerve (CN IV)

The trochlear nerve is the *fourth cranial nerve*. It is the smallest of all cranial nerves and is the only nerve which emerges from the dorsal aspect of the brainstem (**Fig. 4.19a**). It is a purely motor nerve meant to supply the superior oblique muscle. The trochlear nerve is named so because the nerve supplies the superior oblique muscle which passes through a trochlea (trochlea = pulley).

Functional Components

The trochlear nerve carries the following fibres:

1. **General somatic efferent:** For the superior oblique muscle to help in lateral movement of eyeball
2. **General somatic afferent:** Sensory fibres from the muscle which carry proprioceptive impulses that get relayed to the mesencephalic nucleus

Origin

The motor nucleus that supplies motor fibres is present in the midbrain at the level of the inferior colliculus (**Fig. 4.16b**).

Applied Anatomy

The superior oblique muscle innervated by the trochlear nerve helps in upward movement of the eyeball. Injury to the nerve leads to paralysis of the muscle and double vision (diplopia) on looking downwards.

Trigeminal Nerve (CN V)

The trigeminal nerve is the *fifth cranial nerve* and is the largest of all the cranial nerves. It is a mixed nerve carrying both sensory and motor fibres to different parts of the head as follows:

1. **Predominant sensory impulses** (touch, pain and proprioception) from the face to the sensory cortex
2. **Motor innervation** to (i) muscles of mastication, (ii) tensor tympani, (iii) tensor veli palatine, (iv) anterior belly of digastric and (v) mylohyoid

The nerve is called trigeminal because of its three major divisions discussed below the head 'Branches'.

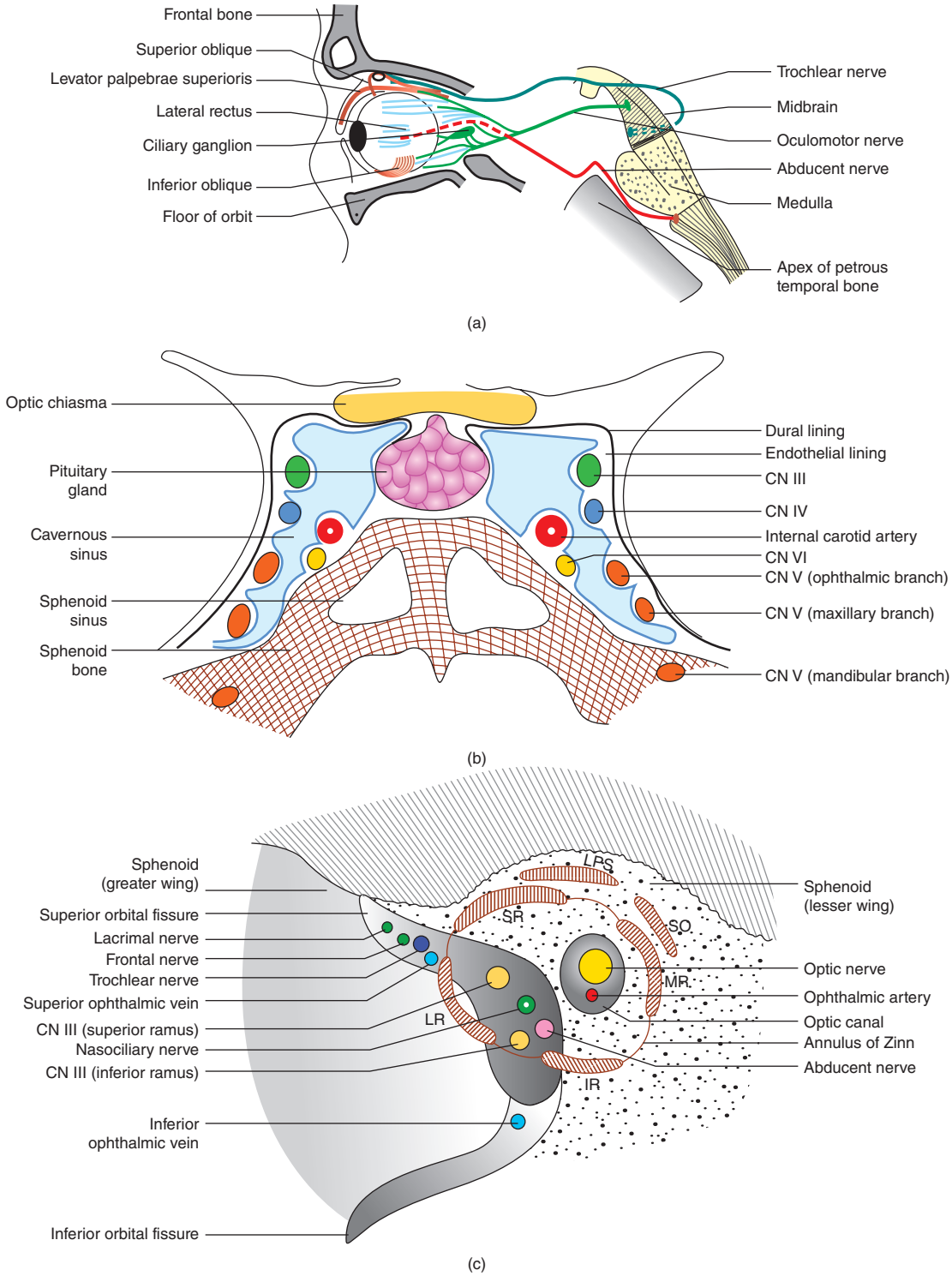


Figure 4.19 (a) Oculomotor, trochlear and abducent nerves. (b) Cranial nerves—relation to cavernous sinus. (c) Cranial nerves—relation to superior orbital fissure. *IR*, inferior rectus; *LPS*, levator palpebrae superioris; *LR*, lateral rectus; *MR*, medial rectus; *SO*, superior oblique; *SR*, superior rectus.

Functional Components

The fibres constituting the trigeminal nerve are as follows:

1. **Somatic motor fibres (exteroceptive):** From the muscles of mastication and temporomandibular joint
2. **Somatic sensory fibres (proprioceptive):** From the skin of face and mucous membrane of mouth and nose

Origin

The trigeminal nerve has two roots: motor and sensory. The motor root: lies anterior and medial to the sensory root.

1. **Motor root:** Two nuclei contribute to the fibres of the motor root: superior and inferior (**Fig. 4.16b**).
   (a) *The superior nucleus* consists of a linear arrangement of cells present along the length of midbrain. This constitutes the *mesencephalic root*.
   (b) *The inferior* or *chief nucleus* is situated in the upper part of the pons.

   The fibres from the superior nuclei join with the inferior nucleus to form the motor root. The motor root is small and attached to the pons, superior to the sensory root. It joins with the mandibular nerve at the foramen ovale to distribute motor fibres.
2. **Sensory root:** This arises from the cells of the semilunar ganglion (also called trigeminal or Gasserian ganglion) which is located in Meckel's cave at the apex of the petrous part of the temporal bone (**Fig. 4.15**). The ganglionic cells possess two types of processes:
   (a) *Peripheral processes* carry sensory impulses from the face to be relayed at the ganglion. They are grouped into three divisions, namely the ophthalmic, maxillary and mandibular.
   (b) *Central processes* form a single sensory root which transmits the sensory information to the brain. The sensory root is attached to the pons below the motor root.

   On entering pons, the sensory root divides into upper and lower roots and sensory fibres which are relayed in the following three nuclei (**Fig. 4.16b**):
   - *Main sensory nucleus* which is located in the upper part of pons and receives impulses of touch/position.
   - *Spinal nucleus* which extends from the main sensory nucleus to the medulla and the upper two segments of the spinal cord and receives pain/temperature impulses.
   - *Mesencephalic nucleus* that extends from the main sensory nucleus into the mid-brain. Proprioceptive fibres from the jaws and teeth are relayed here.

Branches

As discussed earlier, the trigeminal nerve is composed of three main divisions (**Fig. 4.20**). Three large nerves arise from the convex border of

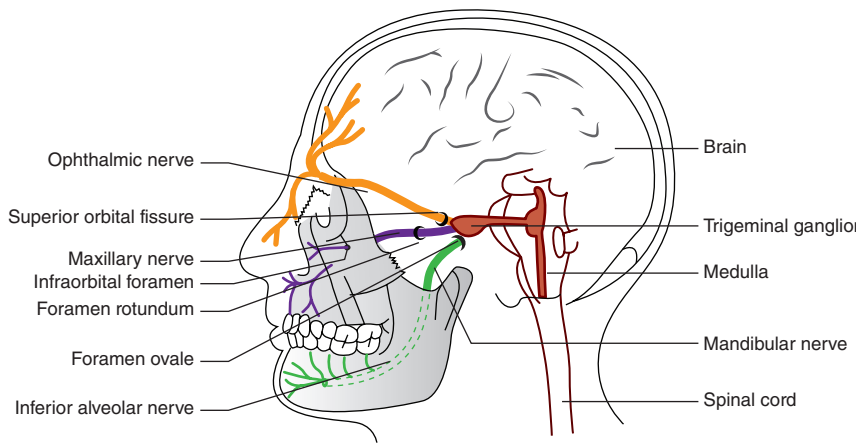


Figure 4.20 Trigeminal nerve—branches.

the trigeminal ganglion: ophthalmic, maxillary and mandibular nerves. The ophthalmic and maxillary nerves consist of exclusively sensory fibres whereas the mandibular nerve is a mixed nerve. Myelination of the fibres of the sensory root begins by the fifth month of foetal life and is completed only by about the third month after birth.

Each branch is discussed in detail in the subsequent paragraphs

Ophthalmic Nerve (Fig. 4.21) It is the first and smallest division of the trigeminal nerve and is purely sensory in function. It carries sensory information from the scalp, forehead, upper eyelid, conjunctiva, cornea of the eye, nose (except alae nasi), nasal mucosa and frontal sinuses.

After its origin from the anteromedial part of the semilunar ganglion, it penetrates the dura mater of Meckel's cave to run along the lateral wall of the cavernous sinus. Within the cavernous sinus, it lies below the III and IV cranial nerves (**Fig. 4.19b**). Later, it enters the orbit through the superior orbital fissure and gives off three branches, namely lacrimal, frontal and nasociliary nerves. The relations of the three branches to the orbit are shown in **Figure 4.19(c)**. Within the orbit, the lacrimal and frontal nerves are located above the orbital muscles while the nasociliary nerve lies between them.

Branches The ophthalmic nerve divides into the following branches:

1. **Frontal nerve:** This large branch of the ophthalmic nerve passes through the superior orbital fissure to reach the orbit. Within the orbit, it divides into two branches: supratrochlear and supraorbital.
   (a) The *supratrochlear nerve* is smaller than the supraorbital branch. It runs superior to the trochlea (pulley) of the superior oblique muscle. It innervates the skin of the lower part of the forehead close to the midline and the conjunctiva and skin of the upper eyelid.
   (b) The *supraorbital nerve* runs through the supraorbital foramen to provide nerve fibres to the upper eyelid. Further, it moves upwards to the forehead to terminate into two branches: medial and lateral.
2. **Lacrimal nerve:** It is the smallest branch of the ophthalmic nerve. From its origin, the nerve traverses through the superior orbital fissure to enter the orbit, enclosed in a dural sheath. In the orbit, it communicates with the zygomatic branch of the maxillary nerve. It enters the lacrimal gland to supply the glandular substance and the conjunctiva. Finally, it pierces the orbital septum and ends in the skin of the upper eyelid.
3. **Nasociliary nerve:** It is an intermediate-sized branch positioned between the superior and the inferior rami of the oculomotor nerve within the orbit. It runs towards the medial wall of the orbit to transit the anterior ethmoidal foramen and enter the cranial cavity. It gains entry into

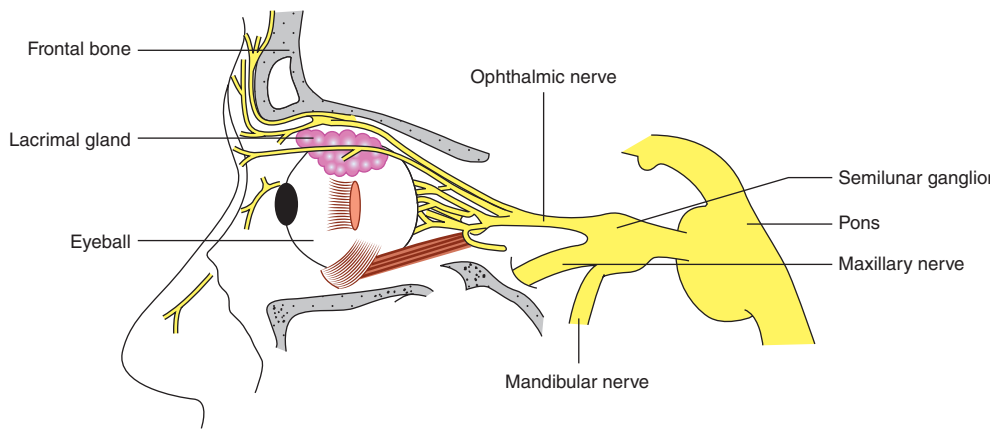


Figure 4.21 Ophthalmic nerve.

the nasal cavity through the crista galli. It gives off *internal nasal branches* which innervate the mucous membrane of the anterior septum and lateral wall of the nasal cavity. The nerve terminates as the *external nasal branch* to supply the skin of the ala and root of nose. The nasociliary nerve branches out into the following nerves:

(a) The *long root of the ciliary ganglion* arises between the two heads of the lateral rectus muscle. It runs lateral to the optic nerve to terminate in the ciliary ganglion.

(b) The *long ciliary nerves* are multiple twigs which accompany the short ciliary nerves from the ciliary ganglion. They contain sympathetic fibres from the superior cervical ganglion to supply the dilator pupillae muscle.

(c) The *infratrochlear nerve* arises just before the nasociliary nerve enters the anterior ethmoidal foramen and innervates the skin of the eyelids and side of the nose, conjunctiva and lacrimal sac. It communicates with the supratrochlear branch of the frontal nerve.

(d) The *ethmoidal branches* arising within the orbit run through the posterior ethmoidal foramen to innervate the ethmoidal cells.

Maxillary Nerve It is the second division of the trigeminal nerve and is positioned between the ophthalmic and mandibular divisions. It is sensory in function, carrying sensations from the maxillary region.

It originates from the centre of the semilunar ganglion and exits the skull through the foramen rotundum, then crosses the pterygopalatine fossa to reach the lateral surface of the maxilla (**Fig. 4.22a**). From here, it runs to the orbit passing through the inferior orbital fissure. The nerve travels along the floor of the orbit through the infraorbital groove and canal and emerges on the face at the opening of the canal called the infraorbital foramen. After its exit, the nerve branches out into multiple twigs which innervate the lower eyelid, side of the nose, upper lip, nose, upper teeth, gums, nasal mucosa, palate and roof of the pharynx, maxillary, ethmoid and sphenoid sinuses and parts of the meninges.

Branches The branches of the maxillary nerve may be studied under four groups on the basis of the anatomical site in which they branch out from the main nerve:

1. **In the cranium:** The *middle meningeal nerve* arises immediately after the origin of the maxillary nerve from the semilunar ganglion. It runs along with the middle meningeal artery to innervate the dura mater.
2. **In the pterygopalatine fossa**
   (a) The *zygomatic nerve* originating at the pterygopalatine fossa passes through the inferior orbital fissure to enter the orbital cavity where it divides into two branches: zygomaticotemporal and zygomaticofacial.
   - The *zygomaticotemporal branch* runs along the lateral wall of the orbit in a groove in the zygomatic bone and receives a branch of communication from the lacrimal nerve. After passing through a foramen in the zygomatic bone, the nerve enters the temporal fossa. It ascends between the bone and the substance of the temporalis muscle, pierces the temporal fascia about 2.5 cm above the zygomatic arch and is distributed to the skin of the side of the forehead. It communicates with the facial nerve and with the auriculotemporal branch of the mandibular nerve. As it pierces the temporal fascia, it gives off a slender twig which runs between the two layers of the fascia to the lateral angle of the orbit.
   - The *zygomaticofacial branch* runs along the floor of the orbit on the lateral aspect. It passes through a foramen in the zygomatic bone to appear on the face and supplies the skin of the cheek. It joins with the facial nerve and with the inferior palpebral branches of the maxillary nerve.

   (b) The *sphenopalatine branches* contribute sensory fibres to the sphenopalatine ganglion (see discussion later in page 89).
   - The *posterior superior alveolar branches* (**Fig. 4.22a**) are given off from the main trunk before it reaches

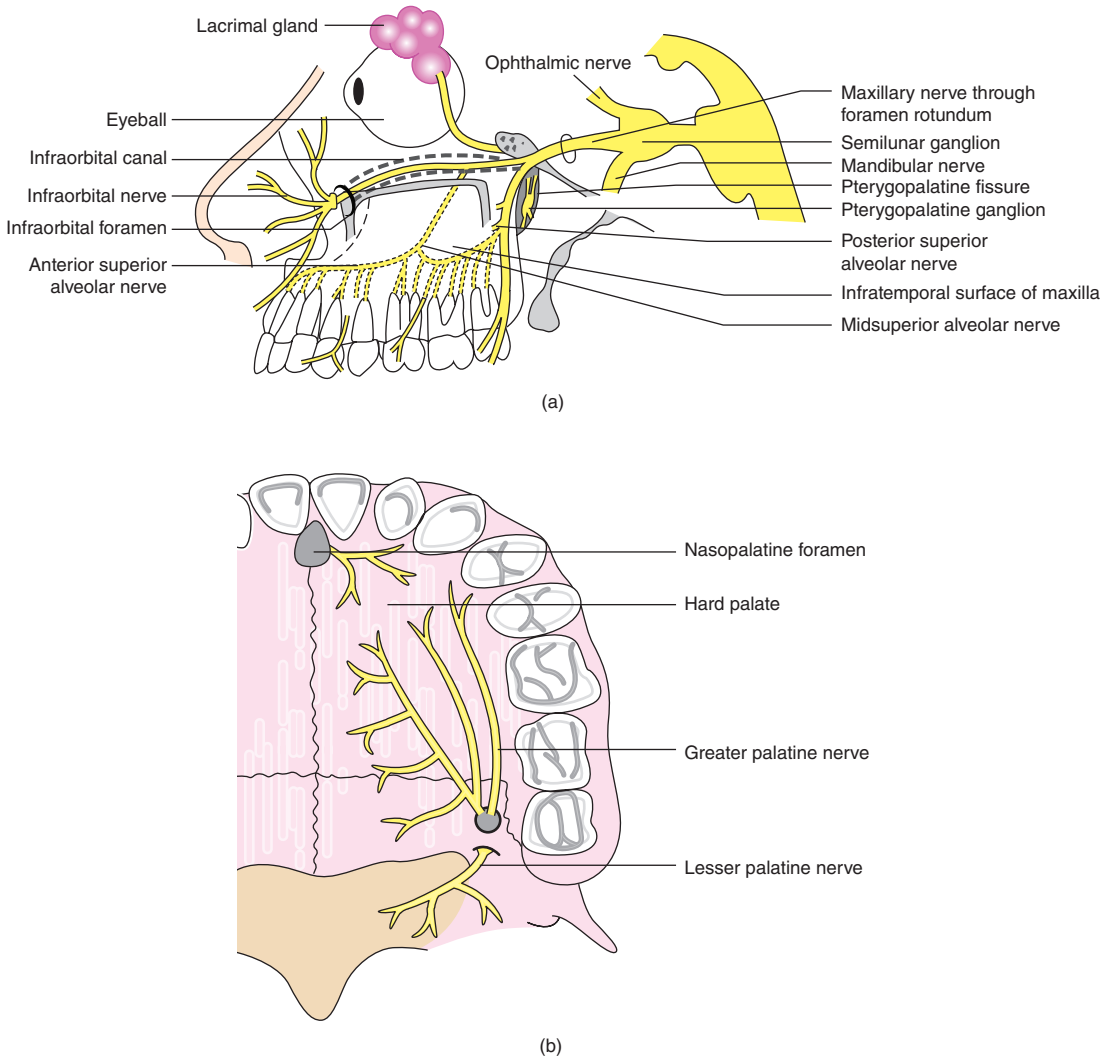


Figure 4.22 Maxillary nerve: (a) branches of the maxillary nerve and (b) palatine branches of the maxillary nerve.

the infraorbital groove. They run vertically down towards the maxillary tuberosity. Several tiny branches arise to innervate the gums and the adjacent mucous membrane of the cheek. Later, they penetrate the infratemporal surface of the maxilla to enter the posterior alveolar canals and supply the lining of maxillary sinus as well as provide pulpal innervation to molar teeth by passing through the foramina at the root apices of teeth.

3. **In the infraorbital canal** (Fig. 4.22a)
   (a) The *middle superior alveolar branch* arises in the posterior part of the infraorbital canal. It takes a course along the lateral wall of the maxillary sinus to provide pulpal innervation to the two premolar teeth and the associated buccal mucoperiosteum.
   (b) The *anterior superior alveolar branch* originates from the main nerve just before its exit from the infraorbital foramen. It reaches the incisors and canines by

running across a canal in the anterior wall of the maxillary sinus and provides pulpal innervation.

The *superior dental plexus* is a network of nerves formed by the middle, anterior and posterior superior alveolar branches.

4. **On the face**
   (a) The *inferior palpebral branches* innervate the skin and conjunctiva of the lower eyelid. They communicate with the facial and zygomaticofacial nerves at the lateral orbit.
   (b) The *external nasal branches* innervate the skin of lateral nose and septum. They communicate with the terminal branches of the nasociliary nerve.
   (c) The *superior labial branches* innervate the skin of the upper lip, mucous membrane of the mouth and labial glands. They constitute the infraorbital plexus by communicating with twigs from the facial nerve.

Relations to the Sphenopalatine Ganglion The sphenopalatine ganglion (also called the ganglion of Meckel) located in the pterygopalatine fossa is closely related to the maxillary nerve (**Fig. 4.10c**). It receives three roots—sensory, motor and sympathetic—of which the sensory root is offered by the maxillary nerve (**Table 4.8**). The sphenopalatine branches of the maxillary nerve constitute the sensory root.

The branches arising from the ganglion are discussed here because of their association with the maxillary nerve and their clinical significance to the face.

Branches of the Sphenopalatine Ganglion (Fig. 4.22a) Four groups of nerves arise from the ganglion:

1. **Orbital branches:** These enter the orbit through the inferior orbital fissure and supply the periosteum of the orbit.
2. **Palatine nerves:** These innervate the roof of the mouth, soft palate, tonsil and nasal cavity. The sphenopalatine branches of the maxillary nerve provide a greater contribution to these. They are grouped into three types: anterior, middle and posterior.
   (a) The *anterior palatine nerve* (**Fig. 4.22b**) courses down the pterygopalatine canal to reach the hard palate through the greater palatine foramen. Within the canal, it gives rise to posterior inferior nasal branches which supply the inferior nasal concha and meatuses by penetrating through tiny foramina in the palatine bone. After its exit from the greater palatine foramen, it runs forward till the incisors in a narrow groove along the lateral aspect of the palate to supply the gums, mucous membrane and glands of the hard palate.
   (b) The *middle palatine nerve* traverses through the minor palatine canals to supply the uvula, tonsil and soft palate.
   (c) The *posterior palatine nerve* also travels through the pterygopalatine canal and opens posterior to the greater palatine foramen. It innervates the soft palate, tonsil and uvula.
3. **Posterior superior nasal branches:** These run through the sphenopalatine foramen to reach the nasal cavity and supply the posterior septum and lateral wall. A prominent branch of the group is the nasopalatine nerve. This also runs through the sphenopalatine foramen to reach the nasal cavity and the septum. From here, it travels inferiorly and anteriorly to reach the palate through the incisive canal.
4. **Pharyngeal nerve:** This originates from the posterior aspect of the ganglion. It runs across the pharyngeal canal and supplies the mucous membrane of the nasal part of the pharynx.

Mandibular Nerve It is the largest branch of the trigeminal nerve. It innervates the mandibular teeth and gums, skin of the temporal region, ear, lower lip and lower part of the face, muscles of mastication and also the mucous membrane of the anterior two-third of the tongue.

The mandibular nerve consists of both sensory and motor fibres which arise from two roots (**Figs 4.15** and **4.16b**):

1. **Sensory root** originating from the semilunar ganglion
2. **Motor root** originating from the motor nucleus

Branches The sensory root of the nerve is larger and unites with the motor root at the foramen ovale. The nerve, as it descends from the cranium, gives off two branches, namely nervus spinosus

and nerve to medial pterygoid. It subdivides into the anterior and posterior trunks which trace different paths. The mandibular nerve gives off numerous branches which may be grouped into the following (**Fig. 4.23**):

1. **Branches from the undivided nerve**
   (a) *Nervus spinosus*: This branch re-enters the skull through the foramen spinosum along with the middle meningeal artery to supply the dura mater and lining of mastoid cells.
   (b) *Nerve to medial pterygoid*: This branch supplies the medial pterygoid muscle.
2. **Branch from the anterior division:** It is smaller and supplies the muscles of mastication and the skin and mucous membrane of the cheek. It

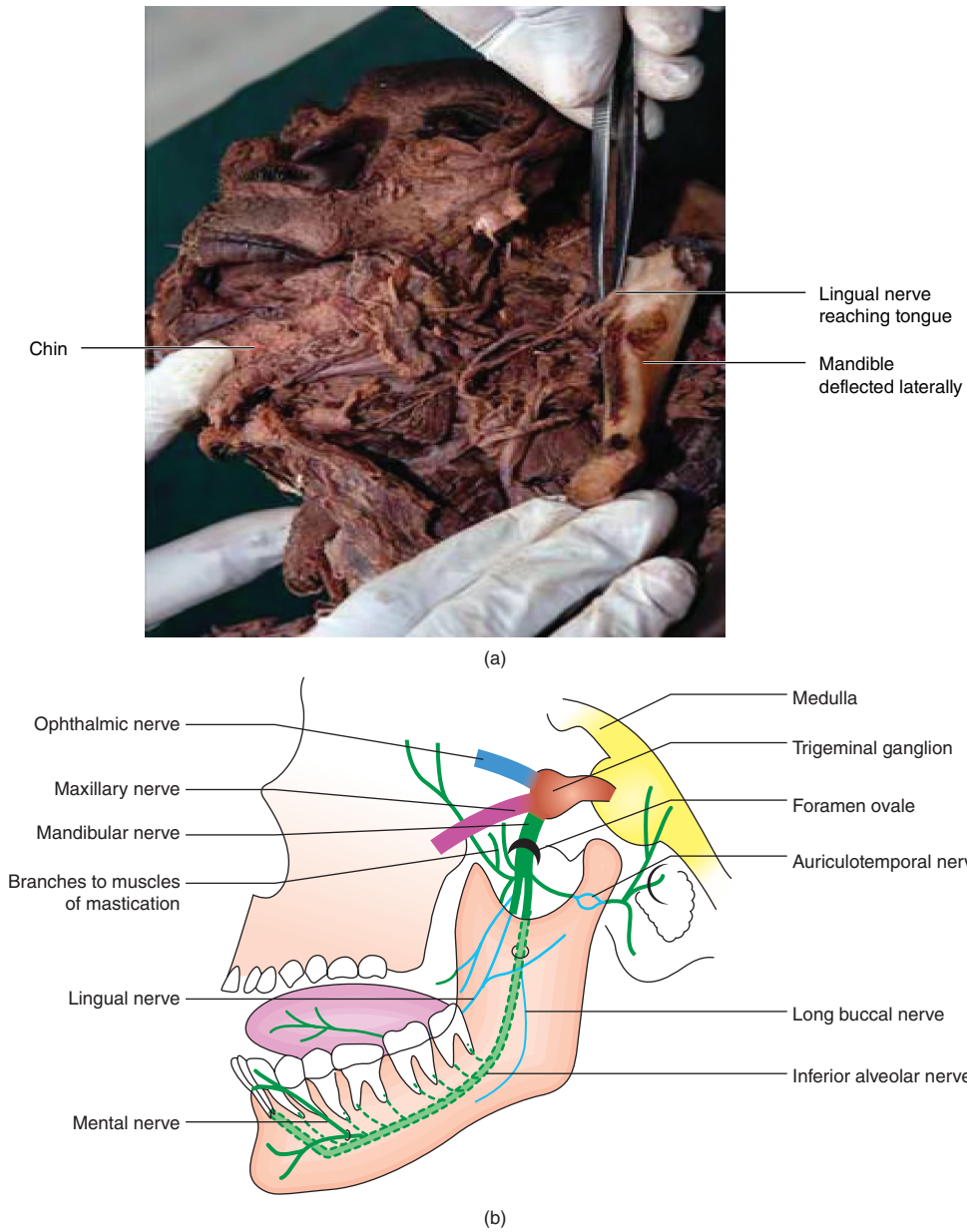


Figure 4.23 Mandibular nerve: (a) dissected specimen and (b) schematic diagram.

gives off four branches: masseteric, deep temporal, buccinator and lateral pterygoid.

(a) The *masseteric nerve* is given off opposite the temporomandibular joint. The nerve reaches the masseter muscle by running across the mandibular notch with the masseteric artery.

(b) The anterior and posterior *deep temporal nerves* arise from the anterior division to supply the temporalis muscle.

(c) The *buccinator nerve* runs between the two heads of the lateral pterygoid muscle to innervate the buccinator muscle.

(d) The *lateral pterygoid nerve* supplies the lateral pterygoid muscle.

3. **Branch from the posterior division:** It is larger than the anterior division and the branches arising out of it are the auriculotemporal, lingual and inferior alveolar nerves.

(a) The *auriculotemporal nerve* begins as two roots encircling the middle meningeal artery. It travels posteriorly to reach the neck of the mandible on the medial side. It carries secretomotor fibres to the parotid gland and innervates the upper part of the ear, the sublingual gland and the mucous membrane of the anterior two-third of the tongue

(b) The *inferior alveolar nerve* is the largest branch of the mandibular nerve. The nerve accompanies the inferior alveolar artery and enters the mandibular foramen to run anteriorly and downwards, below the teeth within the mandibular canal, till it reaches the mental foramen. Here, it terminates by giving off two branches, namely incisive and mental. The branches of the inferior alveolar nerve and their innervation are as follows:

- The *mylohyoid nerve* arises from the inferior alveolar nerve before its entry into the mandibular foramen. It runs anteroinferiorly on the medial surface of the mandible to reach the mylohyoid muscle. It pierces the sphenomandibular ligament to supply the mylohyoid muscle and the anterior belly of the digastric muscle.
- The *alveolar (dental) branches* supply the teeth. Nerve twigs arise from the inferior alveolar nerve corresponding to every tooth. They enter the pulp of the teeth through the apical foramen present at the root tips.
- The *incisive branch* is one of the terminal branches of the inferior alveolar nerve. It runs anteriorly within the inferior alveolar canal to supply the canines and incisors.
- The *mental nerve* is also a terminal branch of the inferior alveolar nerve. It branches out from the inferior alveolar nerve at the mental foramen, which is located between the roots of the mandibular premolars. The nerve emerges through it to divide into three branches that supply the skin over the chin and the skin and the mucous membrane of the lower lip.

(c) The *lingual nerve*, after it branches out from the mandibular nerve, descends between the tensor veli palatini and lateral pterygoid, positioned medial to the inferior alveolar nerve. It runs between the medial pterygoid muscle and the medial surface of the mandibular ramus. The nerve lies in close association with the roots of the mandibular molars. Further, it courses medially to reach the floor of the mouth. It lies between the hyoglossus and the mylohyoid muscles. The nerve carries the sensation from the mucous membrane of the anterior two-third of the tongue and mucosa on the lingual side of the mandible. The nerve loops around the duct of the submandibular gland and runs beneath the mucous membrane of the tongue till its tip (*see* **Fig. 4.29c**).

Applied Anatomy

Lingual Nerve Damage

This frequently occurs during surgical removal of the impacted lower third molars or wisdom teeth. The nerve lies above the periosteum over the lingual cortical plate of the mandible and just below the mucosa at the molar region. It has to be carefully protected while using instruments during the procedure. Injury to lingual nerve leads to paraesthesia or prolonged anaesthesia in the tongue and lip.

Relations of the Trigeminal Nerve to Ganglia The trigeminal nerve is related to four small ganglia through its branches:

1. Ciliary ganglion (related to the ophthalmic nerve)
2. Sphenopalatine/pterygopalatine ganglion (related to the maxillary nerve)
3. Otic ganglia
4. Submandibular ganglia (related to the mandibular nerve)

The sensory input/root for all these ganglia is from the trigeminal nerve; the motor and sympathetic roots are from different sources (**Fig. 4.10c**; **Table 4.8**).

Applied Anatomy

Wallenberg Syndrome

This is a clinical condition in which a stroke causes loss of pain/temperature sensation (but not touch/position sensation) from one side of the face and the opposite side of the body. At the medullary level, the ascending spinothalamic tract (which carries pain/temperature information from the opposite side of the body) is close to the descending spinal tract of the fifth nerve (which carries pain/temperature information from the same side of the face). When blood supply to this area is compromised by stroke, it destroys both tracts simultaneously.

Trigeminal Neuralgia (Tic Douloureux/ Fother–Gill's Disease)

This is a clinical condition characterized by paroxysmal lancinating facial pain confined to the distribution of one or more divisions of the trigeminal nerve. It is a disorder of the sensory nucleus of the trigeminal nerve which usually affects one side of the face with characteristic trigger zones.

Trigemino-Cardiac Reflex (TCR)

This is a phenomenon that consists of bradycardia, arterial hypotension, apnoea and gastric hypermobility. TCR occurs during the peripheral stimulation of the sensory branches of the trigeminal nerve. This is frequently seen while treating zygomatic bone fractures.

Abducent Nerve (CN VI)

The abducent nerve is the *sixth cranial nerve*. It is purely motor in function and supplies an extraocular muscle called lateral rectus.

Functional Components

The abducent nerve carries the following fibres:

1. **General somatic efferent:** These are motor fibres for the lateral rectus muscle to help in lateral movement of eyeball.
2. **General somatic afferent:** These are sensory fibres from the muscle which carry proprioceptive impulses. They are relayed to the mesencephalic nucleus.

Facial Nerve (CN VII)

The facial nerve is the *seventh cranial nerve*. This is a mixed nerve containing both sensory and motor fibres.

Functional Components

1. **Branchial efferent fibres:** For scalp, auricle, elevation of hyoid, facial muscles, buccinator and platysma, stapedius, stylohyoid and posterior belly of the digastric (**Fig. 4.24**)
2. **Special visceral afferent fibres:** For carrying taste sensation from the anterior two-third of the tongue
3. **General visceral efferent fibres:** For carrying secretomotor impulses to submandibular and sublingual salivary glands and lacrimal and nasal glands
4. **General somatic afferent fibres:** For carrying proprioceptive impulses

Origin

Four nuclei located in lower pons contribute to the formation of the facial nerve (**Fig. 4.16b**):

1. **Motor nucleus:** Gives rise to branchial efferent fibres
2. **Nucleus of tractus solitarius:** Contributes special VA fibres
3. **Superior salivatory nucleus:** Gives rise to GVE fibres

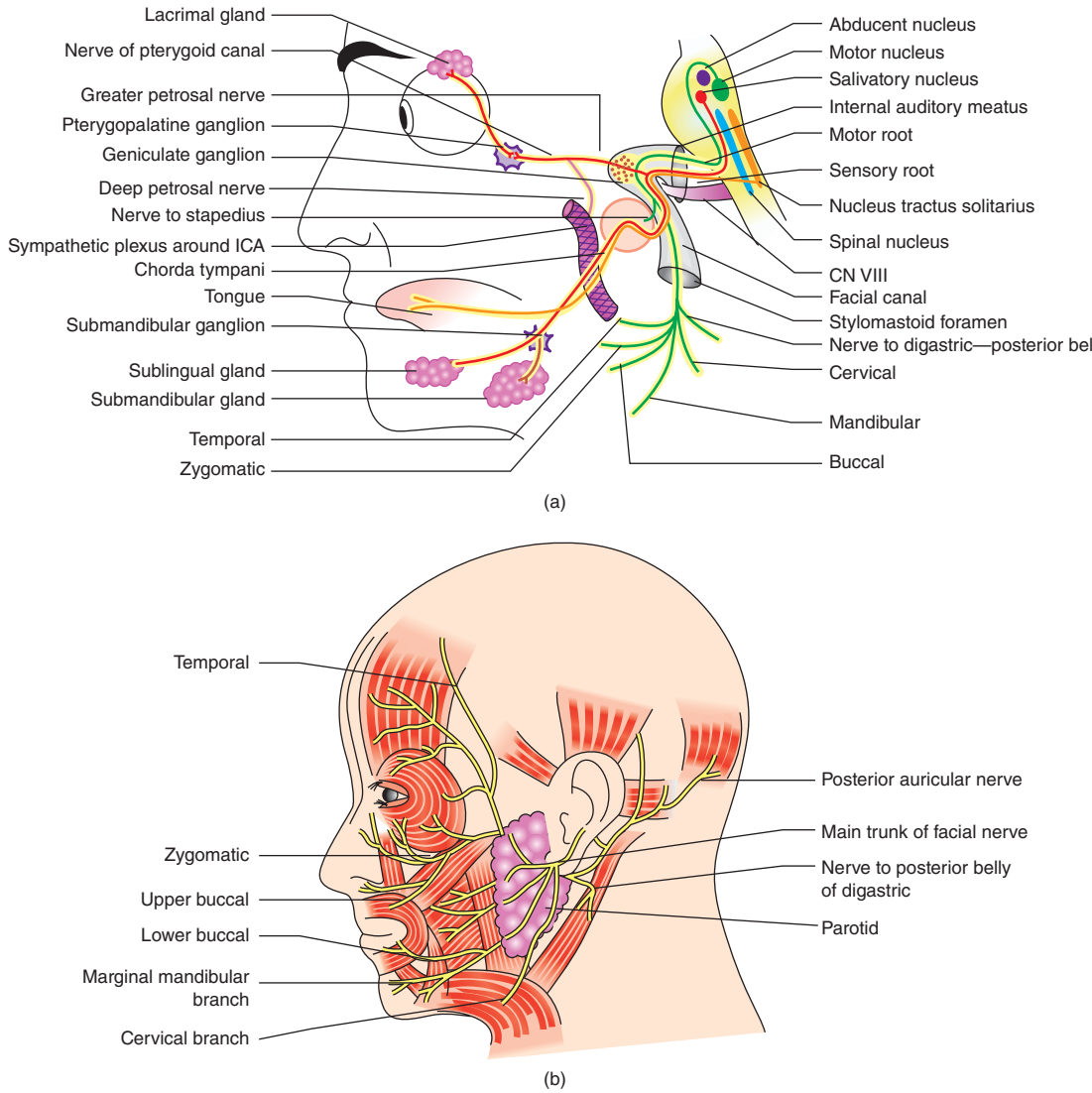


Figure 4.24 (a) Facial nerve. (b) Facial nerve—facial course. *ICA*, internal carotid artery.

4. **Lacrimatory nucleus:** Gives rise to general sensory afferent in addition to GVE fibres

The facial nerve consists of two roots: motor root and sensory root (**Fig. 4.24a**).

The *motor root* arises from the motor nucleus located in the lower part of the pons. It winds around the abducent nucleus to remain medial to the sensory root.

The *sensory root*, also called nervus intermedius or the nerve of Wrisberg, is given off by the geniculate ganglion, which is located on the geniculum within the facial canal. This ganglion contains unipolar cells with central and peripheral branches. The central branches form the sensory root in the internal acoustic meatus and reach the lower border of the pons between the motor root and the acoustic nerve. Finally, the fibres of the sensory root terminate at the medulla oblongata and the glossopharyngeal nucleus. The peripheral branches of the cells of the geniculate ganglion continue into the branches of the facial nerve, chorda tympani and greater superficial petrosal nerves.

Course

The course of the facial nerve may be studied under the following five headings (Fig. 4.24):

1. **Intracranial:** After its origin at the pons, the motor root of the facial nerve takes a tortuous course. It runs upwards and around the nucleus of the abducent nerve. Then, it descends to emerge between the olive and the inferior peduncle and enter the internal acoustic meatus.
2. **Within the meatus:** The two roots of the facial nerve together pass laterally and anteriorly with the acoustic nerve to the internal acoustic meatus. Within the meatus, the motor root lies in a groove above the acoustic nerve and the sensory root lies between the two. Here, some twigs of the facial nerve join with the acoustic nerve.
3. **Within the facial canal:** The facial nerve traverses through the facial canal. Initially, it runs along the lateral direction between the cochlea and the vestibule and courses towards the tympanic cavity; then, the nerve turns backwards and downwards to reach the stylomastoid foramen. The nerve presents a reddish swelling called geniculum, where the direction of its course changes.
4. **At the stylomastoid foramen:** The facial nerve exits the facial canal through the stylomastoid foramen. The nerve runs forwards, across the external carotid artery, and gives off branches behind the ramus of the mandible.
5. **On the face:** Five branches—temporal, zygomatic, buccal, mandibular and cervical nerves—are given off by the facial nerve on the face and these supply the muscles of facial expression.

Branches (Table 4.11)

1. **Greater superficial petrosal nerve:** This originates at the geniculate ganglion and contains sensory fibres to the mucous membrane of the soft palate. It runs across anteriorly through the hiatus of the facial canal, to the foramen lacerum where it receives a twig from the tympanic plexus. Within the foramen, it is joined by the deep petrosal nerve, which originates from the sympathetic plexus on the internal carotid artery, to form the nerve of the pterygoid canal. The nerve to the pterygoid canal transits the pterygoid canal and ends in the sphenopalatine ganglion.
2. **Nerve to the stapedius:** This is given off in front of the pyramidal eminence of the ear and runs through a passage within the eminence to innervate the stapedius muscle.
3. **Chorda tympani nerve:** This originates during the downward course of the facial nerve, behind the tympanic cavity, at approximately 6 mm from the stylomastoid foramen. It runs upwards and forwards in a canal and enters the tympanic cavity. It travels across the tympanic cavity to exit through a foramen present at the inner end

Table 4.11 Facial Nerve Branches

Anatomical Site	Branches	Nature of Innervation
Within the facial canal	Nerve to the stapedius muscle	Motor (stapedius muscle)
	Chorda tympani	Taste sensation (tongue)
	Posterior auricular	Motor
At the exit of the stylomastoid foramen	Digastric	Motor
	Stylohyoid	Motor
On the face	Temporal	Motor
	Zygomatic	Motor
	Buccal	Motor
	Mandibular	Motor
	Cervical	Motor

of the petrotympanic fissure called the *canal of Huguier*. Later, it descends vertically towards the medial surface of the sphenoid to remain between the lateral and the medial pterygoid muscles. Finally, it ends by joining with the lingual nerve. The chorda tympani carries the following fibres: (i) efferent fibres received from the motor root which reach the submandibular ganglion to innervate the submandibular and sublingual glands and (ii) afferent fibres, more than the efferent fibres, that traverse through the muscles of the tongue to innervate the mucous membrane covering its anterior two-third.

4. **Posterior auricular nerve:** This originates from the facial nerve as it emerges from the stylomastoid foramen. It travels forwards to run between the mastoid process and the external acoustic meatus. At this point, it communicates with the posterior branch of the great auricular nerve and the lesser occipital nerve. Later, it branches out as auricular and occipital branches. The *auricular branch* provides motor innervation to the posterior auricular and intrinsic muscles of the ear while the *occipital branch* runs posteriorly to supply the occipitalis muscle.
5. **Digastric branch:** This originates near the stylomastoid foramen and innervates the posterior belly of the digastric muscle.
6. **Stylohyoid branch:** This arises along with the digastric branch and supplies the stylohyoid muscle.
7. **Temporal branches:** These run across the zygomatic arch to reach the temporal region. They innervate the auricular muscles and communicate with the zygomaticotemporal branch of the maxillary nerve and auriculotemporal branch of the mandibular nerve. The anterior branches innervate the frontalis, orbicularis oculi and corrugator muscles and join the supraorbital and lacrimal branches of the ophthalmic nerve.
8. **Zygomatic branches:** These traverse the zygomatic bone towards the orbit to supply the orbicularis oculi. These branches communicate with the lacrimal nerve and the zygomaticofacial branch of the maxillary nerve.
9. **Buccal branches:** These originate as multiple twigs and run forwards in a horizontal direction. They consist of two groups of fibres: (i) *superficial branches* that run beneath the skin to supply the superficial muscles of the face and (ii) *deep branches* that run at a deeper plane and supply zygomaticus, labii superioris, buccinator and orbicularis oris muscles.
10. **Mandibular branch:** This runs below the platysma muscle and innervates the muscles of the lower lip and chin. It also communicates with the mental branch of the inferior alveolar nerve.
11. **Cervical branch:** This lies below the platysma and gives off multiple twigs over the lateral aspect of the neck which supply the platysma muscle.

Applied Anatomy

The abducent nerve is more prone to compression during raised intracranial pressure because of its sharp bend over the apex of the petrous temporal bone.

Communications

The facial nerve communicates with the glossopharyngeal, auricular branch of the vagus, great auricular nerve of the cervical plexus, auriculotemporal nerve and lesser occipital nerve. It also communicates with the terminal branches of the trigeminal and cervical nerves supplying the skin.

Applied Anatomy

Facial Nerve (CN VII) Damage

This causes paralysis of the orbicularis oculi, and eyelids do not close fully. Normal protective blinking of the eye is also lost. This leads to corneal drying and lack of protection from dust and small particles.

Facial Palsy

This is a medical condition characterized by unilateral facial muscle paralysis of sudden onset due to the involvement of facial nerve. It may result from trauma, compression or infection of the facial nerve that supplies the facial muscles. The clinical features are muscle weakness and a distorted facial expression. Facial palsy can result following an improper LA the technique. During intraoral injection of LA solution, the entry of the needle too far posteriorly into the parotid gland causes damage to the terminal branches of the facial nerve which leads to facial palsy.

Auditory/Vestibulocochlear Nerve (CN VIII) (Fig. 4.25)

The acoustic or auditory or vestibulocochlear nerve is the *eighth cranial nerve*. It is a purely sensory nerve which is composed of two different types of fibres with varying sensory receptors and functions:

1. Vestibular nerve (nerve of balance)
2. Cochlear nerve (nerve of hearing)

Functional Components

General somatic afferent fibre is responsible for equilibrium and special somatic afferent fibre is responsible for hearing.

Origin (Fig. 4.16b)

The *vestibular nerve* is the nerve of equilibration. The bipolar neurons which give rise to this nerve are located in the vestibular ganglion (ganglion of Scarpa). The ganglion is present in the outer end of the internal auditory meatus. The vestibular nerve fibres are relayed in the four vestibular nuclei (superior, spinal, medial and lateral) present in the pons and medulla oblongata. Further relay of fibres extends to the thalamus and the cerebellum.

The *cochlear nerve* is the nerve of hearing. The fibres arise from bipolar cells in the spiral ganglion of the cochlea present in the osseous spiral lamina of the ear. The nerve runs along the internal auditory meatus along with the vestibular nerve and across the subarachnoid space and terminates in the cochlear nucleus. Two cochlear nuclei—dorsal and ventral—are present at the junction of the medulla and pons. Impulses from the cochlear nuclei get transmitted to the thalamus and finally terminate in the auditory area of the cerebral cortex.

Glossopharyngeal Nerve (CN IX)

The glossopharyngeal nerve is the *ninth cranial nerve*. It is a mixed nerve containing both motor and sensory fibres. As the name denotes, it innervates the tongue and the pharynx.

It carries general sensation from the mucous membrane of the pharynx, fauces and palatine tonsil and the taste sensation from the posterior part of the tongue. The nerve plays a very important role in initiation of the swallowing reflex and secretion of saliva by the parotid gland.

Functional Components (Fig. 4.26)

1. **Branchial efferent fibres:** These cause elevation of larynx.
2. **General visceral efferent fibres:** These are secretomotor to the parotid gland.
3. **Special visceral afferent, general visceral afferent and general somatic afferent fibres:** These carry taste fibres from the posterior one-third of the tongue and sensation from the mucous membrane of pharynx and the posterior one-third of the tongue.

Three nuclei in medulla give rise to fibres which form the glossopharyngeal nerve:

1. **Nucleus ambiguus:** This gives rise to branchial efferent fibres.
2. **Inferior salivatory nucleus:** This contributes to the GVE fibres.
3. **Nucleus of tractus solitarius:** This gives off special VA, general VA and GSA fibres.

The impulses transmitted by this nerve get relayed at the thalamus from where they finally get transmitted to the gustatory area of the cerebral cortex.

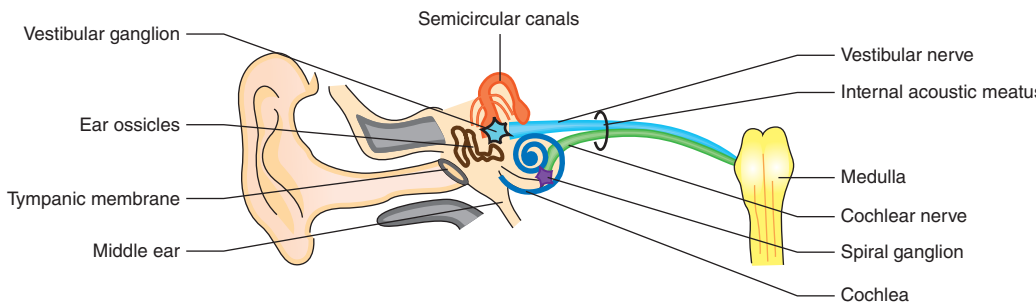


Figure 4.25 Vestibulocochlear nerve.

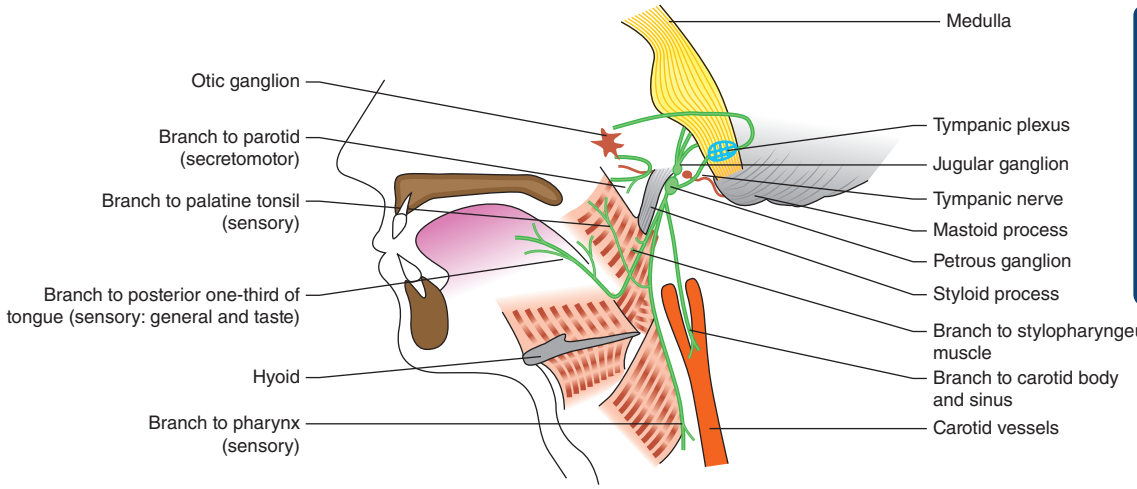


Figure 4.26 Glossopharyngeal nerve.

Origin

The glossopharyngeal nerve is connected to the lateral and upper part of the medulla by multiple filaments. As it is a mixed nerve, the origin of its fibres is varied (**Fig. 4.15b**)

1. **Sensory fibres** originate from the cells of the superior and petrous ganglia, which are situated on the trunk of the nerve
2. **Somatic motor fibres** arise from the nucleus ambiguus to join the fibres of the sensory root.
3. **Sympathetic efferent fibres** which are both preganglionic motor fibres and preganglionic secretory fibres are from the dorsal nucleus. The secretory fibres reach the otic ganglion from where arise the secondary neurons which supply the parotid gland.

Course

From the medulla oblongata, the glossopharyngeal nerve exits the cranium through the central part of the jugular foramen within a sheath of dura mater. Within the jugular foramen, the nerve enlarges to form two ganglia: superior/jugular and inferior/petrous (**Fig. 4.28b**).

As it courses forwards, it furrows the petrous part of the temporal bone and runs between the internal jugular vein and the internal carotid artery (**Fig. 4.26**). It then proceeds anterior to the internal carotid artery lying beneath the styloid process and the associated muscles to reach the lower border of the stylopharyngeus (**Fig. 4.29b**). Here, it takes an upward turn lying over the stylopharyngeus muscle and enters the pharynx by running between the superior and middle constrictor muscles. Further, it runs to reach the lateral side of the tongue, beneath the hyoglossus muscle to innervate the palatine tonsil, base of the tongue and mucous glands of the oral cavity (**Fig. 4.29c**).

Branches

1. **Tympanic nerve:** Also called the nerve of Jacobson, the tympanic nerve emerges from the petrous ganglion and reaches the tympanic cavity enclosed by a canal (called the inferior tympanic canaliculus) in the petrous part of the temporal bone. Within the tympanic cavity, it splits into numerous branches to form the *tympanic plexus* which supplies the mucous membrane of the tympanic cavity and mastoid air cells.
2. **Carotid branches:** These travel along and innervate the trunk of the internal carotid artery.
3. **Pharyngeal branches:** These form the pharyngeal plexus which innervate the pharyngeal muscles and mucous membrane of pharynx.
4. **Muscular branch:** This is distributed to the stylopharyngeus.
5. **Tonsillar branches:** These supply the palatine tonsil, soft palate and fauces through a tonsillar plexus.

Communicating Branches

The glossopharyngeal nerve communicates with cranial nerves such as:

1. Vagus nerve
2. Facial and sympathetic nerves

Vagus Nerve (CN X)

The vagus nerve (**Fig. 4.27**) is the *10th cranial nerve*. It is known for its extensive course across the neck, thorax and abdomen. It is the longest cranial nerve and named *vagus* as it correlates with the word *vagrant* that denotes wandering from one region to another. It is a mixed nerve with both sensory and motor fibres.

Functional Components

1. **Branchial efferent fibres:** For the movement of muscles of the palate, pharynx and larynx
2. **General visceral efferent fibres:** For motor and secretomotor functions to bronchial tree and gut. They are also inhibitory to the heart.
3. **General visceral afferent fibres:** For sensation from the viscera
4. **Somatic visceral afferent fibres:** For taste from the posteriormost region of tongue and epiglottis
5. **General somatic afferent fibres:** For sensation from the skin of the external ear

Nuclei of Origin

Three nuclei in medulla (**Fig. 4.15b**) contribute to the formation of the vagus nerve as follows:

1. Nucleus ambiguus—branchial efferent fibres
2. Dorsal nucleus of vagus—general visceral efferent and general visceral afferent
3. Nucleus of tractus solitarius—special visceral afferent and general somatic afferent fibres

Course

The vagus nerve arises as 8 or 10 filaments from the medulla oblongata below the glossopharyngeal nerve.

Cranial All the filaments of the nerve arising at the medulla converge at the cranial level to form the nerve proper and exit the cranium through the jugular foramen. It passes through the foramen, covered by a dural sheath which it shares with the accessory nerve. Here, the nerve lies in close association with the glossopharyngeal nerve which lies anterior to the vagus and is separated from each other by a thin septum. The vagus displays a characteristic swelling within the foramen called the superior/jugular ganglion. Further down, below the jugular foramen, the cranial portion of the accessory nerve communicates with the vagus nerve to produce a second swelling called the inferior ganglion/ganglion nodosum. Thus, the fibres of the cranial part of the accessory nerve get dispersed to the pharyngeal and laryngeal branches of the vagus nerve.

The vagus nerve descends along the neck enclosed within the carotid sheath. It remains positioned between the internal jugular vein and the internal carotid artery till it reaches the thyroid cartilage after which it is between the internal jugular vein and the common carotid artery. The course of the nerve is different on the two sides of the body as explained below.

On the **right side**, the nerve travels across the subclavian artery. It runs along the trachea and between the subclavian artery and the right innominate vein to the posterior aspect of the lung, to form the posterior pulmonary plexus. From here, nerve fibres ramify on the oesophagus and join with similar branches from the opposite side to form the oesophageal plexus.

On the **left side**, the vagus nerve runs between the left carotid and subclavian arteries. It forms the posterior pulmonary plexus behind the left lung, joins with the nerve of the right side in the oesophageal plexus and finally joins the hepatic plexus.

Communicating Branches

1. The superior ganglion is connected to the (i) cranial portion of the accessory nerve, (ii) petrous ganglion of the glossopharyngeal (iii) facial nerve through its auricular branch and (iv) superior cervical ganglion.
2. The inferior ganglion is connected to the (i) cranial part of the accessory nerve, (ii) vagus nerve (iii) hypoglossal nerve and (iv) superior cervical sympathetic ganglion.

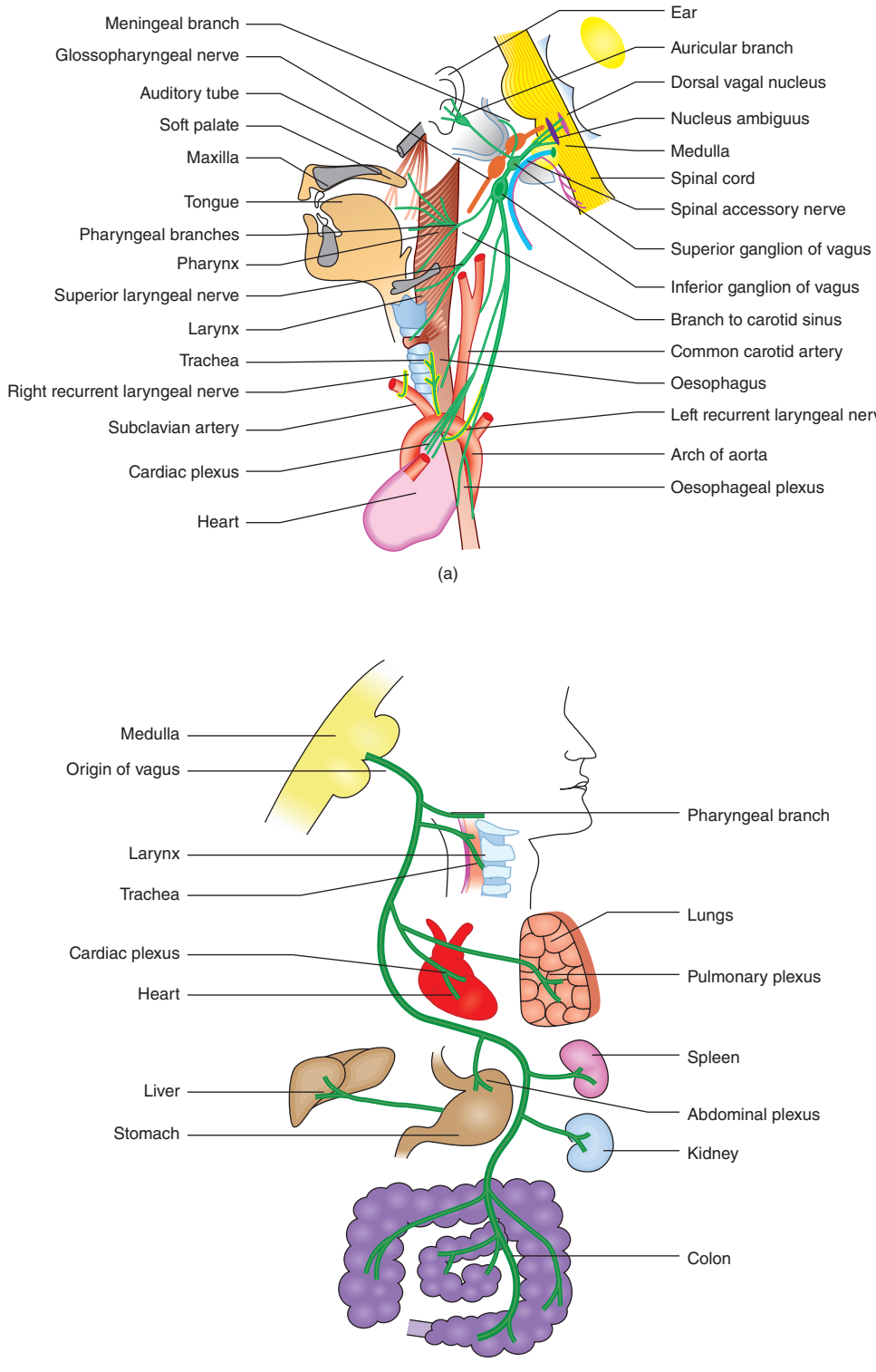


Figure 4.27 (a) Vagus nerve. (b) Vagus—distribution.

Branches

The vagus nerve gives rise to numerous branches at the following levels: neck, thorax and abdomen.

Nerves Arising at the Neck

1. The **meningeal branch** arises from the superior ganglion and supplies the dura mater in the posterior cranial fossa.
2. The **auricular branch** (nerve of Arnold) also originates from the jugular ganglion. The nerve emerges out through the tympanomastoid fissure and divides into multiple twigs which supply the skin of the back of the ear and the posterior part of the external acoustic meatus and tympanic membrane.
3. The **pharyngeal branch** is given off from the upper part of the inferior ganglion. It is the principal motor nerve of the pharynx. When it reaches the upper border of the middle constrictor, it divides into multiple minor branches which along with branches from the glossopharyngeal, sympathetic and external laryngeal nerves form the pharyngeal plexus. This plexus innervates the muscles and mucous membrane of the pharynx and the muscles of the soft palate, except the tensor veli palatini.
4. The **superior laryngeal nerve** also arises from the inferior ganglion. It receives some sympathetic fibres from the superior cervical ganglion. It reaches the lateral aspect of pharynx to branch out into external and internal laryngeal nerves:
   (a) The *external laryngeal branch* is smaller and supplies the cricothyroid muscle. In addition, it sends branches to the pharyngeal plexus.
   (b) The *internal laryngeal branch* after piercing the thyrohyoid membrane supplies the mucous membrane of the larynx.
5. **Cardiac branches**: These are of two groups: superior and inferior cardiac branches which are given off at the upper and lower parts of the neck, respectively. In addition, more cardiac branches arise from the vagus nerve at the level of the superior mediastinum and from recurrent laryngeal branches. All the cardiac branches terminate in the cardiac plexuses (superficial and deep) which supply the heart.

Branches in the Thorax

1. **Bronchial branches** combine with sympathetic fibres to form the pulmonary plexus which supply the lung.
2. **The recurrent nerve** traces different routes on the right and left sides. On the right side, the nerve originates at the level of the subclavian artery. It runs around the vessel and moves upwards towards the trachea. On the left side, it is given off at the level of the arch of aorta. The nerve on either side runs upwards in the groove between the trachea and oesophagus and reaches the larynx to supply the muscles, except the cricothyroid muscle. The recurrent nerve (Rt and Lt) gives off multiple cardiac filaments (more by the left than the right) to the deep part of the cardiac plexus as well as branches to the oesophagus, trachea and pharynx. The recurrent laryngeal nerve is closely associated with the lower pole of the thyroid gland. Therefore, it has to be carefully preserved during thyroid surgeries.

Branches in the Abdomen

1. **Oesophageal branches** join with similar branches of the opposite side to form the oesophageal plexus from where nerves are distributed to the oesophagus.
2. **Gastric branches** join the gastric plexus which supply the stomach. The right and left vagus nerves form the posterior and anterior gastric plexus, respectively, on the stomach.
3. **Celiac branches** join the celiac plexus and innervate the pancreas, spleen, kidneys, suprarenal bodies and intestine.
4. **Hepatic branches** join the hepatic plexus and innervate the liver.

Spinal Accessory Nerve (CN XI)

The accessory nerve is the *11th cranial nerve*. It is motor in function.

Functional Components (Fig. 4.28a)

The nerve carries special visceral branchial fibres through both the cranial and the spinal roots.

1. **Cranial root:** This serves as an adjunct to the vagus nerve and supplies the muscles of the palate, pharynx, larynx and heart.
2. **Spinal root:** This supplies the sternocleidomastoid and the trapezius muscles.

Origin (Fig. 4.28b)

1. **Cranial root:** The neurons contributing to the cranial part of the accessory nerve are present in the nucleus ambiguus (**Fig. 4.16b**).
2. **Spinal root:** This arises from the spinal nucleus located on the lateral part of the anterior grey column of the spinal cord from C1 to C5 levels.

Course

Cranial Part

1. The nerve fibres of the cranial part arise as multiple twigs from the lateral aspect of the medulla, just below the origin of the vagus nerve. Later, the rootlets merge to form a single nerve trunk. During its exit from the medulla, it is accompanied by the spinal part and the glossopharyngeal nerves (**Fig. 4.28b**).
2. During its passage through the jugular foramen, the fibres of the cranial part intermingle with the fibres of the spinal part (**Fig. 4.28b**). At this point, it is also linked to the superior ganglion of the vagus nerve by a few nerve filaments.
3. As it emerges out of the foramen, it separates from the spinal portion. The cranial part descends further and gets fused to the vagus at the level of the inferior ganglion. Thus, the fibres of the cranial part get distributed to the muscles of the palate, pharynx and larynx by running through the pharyngeal and superior laryngeal branches of the vagus nerve. Some fibres progress further down into the trunk of the vagus nerve and get distributed along with the recurrent nerve (cardiac nerves) to the heart.

Spinal Part

This part is larger than the cranial part.

1. The fibres of the spinal part after their origin from the lateral spinal cord merge to form a single trunk in the vertebral canal.
2. This runs upwards, between the dorsal nerve roots and the ligamentum denticulatum to enter the skull through the foramen magnum.
3. Later, it courses laterally towards the jugular foramen along with glossopharyngeal and vagus nerves. As discussed earlier, within the foramen it shares its dural sheath with the vagus nerve, although a layer of arachnoid separates the accessory nerve from the vagus nerve. Also, here it fuses with the cranial part and receives filaments from the cranial part.

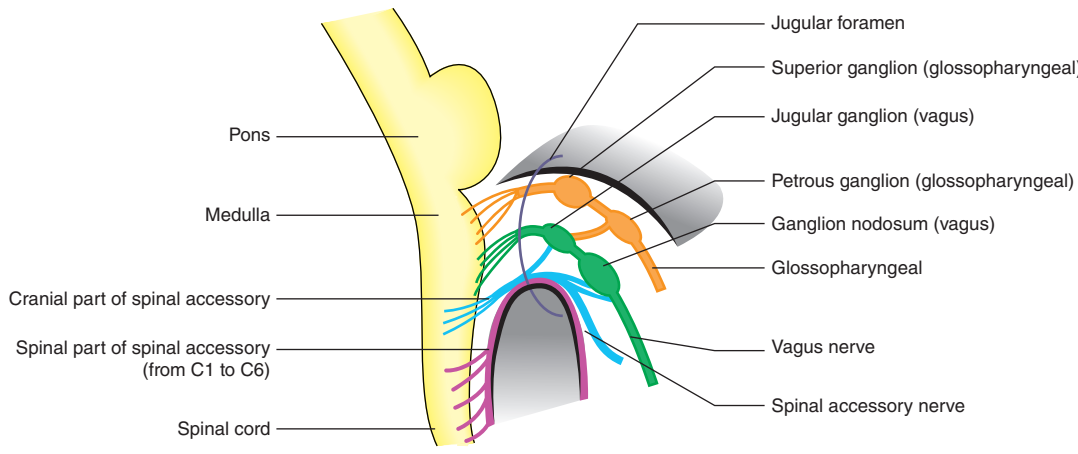
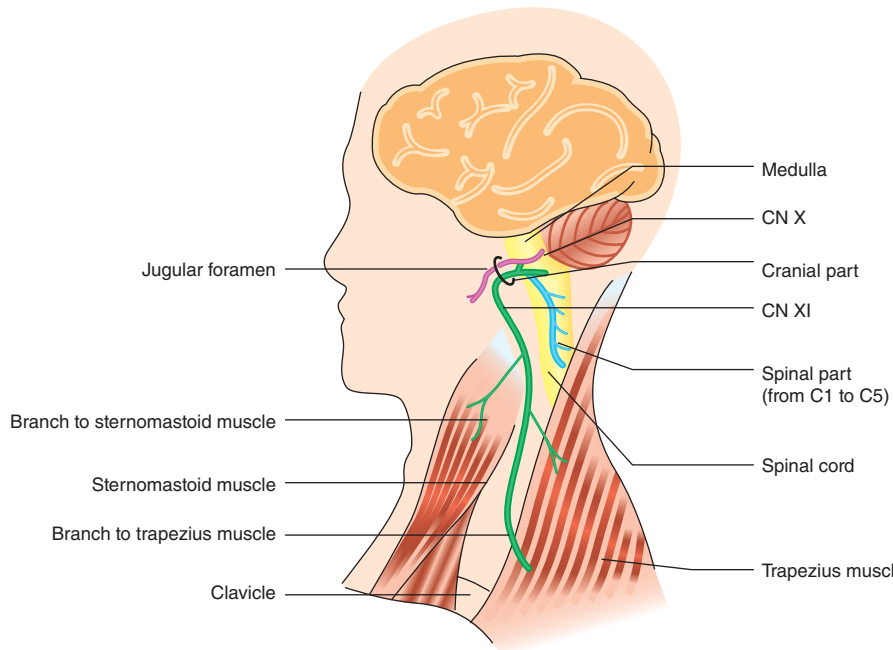


Figure 4.28 (a) Glossopharyngeal, spinal accessory and vagus nerves—relations at the jugular foramen. *(Continued)*



(i)



(ii)

(b)

Figure 4.28 *(Continued)* (b) Spinal accessory nerve: (i) dissected specimen and (ii) schematic diagram.

4. But it immediately separates from the cranial part as it emerges from the jugular foramen.
5. From the foramen the nerve runs downward between the internal jugular vein and the internal carotid artery till it reaches a point between the angle of the mandible and the mastoid process (**Fig. 4.28a**)
6. The nerve now traces a posterior course lying below the sternocleidomastoid muscle, finally piercing the upper part of the muscle where it communicates with the spinal nerves C2 and C3 (**Fig. 4.14**)
7. The nerve then enters the posterior triangle of the neck running inferiorly and posteriorly (**Fig. 4.29c**).

Further, the spinal part exits the triangle 5 cm above the clavicle to remain under the trapezius muscle and forms a plexus with the third and fourth cervical nerves, from where the muscle receives its innervation.

Branches

The spinal accessory nerve is an entirely motor nerve. Its muscular branches are as follows:

1. Branch to the sternocleidomastoid muscle
2. Branch to the trapezius muscle
3. In addition, the regions innervated through the cranial part of the accessory nerve are as follows:
   (a) Palate
   (b) Pharynx
   (c) Larynx
   (d) Heart

Hypoglossal Nerve (CN XII)

The hypoglossal nerve is the *12th cranial nerve*. Its functions are exclusively motor and it is the major nerve supplying the muscles of the tongue.

Functional Components

1. **General somatic efferent fibres:** These are motor fibres arising from the hypoglossal nucleus and innervate all the muscles of the tongue except the palatoglossus.
2. **General sensory fibres:** These carry the proprioceptive fibres from the tongue to be relayed at the spinal nucleus of CN V.

Origin

The fibres of the hypoglossal nerve arise from the hypoglossal nucleus which lies in the medulla, deep to the hypoglossal triangle (**Fig. 4.16b**). They emerge as numerous rootlets from the vertical groove between the pyramid and the olive. These fibres then converge to form a bundle that pierces the dura mater and exits the cranium through the hypoglossal/anterior condylar canal (**Fig. 4.15**).

Course (Fig. 4.29)

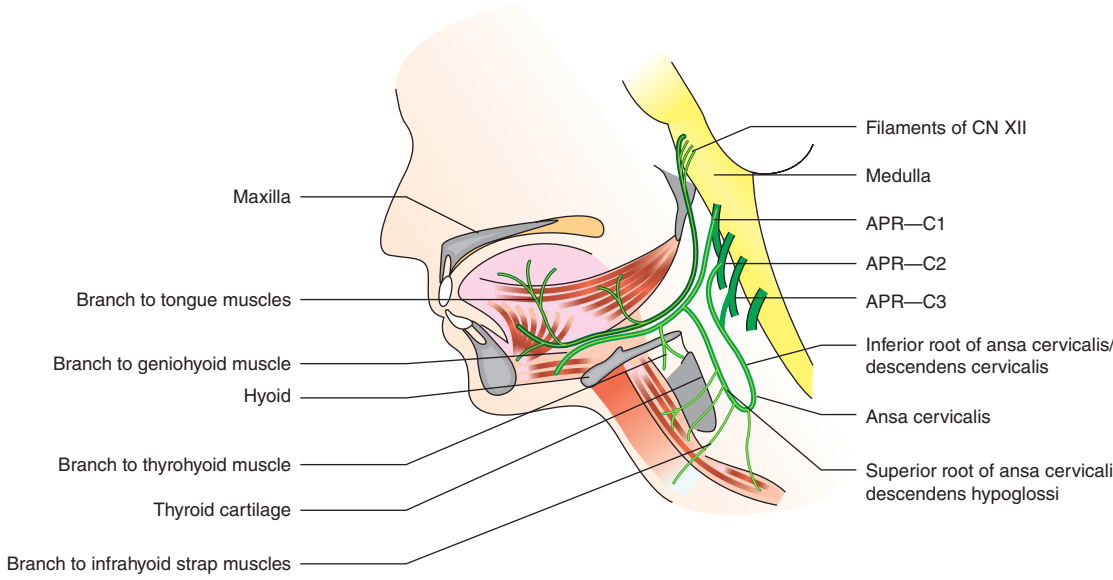
After exiting the cranium, the nerve descends down vertically between the internal carotid artery and the internal jugular vein till it reaches the angle of the mandible. The relation of the hypoglossal nerve with the glossopharyngeal, vagus and accessory nerves is shown in **Figure 4.29(b)**. At this level, it lies below the posterior belly of the digastric muscle and runs across the internal and external carotid arteries and the prominent loop formed by the lingual artery to enter the submandibular region. It curves above the level of greater cornu of hyoid to travel anteriorly.

Further, it runs between the mylohyoid and the hyoglossus muscles to finally reach the floor of the mouth. Here, the nerve remains inferior to the lingual nerve, submandibular duct and deep part of the submandibular gland. It terminates by sending branches to the intrinsic and extrinsic muscles of the tongue. A special feature of the hypoglossal nerve is the formation of a thin nerve loop at the neck called the *ansa hypoglossi/ansa cervicalis* (**Fig. 4.29a** and **b**). The loop is formed by a superior and an inferior root. The superior root is an extension of the hypoglossal nerve and carries C1 fibres. The inferior root is formed by fibres from spinal nerves C2 and C3. The two roots unite and form the loop in front of the common carotid artery.

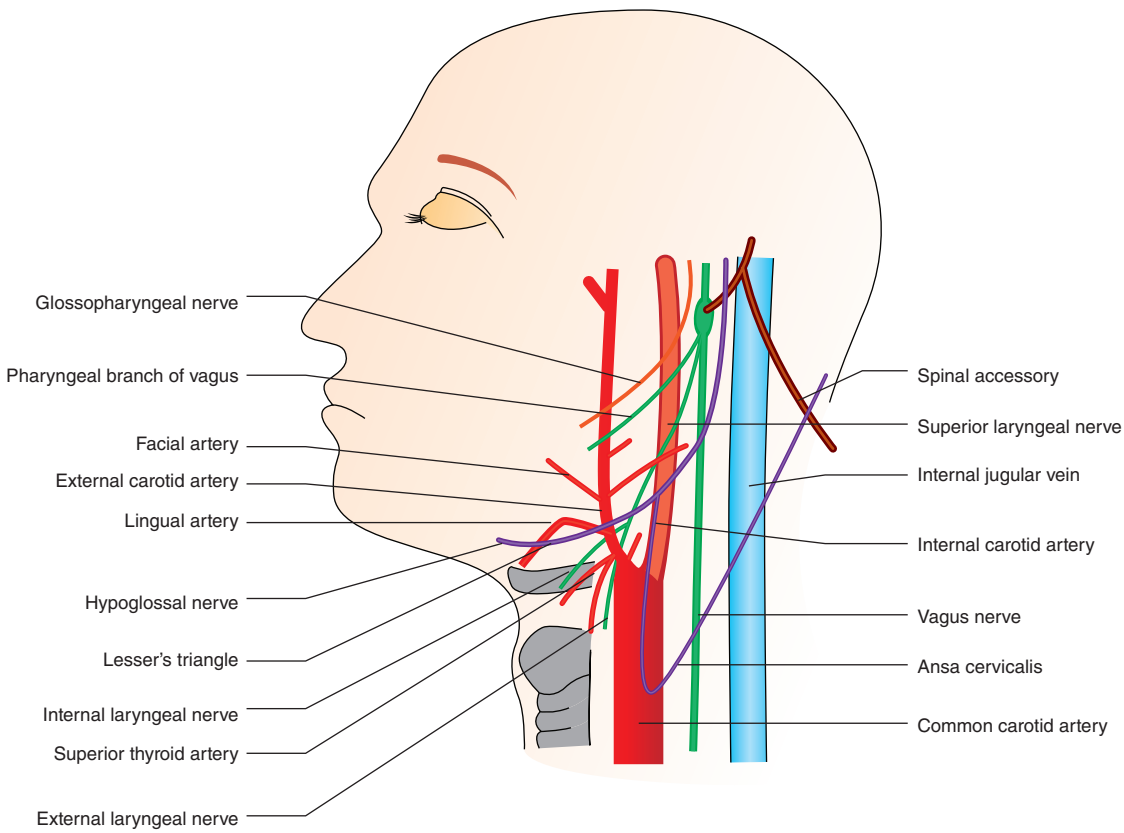
Branches

The innervating fibres of the hypoglossal nerve may be categorized into two types:

1. **Branches of the hypoglossal nerve proper** These are thin, delicate, muscular branches



(a)



(b)

Figure 4.29 (a) Hypoglossal nerve. (b) Hypoglossal nerve—relations at the level of the neck. *APR*, anterior primary ramus. *(Continued)*

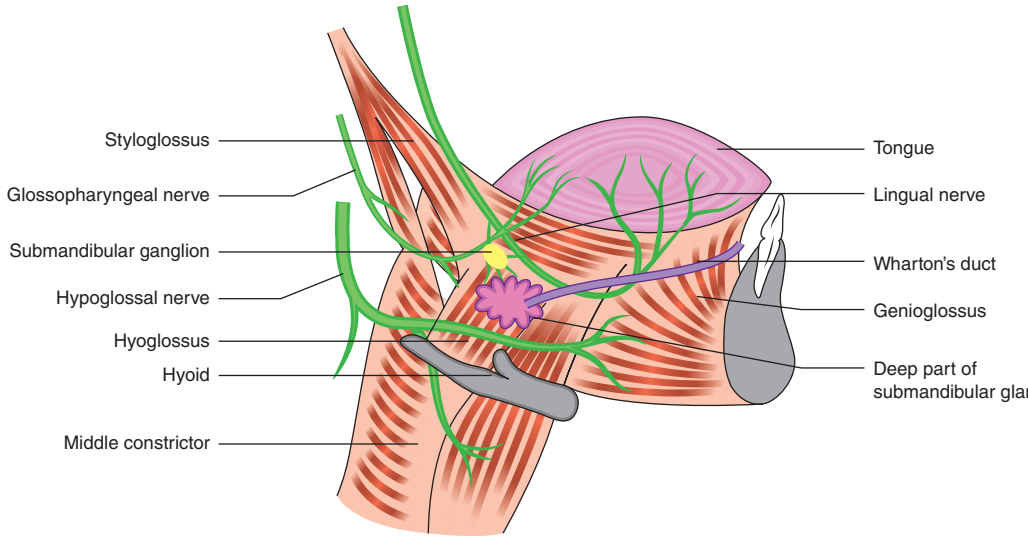


Figure 4.29 *(Continued)* (c) Hypoglossal nerve—relations at the level of the floor of the mouth.

which innervate the following from the inferior surface of the tongue:

(a) *Extrinsic muscles (except palatoglossus)*: Styloglossus, genioglossus, hyoglossus

(b) *Intrinsic muscles*: Superior longitudinal, inferior longitudinal, transverse and vertical

2. **Branches containing the spinal nerve C1**

(a) *Meningeal branches/dural branches:* Within the hypoglossal canal, the hypoglossal nerve gives off multiple meningeal filaments to the dura mater lining the posterior fossa of the skull.

(b) *Branches to the thyrohyoid and geniohyoid:* These branches contain C1 fibres and originate at the posterior border of the hyoglossus to innervate the thyrohyoid and geniohyoid muscles.

(c) *Branch from the descending hypoglossi:* This branch supplies the superior belly of the omohyoid muscle.

(d) *Branches from the ansa hypoglossi:* These innervate the infrahyoid muscles, sternohyoid and sternothyroid, and the inferior belly of the omohyoid muscle.

Communicating Branches

The hypoglossal nerve communicates with other nerves through its branches either by giving off a few nerve fibres or by receiving a few branches from other nerves such as vagus, lingual, sympathetic and cervical nerves.

REGIONAL NERVE SUPPLY

The nerve supply of the various anatomical sites of the oral cavity are summarized in **Table 4.12** and in **Figures 4.30** and **4.31**.

SENSORY INNERVATION OF THE FACE

The sensory innervation of the face is exclusively by the three divisions of the trigeminal nerve and their branches (**Fig. 4.32**). The branches of the trigeminal nerve and the areas innervated by them are given in **Table 4.13**.

Table 4.12 Innervation of the Head

Anatomical Site	Muscles Involved	Function	Innervation
Face	Muscles of facial expression	• Motor	• Facial nerve
		• Sensory	• Trigeminal, cervical plexus
Soft palate	Muscles of soft palate	• Motor	• Cranial part of CN XI through pharyngeal plexus except tensor palati which is by CN V_3
Orbit	Muscles of orbit except superior oblique and lateral rectus	• Motor	• Oculomotor nerve
	Superior oblique	• Motor	• Trochlear nerve
	Lateral rectus	• Motor	• Abducent nerve
	Levator palpebrae superioris	• Motor	• Oculomotor
		• Involuntary elevation of upper eyelid	• Sympathetic innervation
	Intraocular muscles	• Parasympathetic (ciliary muscle contraction)	• Oculomotor
		• Sympathetic (ciliary muscle relaxation)	• Fibres from cervical ganglia
Tongue	Anterior two-thirds	• Taste	• Chorda tympani, CN VII
		• General sensation	• Lingual nerve
	Posterior one-third	• Taste and general sensation	• Glossopharyngeal nerve
	All intrinsic and extrinsic muscles except palatoglossus	• Motor	• Hypoglossal nerve
	Palatoglossus	• Motor	• Pharyngeal plexus of vagus

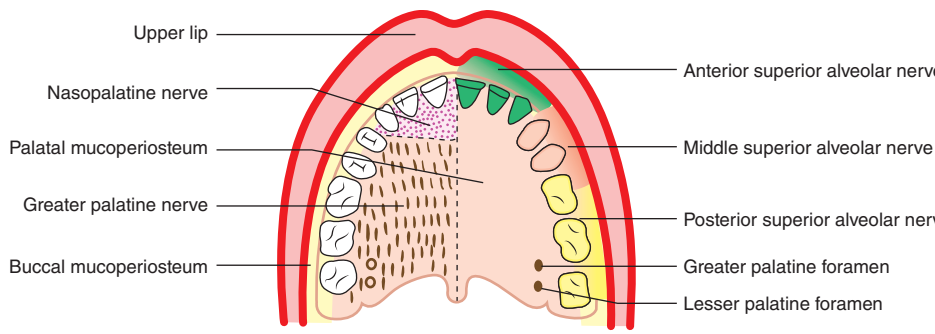


Figure 4.30 Dental innervation—maxillary jaw and teeth.

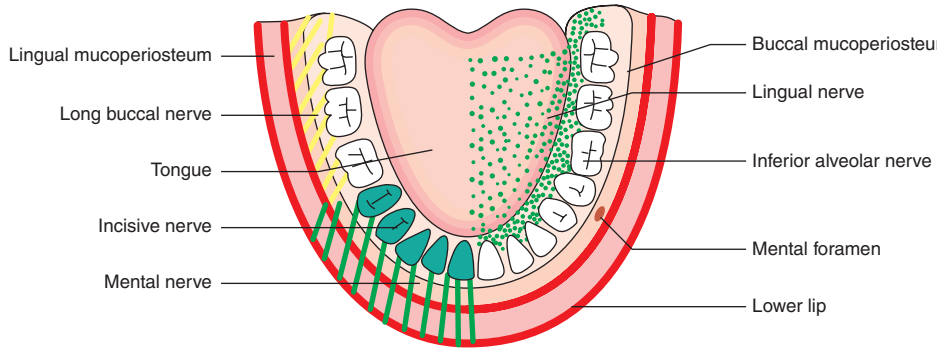


Figure 4.31 Dental innervation—mandibular jaw and teeth.

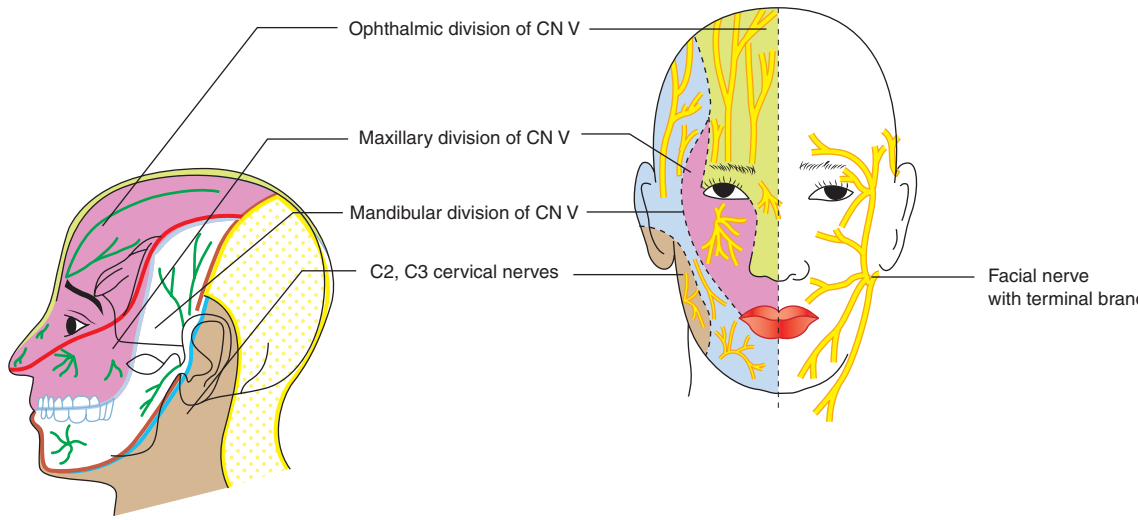


Figure 4.32 Sensory nerve and innervation of the face.

Table 4.13 Sensory Innervation of the Face

Nerve Type	Division	Branches		Region Supplied
Cranial nerve (trigeminal nerve)	Ophthalmic nerve	Lacrimal		Lateral portion of the upper eyelid and conjunctiva and lacrimal gland
		Frontal	Supraorbital	Upper eyelid, scalp
			Supratrochlear	Medial forehead, medial portion of the upper eyelid and bridge of the nose
		Nasociliary	Infratrochlear	Skin of the eyelids, side of the nose, conjunctiva, lacrimal sac and caruncula lacrimalis
			External nasal	Mucous membrane of anterior septum, lateral wall of nasal cavity
			External nasal	Skin of the ala and apex of the nose

(Continued)

Table 4.13 *(Continued)*

	Maxillary nerve	Infraorbital	Lateral aspect of the nose, lower eyelid, medial cheek and upper lip
		Zygomaticofacial	Skin on the prominence of the cheek
		Zygomaticotemporal	Skin of the side of the forehead
	Mandibular nerve	Auriculotemporal	Auricle, external acoustic meatus, outer side of the tympanic membrane and the skin in the temporal region and the temporomandibular joint
		Mental	Skin of the chin and the lower lip
		Buccal	Lower cheek, gums and mucous membranes of the mouth
Spinal nerves (cervical plexus)	Great auricular nerve	–	Skin over angle of jaw
	Lesser occipital	–	Ear and neck behind parotid

Key Points

1. Peripheral nerves are of three basic types: motor, sensory and autonomic.
2. The somatic axons innervate skeletal muscles and the autonomic axons innervate glands, smooth muscle and cardiac muscle.
3. The number of spinal nerves in the thoracic, lumbar and sacral regions corresponds to the number of vertebrae. However, in the cervical region, there are eight cervical nerves but only seven cervical vertebrae.
4. The sensory supply to the face is mainly by the following:
   (a) Three divisions of the trigeminal nerve
   (b) C2 and C3 cervical nerves
5. Cranial nerves are of three types: exclusively sensory, exclusively motor and mixed.
   (a) Exclusively sensory cranial nerves: I, II and VIII
   (b) Exclusively motor cranial nerves: III, IV, VI, XI and XII
   (c) Mixed cranial nerves: V, VII, IX and X
6. All the cell bodies of the sensory neurons are located outside the brain in ganglia, except the proprioceptive sensory neurons in the head region. These have their cell bodies in the mesencephalic nucleus. The cell bodies of motor neurons lie within the brain in nuclei.
7. The ophthalmic nerve carries sensory information from the following:
   (a) Scalp and forehead
   (b) Frontal sinuses
   (c) Parts of the meninges (dura and blood vessels)
   (d) Upper eyelid, conjunctiva and cornea of the eye
   (e) Nose and nasal mucosa
8. The maxillary nerve carries sensory information from the following:
   (a) Maxillary, ethmoid and sphenoid sinuses
   (b) Parts of the meninges
   (c) Lower eyelid and cheek
   (d) Nose and nasal mucosa

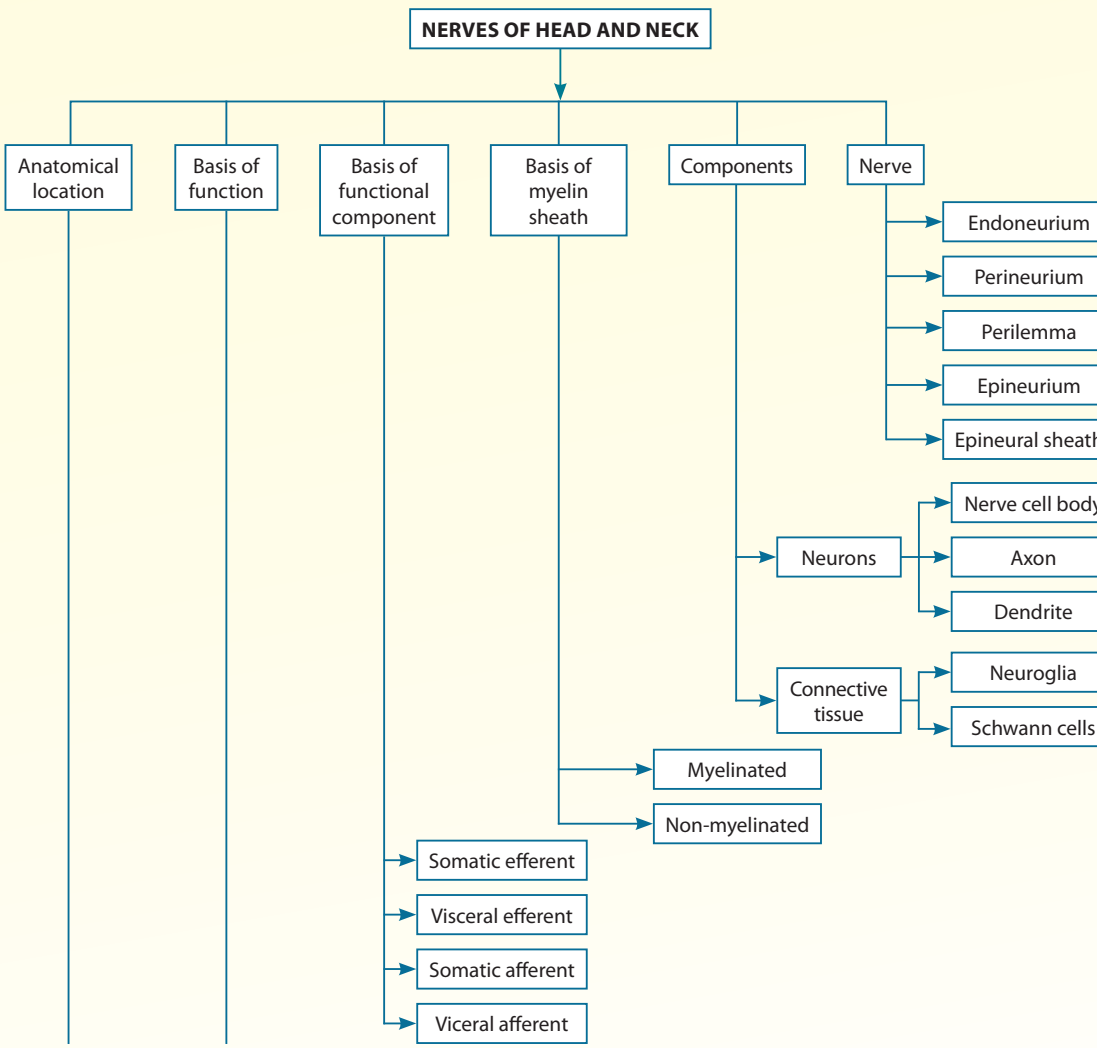
(e) Upper lip, palate and roof of the pharynx
(f) Upper teeth and gums

9. The mandibular nerve carries sensory information from the following:
   (a) Lower lip
   (b) Lower teeth and gums
   (c) Chin and jaw (except the angle of the jaw, which is supplied by C2–C3)
   (d) Parts of the external ear
   (e) Parts of the meninges; also carries motor innervation to muscles of mastication and tensor tympani
10. The pulpal innervation of maxillary teeth is as follows:
   (a) *Upper incisors:* Anterior superior alveolar nerve
   (b) *Upper canines:* Anterior superior alveolar nerve
   (c) *Upper premolars:* Middle superior alveolar nerve
   (d) *Upper I molar*
      - Middle superior alveolar nerve to mesiobuccal root
      - Posterior superior alveolar nerve to distobuccal root and palatal root
   (g) *Upper II and III molars:* Posterior superior alveolar nerve
11. The pulpal innervation of mandibular teeth is as follows:
   (a) *Lower incisors:* Incisive nerve
   (b) *Lower canines:* Incisive nerve
   (c) *Lower premolars:* Inferior alveolar nerve
   (d) *Lower molars:* Inferior alveolar nerve
12. Mucoperiosteal nerve supply is as follows:
   (a) *Mandibular buccal:* Long buccal nerve
   (b) *Maxillary buccal:* Anterior, middle and posterior superior alveolar nerve
   (c) *Lingual:* Lingual nerve
   (d) *Palatal:* Nasopalatine and greater palatine
13. Cranial nerves with unique features:
   (a) *Longest:* Vagus nerve
   (b) *Shortest:* Olfactory nerve
   (c) *Largest cranial nerve:* Trigeminal nerve
   (d) *Only nerve that originates from the dorsal surface:* Trochlear nerve
   (e) *Longest intraosseous course:* Facial nerve
   (f) *Longest intracranial course:* Trochlear nerve
   (g) *Thickest:* Optic nerve
14. Important foramina in the head and nerves that pass through:
   (a) *Foramen ovale:* Mandibular nerve
   (b) *Foramen rotundum:* Maxillary nerve
   (c) *Superior orbital fissure:* Ophthalmic nerve, abducent nerve, trochlear nerve and oculomotor nerve
   (d) *Mandibular foramen:* Inferior alveolar nerve
   (e) *Mental foramen:* Mental nerve
   (f) *Greater palatine foramen:* Greater palatine nerve
   (g) *Infraorbital foramen:* Infraorbital nerve
   (h) *Jugular foramen:* Glossopharyngeal nerve, vagus nerve and spinal accessory nerve
   (i) *Hypoglossal canal:* Hypoglossal nerve
15. The four ganglia related to the trigeminal nerve are as follows:
   (a) *Ciliary ganglion:* Related to the ophthalmic nerve

(b) *Sphenopalatine ganglion:* Related to the maxillary nerve
(c) *Otic ganglion*
(d) *Submandibular ganglia:* Related to the mandibular nerve
(e) Sensory input for all ganglia is from the trigeminal nerve, whereas the motor and sympathetic input are from various sources.

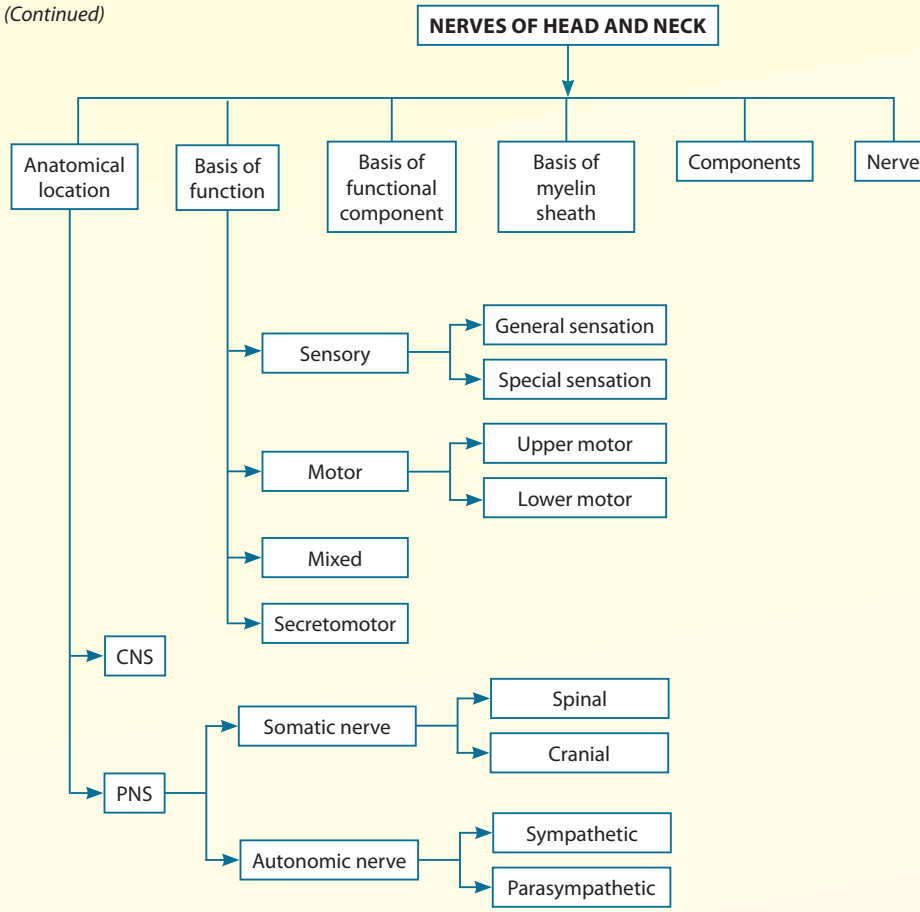
16. The four cranial nerves that carry parasympathetic fibres are as follows:
(a) Oculomotor
(b) Facial
(c) Glossopharyngeal
(d) Vagus

Mind Map



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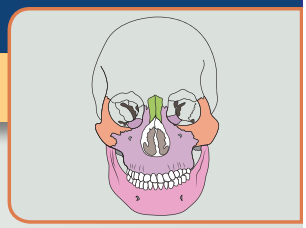
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Multiple Choice Questions

1. Sensory nerves carry impulses from
   (a) Brain to periphery
   (b) Periphery to brain
   (c) Skin to heart
   (d) Skin to joints
2. Ganglion is a
   (a) Collection of nerve cell bodies
   (b) Collection of axons
   (c) Collection of muscle fibres
   (d) Collection of nuclei
3. The autonomic nerves control
   (a) Voluntary function
   (b) Skeletal muscles
   (c) Involuntary function
   (d) Masseter
4. The ciliary ganglion is situated near the
   (a) Orbit
   (b) Oral cavity
   (c) Ear
   (d) Cranium
5. The trigeminothalamic tract carries the sensation of
   (a) Pain
   (b) Temperature
   (c) Pain and temperature
   (d) Pressure
6. The largest cranial nerve is the
   (a) Glossopharyngeal nerve
   (b) Trigeminal nerve
   (c) Optic nerve
   (d) Oculomotor nerve
7. The semilunar ganglion occupies a cavity called Meckel's cave present in the
   (a) Frontal bone
   (b) Temporal bone
   (c) Zygomatic bone
   (d) Maxilla
8. The maxillary nerve passes through the
   (a) Foramen rotundum
   (b) Foramen lacerum
   (c) Carotid canal
   (d) Superior orbital fissure
9. The posterior superior alveolar nerve is a branch of the
   (a) Mandibular nerve
   (b) Abducent nerve
   (c) Maxillary nerve
   (d) Hypoglossal nerve
10. The mandibular nerve is
    (a) Mixed
    (b) Sensory
    (c) Motor
    (d) Secretomotor

11. The sixth cranial nerve is the
    (a) Trochlear nerve
    (b) Abducent nerve
    (c) Optic nerve
    (d) Hypoglossal nerve
12. The taste sensation to the tongue is provided by the
    (a) Lingual nerve
    (b) Petrosal nerve
    (c) Palatine nerve
    (d) Chorda tympani
13. The sensory nerve to the angle of the jaw is the
    (a) Facial nerve
    (b) C2–C3 cervical nerve
    (c) Trigeminal nerve
    (d) Abducent nerve
14. Bell's palsy results due to the involvement of the following cranial nerve:
    (a) Facial nerve
    (b) Trigeminal nerve
    (c) Glossopharyngeal nerve
    (d) Trochlear nerve
15. Paraesthesia is
    (a) Abnormal growth of nerve
    (b) Tumour of nerve
    (c) Loss of sensation
    (d) Abnormal sensation of pain

CHAPTER 5



Vasculature of the Head and Neck

Overview

The anatomical units of the body that carry, transport or circulate body fluids such as blood or lymph in tube-like structures (called vessels) are called vasculature. The elastic, muscular tubes, which differ in architecture and function, are of two main types: artery and vein. Artery is a type of vessel that carries blood away from the heart to the cells, tissues and organs of the body whereas vein is the vessel that carries blood to the heart from the rest of the body. The arterial supply of the head and neck is primarily through the external carotid artery (and its branches) and internal carotid artery. The branches of the external carotid artery in the face are maxillary artery, facial artery, lingual artery, superficial temporal artery and transverse facial artery. The maxillary artery supplies the muscles of mastication, maxilla, mandible, teeth and nose. The major venous drainage for the head and neck is through the internal jugular vein formed by the union of various tributaries such as inferior petrosal sinus, common facial vein, lingual vein, pharyngeal vein, superior thyroid vein, middle thyroid vein and occipital vein.

INTRODUCTION

The term *vasculature* refers to the anatomical units of the body that carry, transport or circulate body fluids such as blood or lymph in tube-like structures called vessels. The elastic, muscular tubes, which differ in architecture and function, are of two main types:

1. Artery
2. Vein

Artery is the type of vessel that carries blood away from the heart to the cells, tissues and organs of the body, while *vein* carries blood to the heart from the rest of the body.

The terms commonly used to describe the vasculature of head and neck are defined in **Box 5.1**.

Box 5.1 Vasculature-Related Essential Terminology

- **Anastomosis:** It is the communication between arterial vessels or branches.
- **Arteriovenous anastomosis:** It is the communication between artery and vein; the cause may be surgical, traumatic or pathologic. Such communications are abundant in lips and skin.
- **Branch:** It is a smaller division of the vessel originating from a main trunk; it is used in relation to arteries (e.g. small arteries branch out from bigger arteries).
- **Cavernous venous sinus:** It is a venous sinus present in the middle cranial fossa on either side of the body of sphenoid.
- **Collateral circulation:** These are alternative channels to supply blood when the principal vessel is blocked.
- **End artery:** It is an artery that does not possess collateral circulation. If the end artery is affected, the area supplied by the artery becomes necrosed (e.g. central artery of retina).
- **Perfusion:** It is the physiologic process of delivery of nutrients to tissues through arterial blood.
- **Tributary:** It is a smaller division of vessel joining or emptying into a main trunk; it is used in relation to veins (e.g. tributaries draining contents into bigger veins).
- **Vena comitans:** It is a vein that accompanies an artery (*pl.* venae comitantes).
- **Venous sinus:** These are valveless venous spaces present in the cranium receiving blood from brain and meninges. The venous sinuses are lined by dura mater.

COMPONENTS OF THE VASCULAR SYSTEM: THE VASCULAR TREE (Fig. 5.1)

The vascular tree originates from the heart (left ventricle) as the aorta, the biggest artery. It then branches out as arteries to transport pure blood to various organs. The arteries divide to form arterioles and then capillaries. All exchange of nutrients and gases occurs at the capillary level. Capillaries open into the venules, which unite to form veins. Veins unite with other veins and finally form two great veins, the superior and inferior vena cavae, that open into the right atrium for purification.

There are two exceptions to the nature of blood carried by the two vessels:

1. Pulmonary artery that carries deoxygenated blood
2. Pulmonary vein that carries oxygenated blood

The various components of the vascular tree and their importance are as follows:

1. **Artery:** Large vessel that carries blood from the heart to the periphery
2. **Arteriole:** Small microscopic artery
3. **Capillary:** The thinnest of blood vessels, present in great number. It is at the capillary level that blood moves from the arterial to the venous system and the exchanges of fluid, nutrients and wastes occur between the blood and tissue cells.
4. **Venule:** Small microscopic vein
5. **Vein:** Large vessel that carries blood from periphery to heart

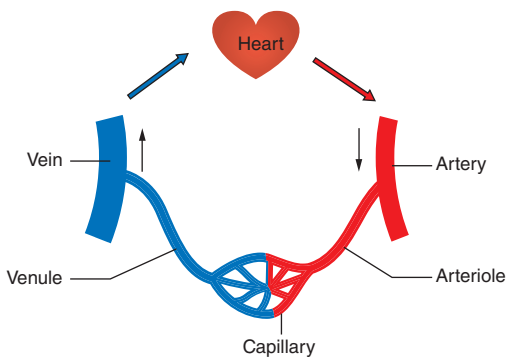


Figure 5.1 Vascular tree.

Importance of Vasculature

The functions of blood vessels are related to their role of blood transport. They play very important roles in establishing homeostasis in relation to various systems.

Arterial blood carries out the following functions:

1. Supplies nutrients
2. Delivers oxygen
3. Carries endogenous hormones
4. Transports exogenous drug molecules to various regions of the body

Veins drain deoxygenated blood and metabolites from different parts of the body and transport them to the heart for purification.

Apart from the aforementioned functions, blood vessels play an important role in thermoregulation and immunity.

Applied Anatomy

Abnormal Bleeding Time

Bleeding time may be prolonged due to platelet disorders as well as disorders of blood vessels. Frequent causes of defective vessel walls are ageing, medication with drugs, such as glucocorticoid (chronic therapy), penicillins and sulphonamides, vitamin C deficiency and conditions such as hereditary haemorrhagic telangiectasia (Osler-Weber-Rendu disease), Henoch–Schönlein purpura or haemolytic uraemic syndrome.

Angiogram

It is the X-ray of blood vessels produced by a technique called angiography and is used in diagnosing pathologic conditions of blood vessels. Angiography is a method by which a radiopaque substance is injected into blood vessels and X-rays are taken. Various abnormalities of blood vessels such as obstruction of lumen and altered vascular architecture may be studied by this technique.

Doppler Ultrasound

It is a form of imaging modality that uses ultrasound waves to give a digital representation of the blood vessels and the blood flow.

Haematogenous Spread

Spread of pathogenic microorganisms or tumour cells from a primary focus to a distant one through blood is called haematogenous spread.

Table 5.1 Distinguishing Features of Artery and Vein

Artery	Vein
Transports blood away from heart	Transports blood towards heart
Carries oxygenated blood (except pulmonary artery)	Carries deoxygenated blood (except pulmonary vein)
Walls contain more muscles	Walls contain less muscles
Narrow lumen	Broad lumen
Transports blood under high pressure	Transports blood under less pressure
No valves	Valves are present

Differences Between Artery and Vein

Arteries and veins differ in various aspects such as macroanatomy, microanatomy and basic functions (Table 5.1).

Microanatomy

The walls of blood vessels consist of the following three layers, which are also called coats or tunics (Fig. 5.2):

1. **Tunica intima:** Innermost coat consisting of endothelial cells and collagen fibres
2. **Tunica media:** Middle coat consisting of elastic and smooth muscle fibres arranged circularly
3. **Tunica adventitia:** Outermost coat consisting of connective tissue arranged longitudinally. This layer contains nerves which supply the blood vessels.

As a rule,

1. The walls of arteries are thicker than those of veins.
2. The lumen of veins is larger than the corresponding arteries.

Applied Anatomy

Atherosclerosis

This is a disease of the arteries in which the walls of the blood vessels become thick, hard and less elastic by deposition of cholesterol, inflammatory cells and calcium. The deposits are called plaques. They can slow the flow of blood through the arteries and predispose to ischaemic diseases.

Differences Between Arterial and Venous Bleeding

Arterial bleeding results in spurting of blood intermittently due to high BP in the arteries. Venous bleeding leads to steady passive flow of blood from wound. Further, arterial blood is bright red whereas venous blood is dark red.

Arresting Bleeding

In dental practice, minor bleeding is arrested by using adrenalin (vaso constrictor) pressure packs or suturing. Bleeding from severed big vessels is managed by ligation. Ligation is the procedure by which the cut ends of vessels are tied with suture materials.

Non-Vital Teeth

Blood supply to the teeth is through vessels entering the dental pulp through the apical foramen. When the vascularity is compromised, it leads to necrosis of the pulp. This clinical condition is called non-vital pulp and is characterized by discoloration of teeth. If untreated, it can progress to infection of the underlying bone. A non-vital tooth is treated by root canal therapy, which

(Continued)

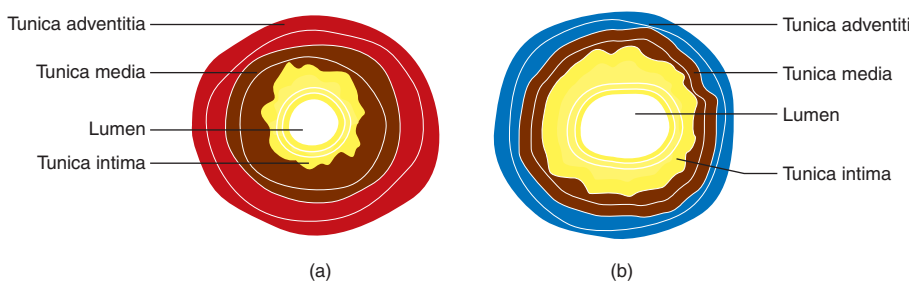


Figure 5.2 Cross-sectional differences: (a) artery and (b) vein.

(Continued)

involves removal of the necrotic pulp and filling up of the root canal with medicament.

Vascular Anomalies

Vascular anomalies of the head and neck are common lesions of childhood. They can be divided into haemangiomas and arteriovenous malformations. Arteriovenous malformations are abnormal communications between artery and vein that occur during the prenatal development. They appear as a tangled mass of arteries and veins which may bleed, leading to complications that can be life-threatening.

ARTERIAL SUPPLY OF THE FACE

Blood supply to the face is predominantly from the branches of two major vessels (**Table 5.2**; **Box 5.2**):

1. External carotid artery (the principal source)
2. Internal carotid artery

Both the arteries are terminal branches of the common carotid artery (CCA; **Fig. 5.3**). The left CCA branches out from the arch of aorta and the right CCA from the brachiocephalic artery. In the neck the CCA of both sides run under the sternomastoid muscle, within the carotid sheath and at the level of the lower four cervical processes. At the upper border of the thyroid cartilage, the CCA divides into the external and internal carotid artery.

Box 5.2 Special Features of Facial Vasculature

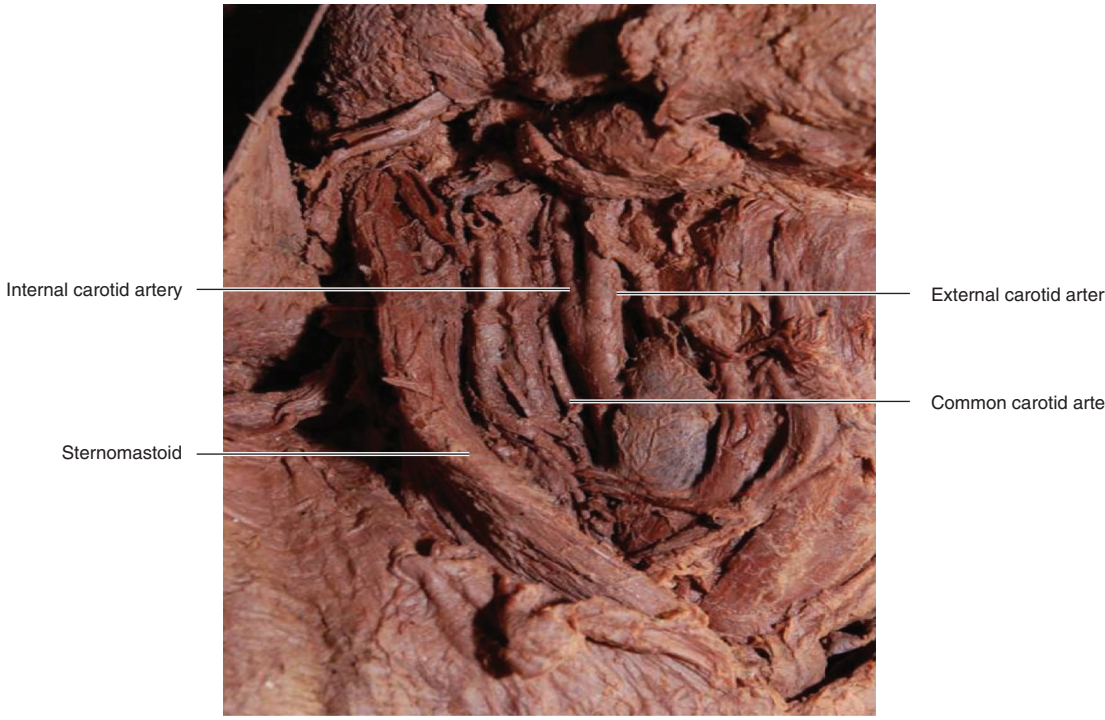
- The facial region has rich vascularity as it is profusely supplied by various vessels with rich anastomoses. Therefore, wounds of the face bleed more but heal faster.
- Interconnections between cranium and face exist through the emissary veins, ophthalmic veins and venous plexuses.
- Veins of the face have no valves unlike that of other regions; therefore, retrograde spread of infection is possible.

External Carotid Artery

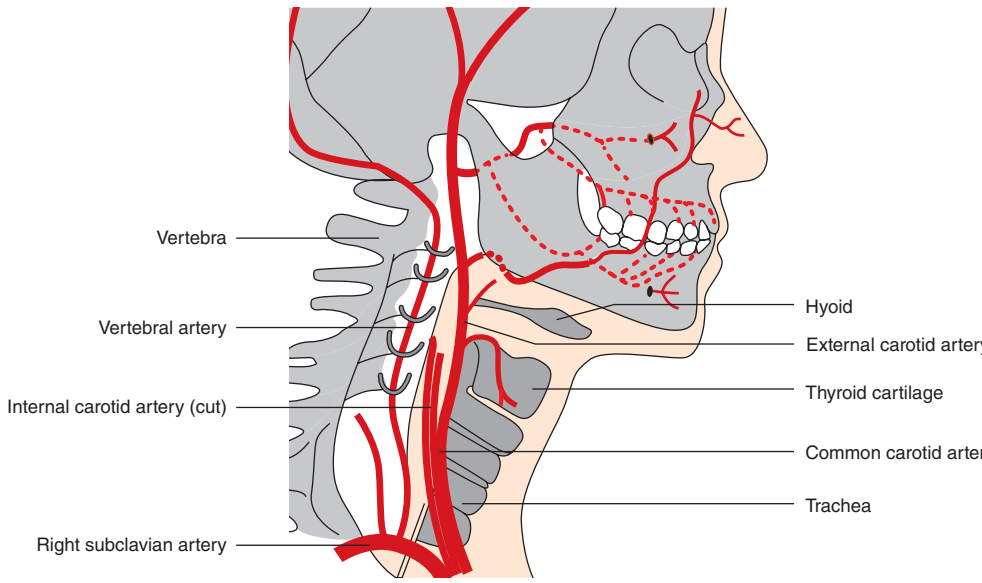
The external carotid artery is the principal artery of the face (**Fig. 5.4**). The course of the external carotid artery begins in the carotid triangle. Throughout, it lies anterior to the internal carotid artery. It runs upwards and terminates at the neck of the mandible by dividing to give off terminal branches, the maxillary and superficial temporal artery. The branches of the external carotid artery

Table 5.2 Arterial Supply to the Face

Main Artery	Branch	Anatomical Region Supplied
External carotid artery	Maxillary	• Muscles of mastication • Maxilla • Mandible • Teeth • Nose
	Facial	• Muscles of facial expression
	Lingual	• Tongue
	Superficial temporal	• Temple, scalp, ear
	Superficial temporal (transverse facial artery branch)	• Salivary glands, masseter
Internal carotid artery	Cavernous part	• Trigeminal ganglion
	Ophthalmic	• Muscles of orbit
	Supratrochlear and supraorbital	• Skin of forehead
	Dorsal nasal	• Upper part of nose



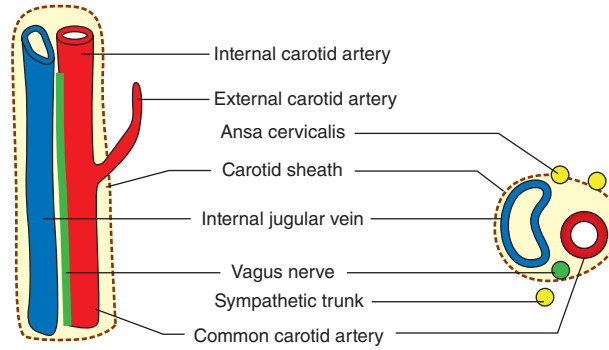
(i)



(ii)

(a)

Figure 5.3 (a) Arterial supply of face: (i) dissected specimen and (ii) schematic diagram. (*Continued*)



(b)

Figure 5.3 (*Continued*) (b) Carotid sheath (right side) with contents.

are superior thyroid, lingual, facial, occipital, posterior auricular, ascending pharyngeal, maxillary and superficial temporal.

The branches of the external carotid artery supply most of the head and neck areas and are discussed individually in the subsequent paragraphs.

Internal Carotid Artery (Fig. 5.5)

The internal carotid artery is the principal artery of the brain and eye though it supplies few regions in the face. After its origin at the level of the thyroid cartilage, it courses upwards towards the cranium. It is divided into four parts in relation to the region through which it passes. The parts of the artery and the anatomic region supplied by them are as follows:

1. **Cervical part:** In relation to the neck (no branches from this part of the artery)
2. **Petrous part:** In the petrous part of the temporal bone
   - *Caroticotympanic branch:* Middle ear
   - *Pterygoid branch or vidian artery:* Communicates with the maxillary artery which is a branch of the external carotid artery

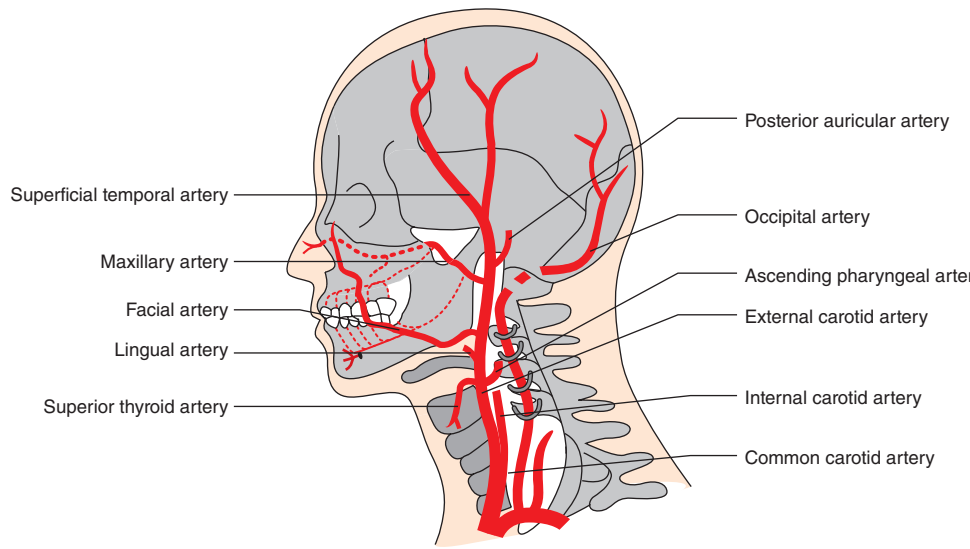


Figure 5.4 External carotid artery—branches.

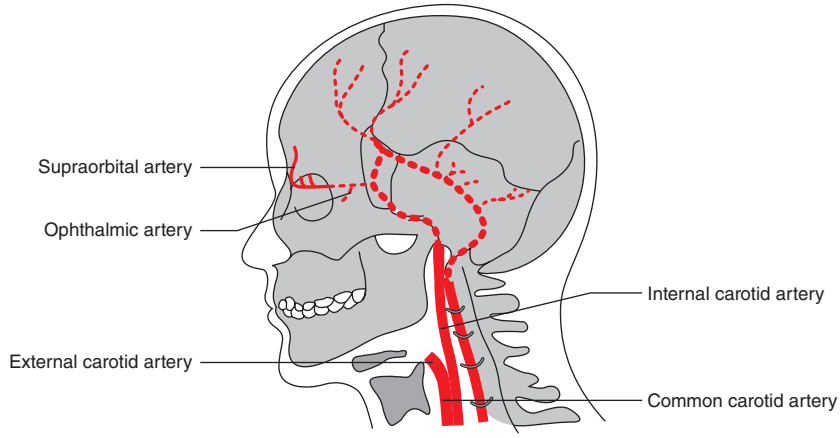


Figure 5.5 Internal carotid artery.

3. **Cavernous part:** Within the cavernous sinus
   - *Cavernous branch:* Trigeminal ganglion
   - *Hypophyseal branch:* Pituitary gland
4. **Cerebral part:** In relation to the brain
   - *Ophthalmic branch:* Eye
   - *Anterior, middle and posterior cerebral branches:* Brain
   - *Posterior communicating artery:* Brain
   - *Anterior choroidal branch:* Hippocampus, tela choroidea of the third ventricle and choroid plexus

The description of all the important branches perfusing the face and their anastomoses are elucidated below.

Facial Artery (Fig. 5.6)

The facial artery is the chief source of vascular supply to the face with rich anastomoses. It is also referred to as the external maxillary artery and forms an important landmark in the face for various surgical procedures.

Origin The facial artery is a branch of the external carotid artery. It originates from the anterior surface of the external carotid artery above the greater cornu of hyoid bone.

Course and Relations The course of the artery from the point of origin is divided into two parts:

1. **Cervical:** Part of the facial artery in the neck
2. **Facial:** Part of the facial artery in the face

The course of the facial artery is tortuous to accommodate the movement of the mobile structures surrounding the artery, such as muscles and mandible. From the origin, the artery runs upwards in the pharynx and reaches the submandibular region.

It passes deep into the posterior belly of the digastric muscle and 'grooves' the submandibular gland posteriorly. It then makes the characteristic S-shaped course, first over the submandibular gland and then over the inferior border of the mandible. It then proceeds forwards over the face by piercing the deep cervical fascia at the anteroinferior attachment of the masseter or the antegonial notch at the lower border of the mandible. At this region, the facial artery is prone to injury during oral surgical procedures, especially while incisions are made for the removal of the impacted lower molars. Care is taken not to extend the incisions deep down to the lower border of the mandible to prevent severance of the artery. The artery then moves up towards the medial angle of the eye, where it is called the angular artery. It remains in a plane between the superficial and deep muscles of facial expression and finally ends by giving off the three terminal branches to the lips and nose.

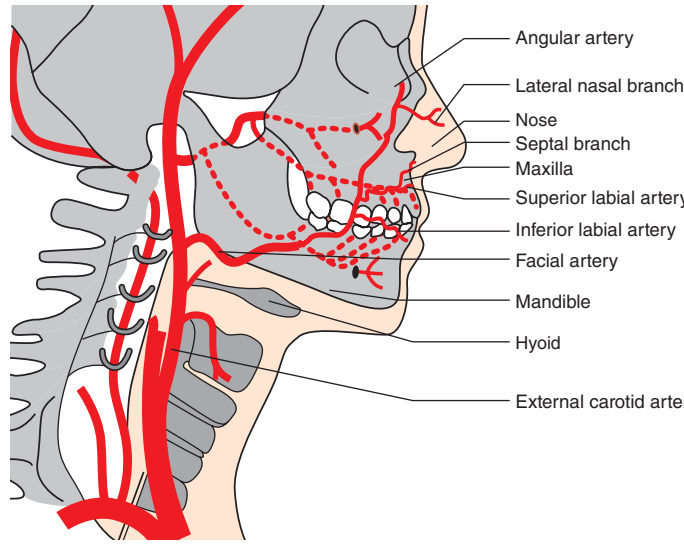


Figure 5.6 Facial artery.

Branches and Regional Supply (Table 5.3)

1. Branches of the cervical part (in the submandibular region)
   (a) *Ascending palatine branch:* Soft palate
   (b) *Tonsillar branch:* Tonsils
   (c) *Submental branch:* Submental triangle and sublingual salivary gland
   (d) *Glandular branch:* Submandibular salivary gland and lymph nodes
2. Branches of the facial part (terminal branches)
   (a) *Inferior labial branch:* Lower lip
   (b) *Superior labial branch:* Upper lip and the anteroinferior part of the nasal septum
   (c) *Lateral nasal branch:* Ala and dorsum of the nose

Anastomoses

1. The terminal branches anastomose with the corresponding branches of the opposite side.
2. Some branches anastomose with the transverse facial artery and infraorbital artery.
3. At the medial angle of the eye, they communicate with the branches of the ophthalmic artery (branch of the internal carotid artery).

Table 5.3 Facial Artery—Course and Branches

Part of Artery (Based on Site of Origin)	Branch	Area Perfused
Cervical part (submandibular region)	Ascending palatine branch	Soft palate
	Tonsillar branch	Tonsils
	Submental	Submental triangle and sublingual gland
	Glandular	Submandibular salivary gland and lymph nodes
Facial part (face)	Inferior labial	Lower lip
	Superior labial	Upper lip and nasal septum (anteroinferior part)
	Lateral nasal	Nose—ala and dorsum

Transverse Facial Artery

The transverse facial artery, a branch of the superficial temporal artery, arises at the level of the parotid gland. It takes its course over the masseter muscle lying between the zygomatic arch and the parotid duct. It terminates by communicating with the arteries in the adjacent region. The transverse facial artery supplies blood to the parotid gland, masseter and overlying skin.

Lingual Artery (Fig. 5.7a)

The lingual artery is the artery of the tongue.

Origin The lingual artery branches out from the external carotid artery at the level of the greater cornu of hyoid bone. Sometimes, it has a common origin with the facial artery; in such a case, it is called the linguofacial trunk.

Course and Relations The course of the lingual artery is related to the hyoglossus muscle. It can be studied as four parts, which are as follows:

1. **First part:** It lies in the carotid triangle. It runs vertically, forming the characteristic loop. The hypoglossal nerve crosses the loop of the lingual artery and forms a triangle called the Lesser's/ lingual triangle with the posterior border of the mylohyoid and digastric muscles. It is of clinical significance because the lingual artery is commonly ligated at this triangle to arrest bleeding from the tongue. This part gives

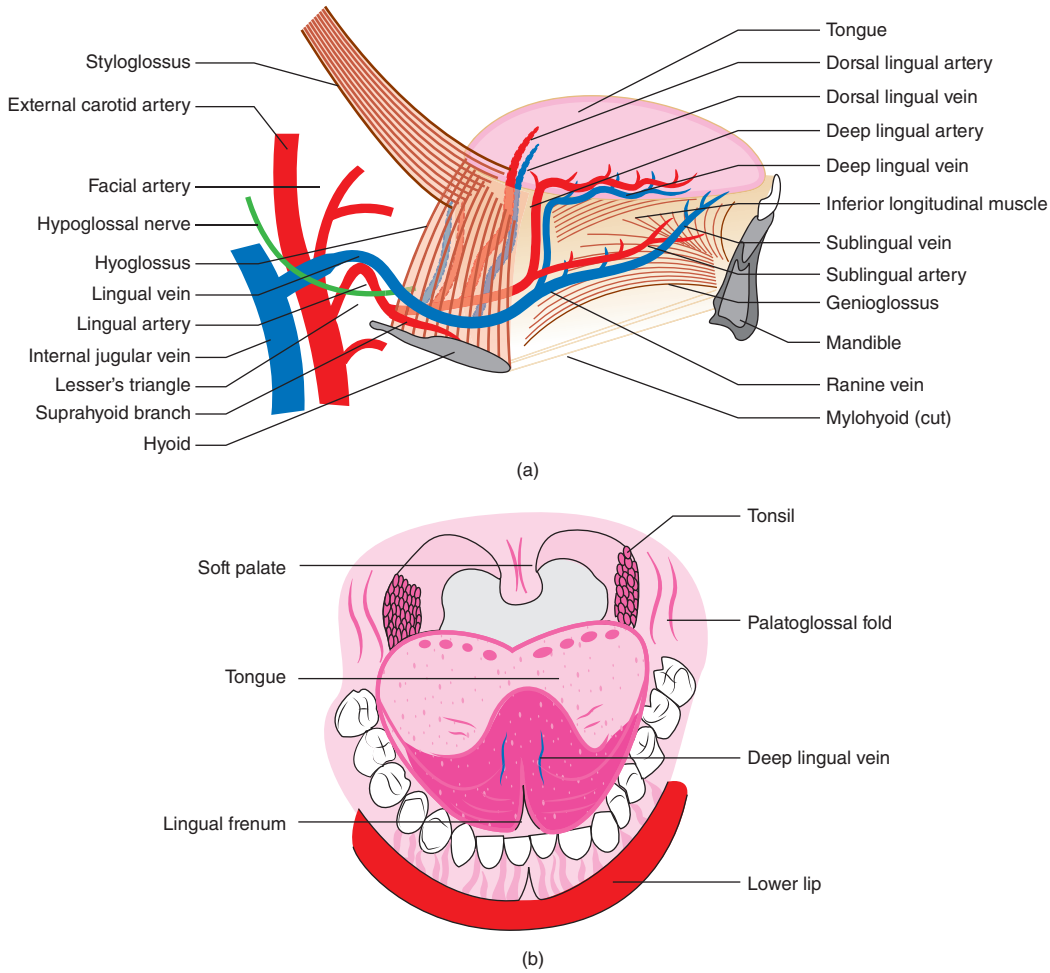


Figure 5.7 (a) Lingual artery and vein. (b) Deep lingual vein.

off the suprahyoid branch before reaching the substance of the tongue.

Applied Anatomy

The first part of lingual artery is of clinical significance because the lingual artery is commonly ligated at this triangle to arrest bleeding from the tongue.

2. **Second part:** This part lies deep to the hyoglossus muscle and gives rise to the dorsal lingual artery.
3. **Third part:** This part is called the deep lingual artery. The artery ascends along the anterior border of hyoglossus and lies between the genioglossus and the inferior longitudinal muscle.
4. **Fourth part:** This part is the course of the artery on the lower surface of the tongue where it is closely related to the lingual nerve. It terminates by giving off the sublingual branch.

Branches and Regional Supply

1. **Hyoid branch:** Supplies the muscles attached to the hyoid bone
2. **Dorsal lingual branch:** Supplies the base of the tongue
3. **Sublingual branch:** Supplies the gland and mylohyoid muscle. It anastomoses with the submental artery (branch of the facial artery).
4. **Deep lingual branch:** Supplies the body and apex of the tongue. One of its terminal branches communicates with the deep lingual artery of the opposite side and is called the arcus raninus.

Applied Anatomy

Sublingual Medication

The sublingual region under the tongue is an ideal location for introducing certain medications (e.g. nitroglycerin for chest pain) to the body. This is because the oral mucosa in this region is very thin and highly vascular. This permits rapid absorption of medication into the cardiovascular system, bypassing the gastrointestinal tract. Some medicines taken orally are inactivated by the detoxification process of the liver.

Maxillary Artery (Fig. 5.8)

One of the terminal branches of the external carotid artery, the maxillary artery is the artery of the jaws and teeth.

Origin The maxillary artery originates from the external carotid artery behind the neck of the mandible.

Course and Relations The course of the maxillary artery is divided into three parts by its relation to the lateral pterygoid muscle. From the neck of the mandible, it runs across the lower border of the lower head of the lateral pterygoid muscle and then crosses between the two heads of the lateral pterygoid muscle to go through the

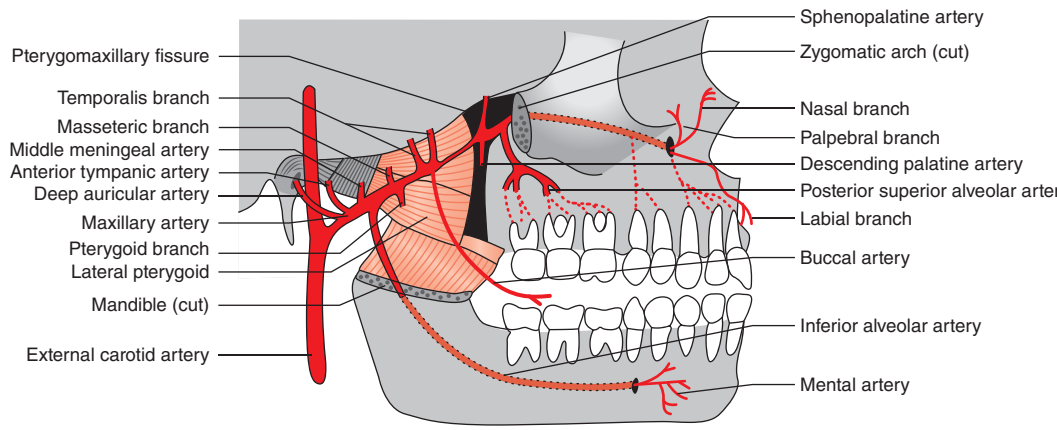


Figure 5.8 Maxillary artery.

pterygomaxillary fissure and reach the pterygopalatine fossa. Various branches are given off during the entire course, supplying numerous structures.

Branches and Regional Supply

1. **First part/mandibular part:** This part extends from the neck of the mandible to the sphenomandibular ligament.
   (a) *Deep auricular branch:* External acoustic meatus, tympanic membrane and temporomandibular joint
   (b) *Anterior tympanic branch:* Middle ear and medial surface of tympanic membrane
   (c) *Middle meningeal branch:* Meninges
   (d) *Accessory meningeal branch:* Meninges and structures of infratemporal fossa
   (e) *Inferior alveolar branch:* Runs on the medial surface of the ramus of mandible until it reaches the mandibular foramen. Before entering the foramen, it gives off two branches: one to the tongue and the other to the mylohyoid muscle. It then enters the mandibular foramen, passes through the mandibular canal and supplies the mandible and every tooth in the lower jaw. A terminal branch, called the mental branch, is given off through the mental foramen to supply the chin.
2. **Second part/pterygoid part:** The second part is superficial to the lower head of the lateral pterygoid and consists of muscular branches that supply the muscles of mastication.
   (a) *Deep temporal branch:* Temporalis muscle
   (b) *Branch to pterygoid muscles:* Lateral and medial pterygoid
   (c) *Branch to masseter:* Masseter muscle
   (d) *Buccal branch:* Buccinator muscle
3. **Third part/pterygopalatine part:** This part spans the region between two heads of lateral pterygoid to pterygopalatine fossa.
   (a) *Posterior superior alveolar branch:* This branch is given off before the maxillary artery enters the pterygomaxillary fissure. The arteries perforate the posterior surface of the maxilla to supply the teeth of the upper jaw—the premolars and molars—and the maxillary sinus.
   (b) *Infraorbital branch:* This branch passes through the inferior orbital fissure to reach the floor of the orbit. It runs over the infraorbital groove and then into the infraorbital canal to finally open onto the face through the infraorbital foramen, which is present below the lower margin of orbit. The branches of the infraorbital artery are as follows:
   - Branches before exiting the orbit: Anterior superior alveolar branches that supply the canine and incisors
   - Branches after exiting the orbit: Branches to the lacrimal sac, nose and upper lip

   (c) *Greater palatine branch:* This artery travels through the greater palatine canal to come out of the greater palatine foramen on the posterior aspect of the hard palate (**Fig. 5.9**). After emerging out, it travels along the lateral margin of the hard palate to reach the incisive canal present between the incisors. It supplies the palate and gums. Before exiting the canal, the greater palatine artery gives off branches called the lesser palatine arteries, which also emerge into the palate through the lesser palatine foramina. They supply the soft palate and tonsils.
   (d) *Pharyngeal branch:* This branch supplies a part of the nasopharynx, sphenoidal sinus and auditory tube.
   (e) *Artery of the pterygoid canal:* This branch runs through the pterygoid canal to supply the pharynx, auditory tube and tympanic cavity.
   (f) *Sphenopalatine branch:* This branch passes through the sphenopalatine foramen to supply the nose.

Applied Anatomy

Osteomyelitis

It is inflammation of the bone and bone marrow and is more common in the mandible than in the maxilla. This is because of the lack of adequate collateral blood supply and the presence of the cortical bone in the mandible whereas the maxilla possesses the cancellous bone with abundant collateral blood supply.

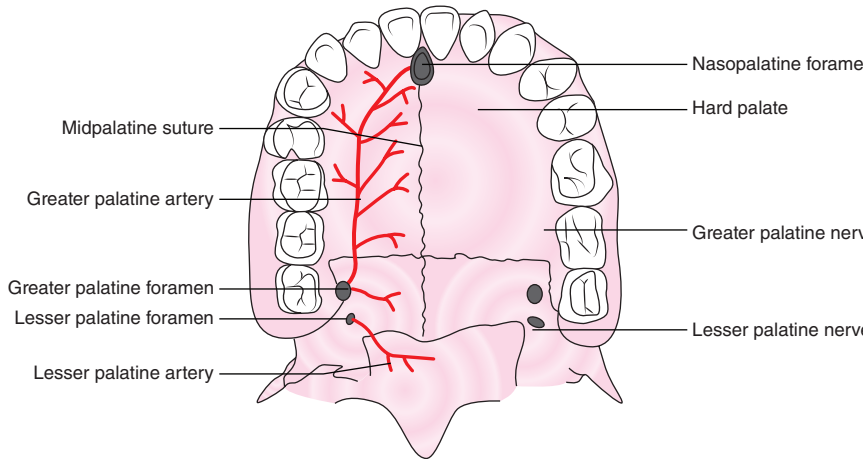


Figure 5.9 Greater and lesser palatine arteries.

Ophthalmic Artery (Fig. 5.10)

Origin A branch of the cerebral part of the internal carotid artery, the ophthalmic artery is given off close to the optic canal.

Course and Relations From its origin, the artery courses forwards to enter the orbit through the optic canal along with the optic nerve enclosed in a common dural sheath. It pierces the sheath after entering the orbit to give rise to numerous branches.

Branches and Regional Supply The ophthalmic artery gives off three main branches, which divide further to supply various structures:

1. **Central branch called the central artery of retina:** This is the first branch of the ophthalmic artery. It is given off within the dural sheath. Initially, it lies inferior to the optic nerve. Later, it pierces the substance of the nerve to reach and supply the optic disc. This is an end artery.

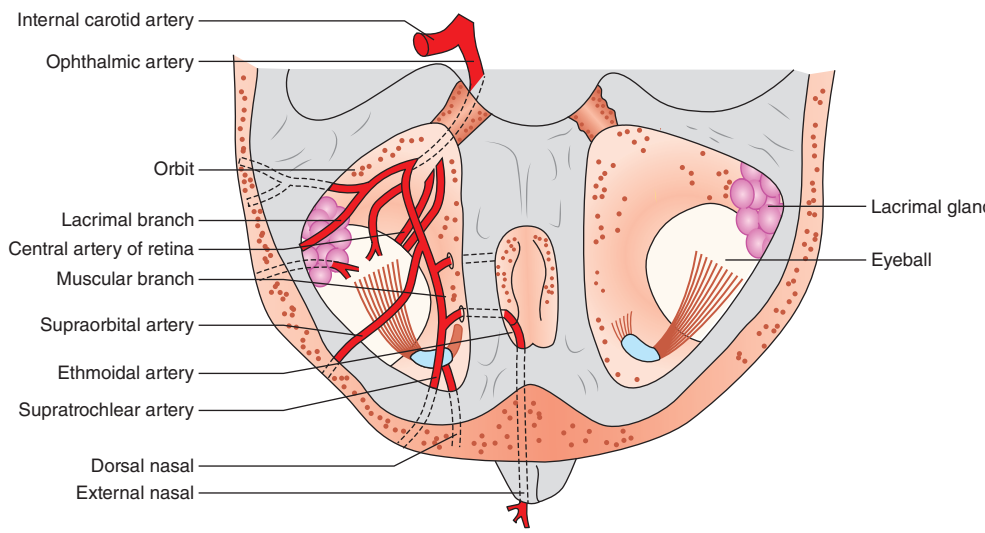


Figure 5.10 Ophthalmic artery—axial section of orbits.

2. **Lateral branch called the lacrimal artery:** This branch is given off after piercing the dural sheath. It runs along the lateral wall of the orbit and divides into numerous branches to supply the following regions:
   (a) *Lacrimal branch:* Lacrimal gland
   (b) *Palpebral branch:* Eyelids
   (c) *Recurrent meningeal branch:* Middle cranial fossa
   (d) *Muscular branches:* Muscles of the orbit
3. **Medial branch called the main trunk:** This branch runs along the medial wall of the orbit and divides into the following branches to supply the corresponding regions:
4. **Central artery of the retina (branch of the ophthalmic artery):** It is an end artery; therefore, obstruction due to an embolus can result in immediate and complete blindness. This condition occurs in old people and is generally unilateral
   (a) *Supratrochlear branch:* Skin of forehead
   (b) *Supraorbital branch:* Skin of forehead
   (c) *Posterior ciliary arteries:* Choroid and iris
   (d) *Anterior and posterior ethmoidal arteries:* Ethmoidal air sinus, part of nose
   (e) *Medial palpebral branch:* Eyelids
   (f) *Dorsal nasal branch:* Dorsum of nose

Other Branches of the External Carotid Artery

The other branches of the external carotid artery which are less significant to the facial region are as follows (**Fig. 5.4**):

1. **Superior thyroid artery:** This branch arises from the anterior surface of the external carotid artery. It traces a downward course along with the external laryngeal nerve to reach the lateral lobe of the thyroid gland. Some of its prominent branches are as follows:
   (a) Superior laryngeal artery
   (b) Sternocleidomastoid branch
   (c) Cricothyroid branch
2. **Occipital artery:** This artery branches out at the same level as the facial artery but from the posterior aspect. It gives off two branches to the sternocleidomastoid muscle.
3. **Posterior auricular artery:** This branch originates from the posterior aspect of the external carotid artery. It runs over the styloid and the mastoid processes to reach the posterior aspect of the auricle. It perfuses the back of the auricle, the skin over the mastoid process, the mastoid antrum and middle ear and the back of the scalp.
4. **Ascending pharyngeal artery:** As the name denotes, this branch ascends to the pharynx from the point of its origin at the medial surface and the lower end of the external carotid artery. It supplies the pharynx, tonsil, auditory tube and middle ear.
5. **Superficial temporal artery:** This is the other terminal branch of the external carotid artery that arises behind the neck of the mandible under the parotid gland. It has a straight ascending course over the zygoma, where it can be palpated. It supplies the scalp, temple, parotid gland, ear, temporalis and facial muscles. Its prominent branches are the transverse facial and middle temporal arteries.

Applied Anatomy

Pulse

The pulses of the superficial temporal and facial arteries can be used for recording the pulse. Anaesthesiologists frequently feel the temporal pulse anterior to the auricle as the artery crosses the zygomatic arch. The facial pulse can be palpated where the facial artery crosses the inferior border of the mandible just anterior to the masseter muscle.

Kiesselbach's Area/Kiesselbach's Triangle

Also called Little's area, it is a region in the anteroinferior part of the nasal septum which is highly vascular. It is a site where five arteries, namely anterior ethmoidal artery, greater palatine artery, sphenopalatine artery, superior labial artery and lateral nasal branch of the facial artery, anastomose to form a vascular network called Kiesselbach's plexus. This is a frequent site of nasal bleeding/epistaxis (**Fig. 5.11**).

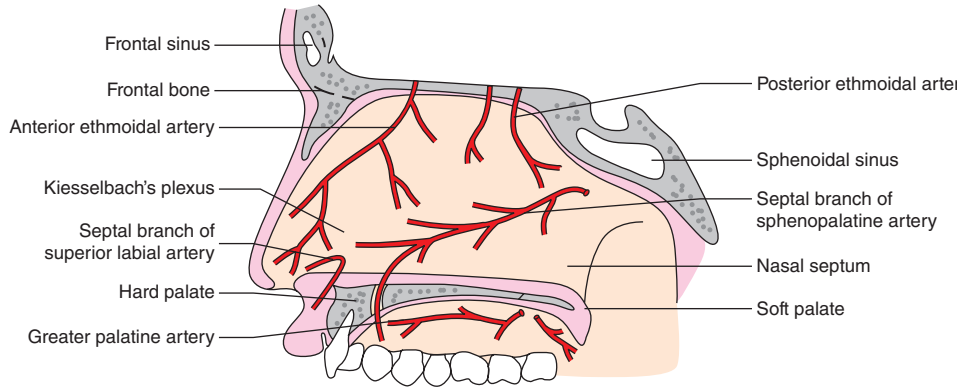


Figure 5.11 Little's area.

VENOUS DRAINAGE OF THE FACE

Features of Facial Veins

1. The predominant draining vessel of the head and neck is the internal jugular vein.
2. Venous drainage from the face is predominantly superficial.
3. Veins of the face accompany the arteries of the face (Fig. 5.12).
4. Veins of the face have no valves
5. Extensive anastomoses exist between veins

Internal Jugular Vein (Fig. 5.13)

Origin

The internal jugular vein (IJV) begins as a continuation of the sigmoid sinus (a specialized vein in the dura mater) at the jugular foramen. It is identified by a dilatation called the superior bulb at the jugular fossa (temporal bone).

Course and Relations

The IJV winds downwards receiving numerous tributaries. It terminates beneath the triangular

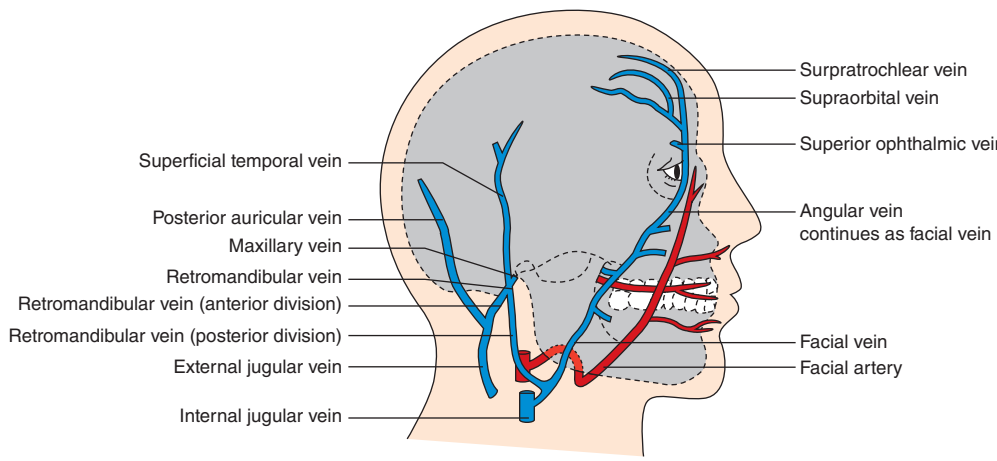


Figure 5.12 Venous drainage of the face.

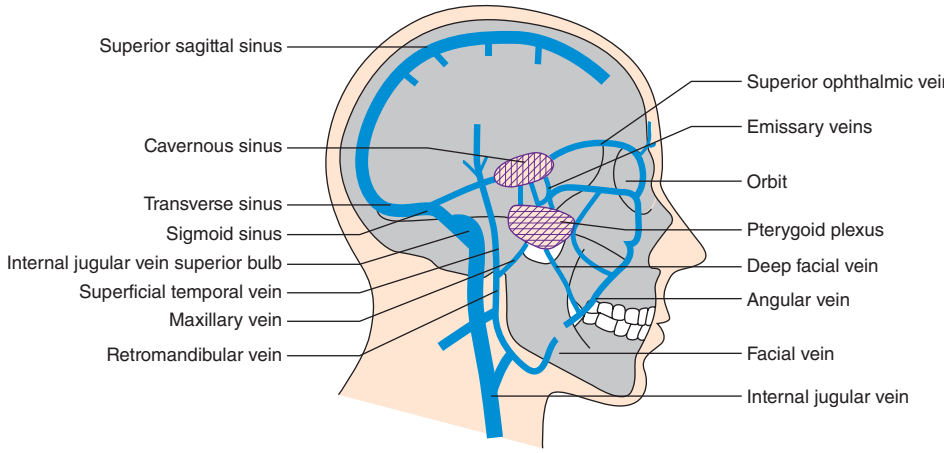


Figure 5.13 Pterygoid plexus.

interval between the sternal and the clavicular head of the sternocleidomastoid muscle, joining the subclavian vein to form the brachiocephalic vein.

Drainage Territory

The IJV receives blood from the brain, face and neck.

Tributaries

1. Inferior petrosal sinus
2. Common facial vein
3. Lingual vein
4. Pharyngeal vein
5. Superior thyroid vein
6. Middle thyroid vein
7. Occipital vein

In addition, the lymphatic ducts open into the junction between the internal jugular and the subclavian veins.

Applied Anatomy

The deep cervical lymph nodes lie adjacent to the IJV; therefore, these are also called jugular nodes. In malignancies, when the nodes get fixed to the vein, the IJV is also excised to prevent the spread of cancer. In some disease states, the venous pressure increases and gets reflected in the jugular vein. It becomes engorged and appears prominently dilated.

Facial Vein (Fig. 5.12)

Origin

The supraorbital and supratrochlear veins unite at the medial canthus of the eye to form the angular vein. This continues downwards as the facial vein in close association with the facial artery.

Course and Relations

The facial vein has a relatively straight course. From the medial corner of the eye, it runs inferiorly to the lower border of the mandible. It crosses the masseter, pierces the deep cervical fascia, reaches the angle of the mandible and joins with the anterior division of the retromandibular vein to form the common facial vein. This in turn drains into the IJV.

Drainage Territory

The facial vein drains scalp, forehead, upper eyelid, external nose, lips, palatine tonsil, submandibular gland and submental structures.

Communications

The facial vein communicates with the cavernous sinus through the superior ophthalmic vein and pterygoid plexus through the deep facial vein (**Fig. 5.13**). Also, the pterygoid plexus communicates with the cavernous sinus through the emissary veins.

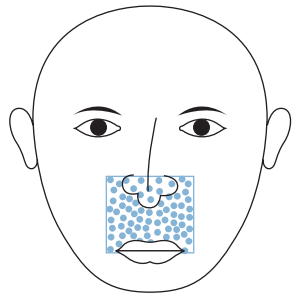


Figure 5.14 Danger area.

Applied Anatomy

The communications of the facial vein can lead to retrograde spread of infection from the face, especially the nose and upper lip to the cavernous sinus of the middle cranial fossa; therefore, this region is called the danger area of the face (**Fig. 5.14**).

Retromandibular Vein (Figs 5.12 and 5.13)

Origin

The retromandibular vein is formed by the union of the superficial temporal and maxillary veins within the parotid gland.

Course and Relations

The retromandibular vein passes downwards through the parotid gland, emerging from its lower border, and divides into two divisions:

1. **Anterior division:** Joins the facial vein to form the IJV
2. **Posterior division:** Pierces the deep fascia and joins the posterior auricular vein to form the external jugular vein

Maxillary Vein (Figs 5.12 and 5.13)

A short vessel that accompanies the first part of the maxillary artery, the maxillary vein is formed by confluence of the veins of the pterygoid plexus. It passes backwards between the sphenomandibular ligament and the neck of the mandible to unite with the superficial temporal vein and form the retromandibular vein.

Pterygoid Plexus (Fig. 5.13)

The prerygoid plexus constitutes a network of very small veins located around and within the lateral pterygoid muscle in the infratemporal region. It is of great significance because of its communications with the other veins. The pterygoid plexus is drained by the maxillary vein.

Communications

The pterygoid plexus communicates with the following veins:

1. Facial vein through the deep facial vein
2. Inferior ophthalmic vein
3. Cavernous sinus (middle cranial fossa) through the emissary veins

Applied Anatomy

Pterygoid plexus acts as a peripheral pump that aids in venous return by the pumping action of the muscle every time the mouth opens. Spread of infection from the pterygoid plexus to the cavernous sinus is possible, which can result in potential life-threatening complications.

Lingual Vein (Fig. 5.7)

Lingual veins are multiple and associated with the lingual artery and the hypoglossal nerve. There are three groups of lingual veins: dorsal lingual, sublingual and deep lingual.

1. **Dorsal lingual vein:** Drains the dorsum and sides of the tongue. It joins the lingual vein which ultimately drains into the IJV.
2. **Sublingual vein:** Located below the tongue, it drains the salivary gland.
3. **Deep lingual vein:** Chief vein of the tongue. It starts inferiorly at the tip of the tongue and runs posteriorly and is visible on the undersurface of the tongue on either side of lingual frenum (**Fig. 5.7b**). It runs posteriorly superficial to the hyoglossus and is joined by the

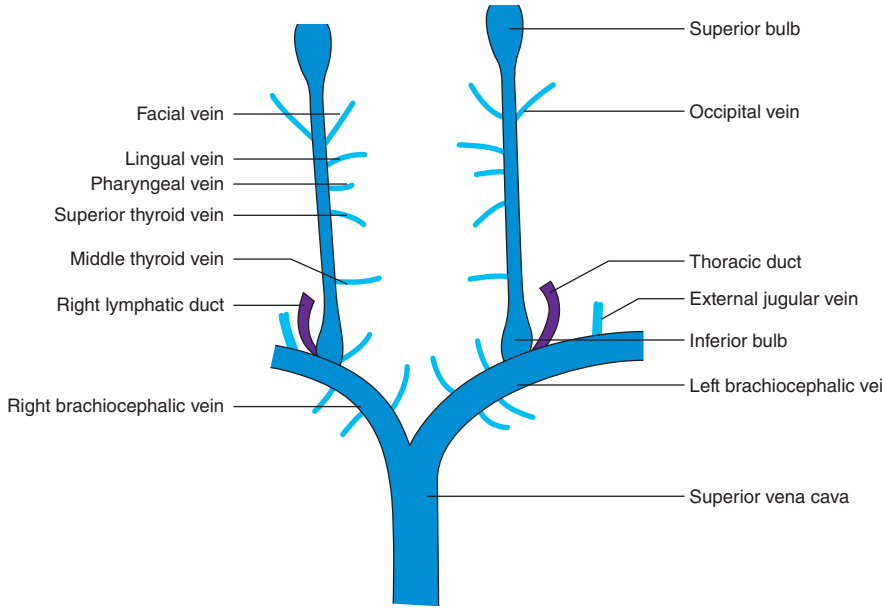


Figure 5.15 Venous drainage of the face and neck.

sublingual vein to form the *vena comitans* or the *ranine vein*.

Lingual veins are tributaries of the IJV; therefore, they ultimately drain either directly into the IJV or sometimes through the common facial vein (**Fig. 5.15**).

External Jugular Vein (Fig. 5.12)

The external jugular vein forms behind the angle of the mandible by the union of the posterior auricular vein and posterior division of the retromandibular vein. It pierces the deep fascia just above the clavicle and drains into the subclavian vein.

Ophthalmic Veins (Figs 5.11 and 5.12)

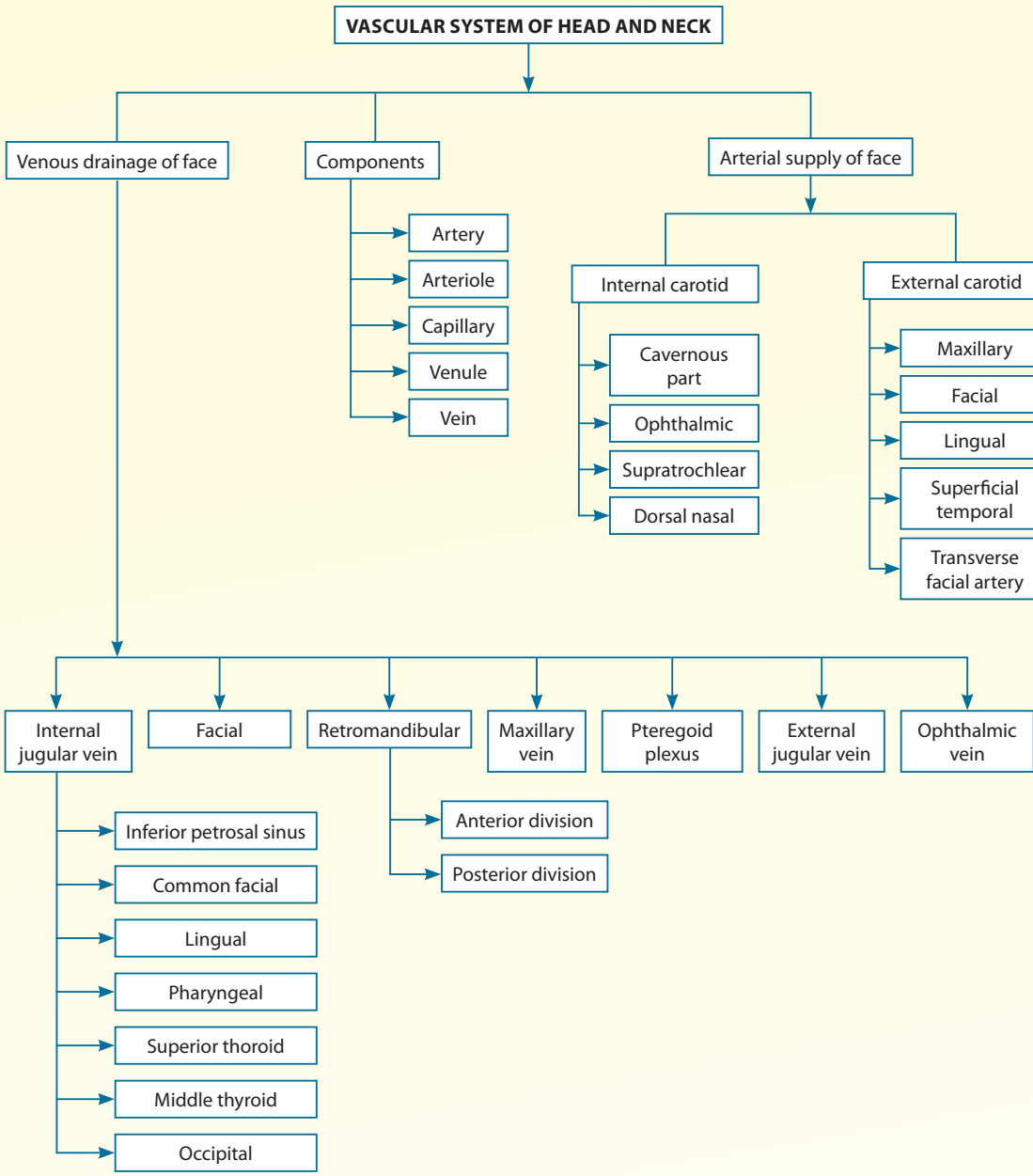
There are two ophthalmic veins and these are closely associated with the optic nerve:

1. **Superior ophthalmic vein:** Lies above the optic nerve. It passes through the superior orbital fissure and drains into the cavernous sinus.
   (a) *Tributaries:* Correspond to branches of the ophthalmic artery
   (b) *Communications:* Supraorbital vein, angular vein
2. **Inferior ophthalmic vein:** Lies below the optic nerve. It passes through the inferior orbital fissure and drains into the cavernous sinus directly or through the superior ophthalmic vein.
   (a) *Tributaries:* From the lacrimal sac, orbital muscles and eyelids
   (b) *Communications:* Cavernous sinus through the inferior orbital fissure

Key Points

1. Arterial supply to the face is mainly by two arteries that are branches of the external carotid artery:
   (a) *Facial artery:* Branch of the external carotid artery
   (b) *Transverse facial artery:* Branch of the superficial temporal artery
2. Some areas of the face are supplied by the branches of the internal carotid artery:
   (a) *Orbital structures:* Ophthalmic artery
   (b) *Skin of forehead:* Supratrochlear and supraorbital branches
   (c) *Eyelids:* Medial palpebral branch
   (d) *Upper part of nose:* Dorsal nasal branch
3. Venous drainage of the face is by the common facial vein.
4. The upper lip and lower part of the nose constitute the danger area of the face. This is because the facial vein which drains these regions is connected to the cavernous sinus present in the cranium through the deep facial vein and pterygoid plexus. Infection can spread from the danger area to the cranium.
5. The retromandibular vein is formed by the union of the superficial temporal and maxillary veins. It splits into two divisions: anterior and posterior.
   (a) *Anterior division*: Unites with the facial vein to form the common facial vein
   (b) *Posterior division*: Unites with the posterior auricular vein to form the external jugular vein
6. Muscles of the eyeball are supplied by the ophthalmic artery (branch of the cerebral part of the internal carotid artery).
7. Arterial supply of the tongue is by the lingual artery (branch of the external carotid artery) and venous drainage is through the deep lingual vein.
8. The maxillary artery is divided into three parts—mandibular, pterygoid and pterygopalatine—on the basis of its relation to the lateral pterygoid muscle.
9. The maxillary artery is a branch of the external carotid artery. It supplies the upper and lower jaws, muscles of mastication, nose and paranasal sinuses and palate.
   (a) *Upper jaw and teeth:* Posterior superior alveolar artery
      - Infraorbital artery
      - Palatine artery
   (b) *Lower jaw and teeth:* Inferior alveolar artery
10. The veins of the face have no valves. They drain into the neck and into the skull; extensive anastomoses exist between facial veins and veins of the cranium. Therefore, infection can spread from the face to the cranium.
11. The pterygoid plexus is a network of veins which lies within and around the lateral pterygoid muscle. It is drained by the maxillary vein. The plexus communicates with the:
   (a) Facial vein
   (b) Cavernous sinus
   (c) Inferior ophthalmic vein

Mind Map


VASCULAR SYSTEM OF HEAD AND NECK
Venous drainage of face
Components
Artery
Arteriole
Capillary
Venule
Vein
Arterial supply of face
Internal carotid
Cavernous part
Ophthalmic
Supratrochlear
Dorsal nasal
External carotid
Maxillary
Facial
Lingual
Superficial temporal
Transverse facial artery
Internal jugular vein
Facial
Retromandibular
Maxillary vein
Pteregoid plexus
External jugular vein
Ophthalmic vein
Inferior petrosal sinus
Common facial
Lingual
Pharyngeal
Superior thoroid
Middle thyroid
Occipital
Anterior division
Posterior division

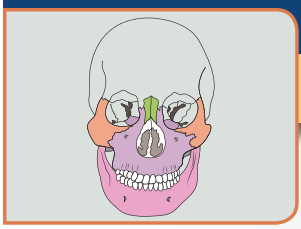
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Multiple Choice Questions

1. The vein that accompanies an artery is called the
   (a) Vena comitans
   (b) Arteriovenous anastomosis
   (c) Capillary
   (d) Venous shunt
2. The artery that carries deoxygenated blood is the
   (a) Pulmonary artery
   (b) Cerebral artery
   (c) Subclavian artery
   (d) Maxillary artery
3. The facial artery is a branch of the
   (a) Internal carotid artery
   (b) External carotid artery
   (c) Cerebral artery
   (d) Superficial temporal artery
4. The maxillary artery is divided into three parts by the
   (a) Buccinator
   (b) Medial pterygoid
   (c) Masseter
   (d) Lateral pterygoid
5. The arterial supply to the lower teeth is by the
   (a) Internal carotid artery
   (b) Infraorbital artery
   (c) Inferior alveolar artery
   (d) Sphenopalatine artery

6. The inferior alveolar artery is a branch of the
   (a) Superficial temporal artery
   (b) Maxillary artery
   (c) Infraorbital artery
   (d) Vertebral artery
7. The muscular branches that supply the muscles of mastication arise from the
   (a) First part of the maxillary artery
   (b) Second part of the maxillary artery
   (c) Third part of the maxillary artery
   (d) Mandibular artery
8. The pterygoid plexus of veins is present
   (a) In the cranial fossa
   (b) Around the lateral pterygoid
   (c) Within the muscles of the tongue
   (d) Within the eye
9. The principal vein of the head is the
   (a) Internal jugular vein
   (b) External jugular vein
   (c) Anterior jugular vein
   (d) Thoracic vein
10. The facial vein drains into the
   (a) Ophthalmic vein
   (b) Internal jugular vein
   (c) Clavicular vein
   (d) External vein
11. Infection of the face reaches the cavernous sinus through the
   (a) Kiesselbach's plexus
   (b) Maxillary artery
   (c) Ophthalmic artery
   (d) Pterygoid plexus
12. Danger area refers to the region involving the
   (a) Eye
   (b) Upper lip and nose
   (c) Floor of the mouth
   (d) Ear
13. The vein formed by the union of the superficial temporal and maxillary veins is the
   (a) Retromandibular vein
   (b) External jugular vein
   (c) Auricular vein
   (d) Subclavian vein
14. Venous drainage of the tongue is by the
   (a) Mandibular vein
   (b) Submandibular vein
   (c) Cervical vein
   (d) Deep lingual vein
15. The confluence of five arteries in the anteroinferior area of the nasal septum is called
   (a) Little's area
   (b) Brittle's area
   (c) Highmore's area
   (d) Burn's area



CHAPTER 6

Lymphatics of the Head and Neck

Overview

The lymphatic system is part of the immune apparatus of the body that is anatomically and physiologically related to the circulatory system. It consists of a network of vessels carrying fluid called lymph from the tissues to the veins of the circulatory system. Lymphatic tissue is widely distributed throughout the body to perform various vital functions. The lymphatic system is composed of lymphatic capillaries, vessels, nodes, ducts and lymphoid tissue. Lymph nodes are small, bean-shaped anatomical structures usually present as clusters embedded in fibrofatty tissue along the course of lymphatic vessels that are generally about 0.5–2.5 cm in size and not palpable under normal circumstances. Microscopically, the lymph node is composed of the outer cortex, inner medulla and hilum. The inner medulla hosts the lymphocytes. Multiple afferent vessels enter the node through the cortex and a single efferent vessels leave the node through the hilum. The lymphatic drainage of the head and neck region is carried through the superficial and peripheral lymph nodes which eventually drain into the deep cervical lymph nodes located in proximity through the course of the internal jugular vein.

INTRODUCTION

The lymphatic system is part of the immune apparatus of the body that is anatomically and physiologically related to the circulatory system. It consists of a network of vessels carrying fluid called lymph from the tissues to the veins of the circulatory system. Lymphatic tissue is widely distributed throughout the body to perform various vital functions.

The movement of lymph along the lymphatic channels is by either the inherent contractions of the lymphatic vessels or the compression of the lymphatic vessels by the contractions of surrounding skeletal muscles.

Because of their relevance in the practice of dentistry, this chapter focuses on the anatomy of the lymph nodes located in the head and neck region. It is of great clinical significance that one-third of the body's lymphatic tissue is located in the head and neck region. As an exception, in the head and neck region, lymphatics are absent in the cornea, the central nervous system, skin and bones.

STRUCTURAL COMPONENTS OF THE LYMPHATIC SYSTEM

The anatomical subunits of the lymphatic system and their individual functions are as follows (**Fig. 6.1**):

1. **Lymphatic capillaries:** These are microscopic, close-ended, porous tubes that form an extensive network in the intercellular spaces within most tissues. They lie very close to the arterial capillaries, which exude tissue fluid into intercellular spaces. The permeability of lymphatic capillaries facilitates entry of tissue fluid into them from intercellular spaces. The tissue fluid entering these lymphatic capillaries is called *lymph*.
2. **Lymphatic vessels (afferent):** These are vessels that collect unfiltered body fluids from lymphatic capillaries and present to the lymph nodes for the filtration process.
3. **Lymph nodes:** A lymph node is a structured collection of lymphoid tissue through which the lymph passes before entering the blood stream. Lymph contents undergo major modification in the nodes. In addition, lymph nodes are sites of production of B lymphocytes which play a significant role in the defence

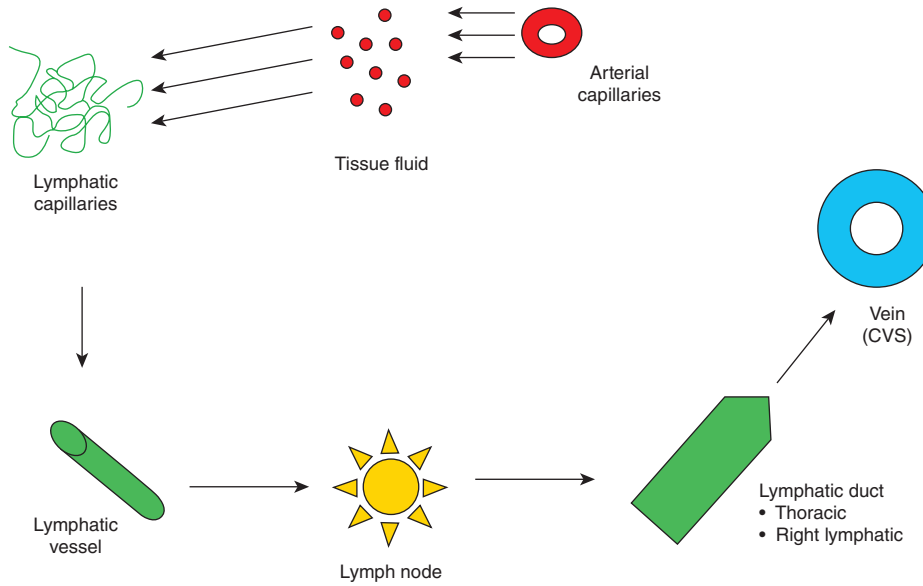


Figure 6.1 Lymphatic network.

mechanism of the body. Lymph nodes are located at multiple sites along the lymphatic system. Several afferent lymph vessels deliver lymph to lymph nodes, whereas drainage is done by a single efferent lymph vessel.

Applied Anatomy

Lymphadenitis

It is defined as inflammation of lymph nodes. The most common cause of lymphadenitis is microbial infection.

Lymphadenopathy

It is the enlargement of lymph nodes. It may be localized to one region or generalized to the whole body. The causes may be infection, autoimmunity or tumour related. The enlargement of size is due to increased production of B lymphocytes.

Metastasis

It is defined as spread of cancer cells through local invasion, blood stream or lymph nodes. Tumours of the head and neck region commonly spread to cervical lymph nodes.

4. **Lymphatic vessels (efferent):** These vessels collect lymph from lymph nodes after filtration and empty these into the bigger lymph channels called lymphatic ducts.

Applied Anatomy

Lymphangitis

Inflammation of lymph vessels is called lymphangitis. Signs and symptoms are reddening of the skin, localized warmth and painful enlargement of adjacent lymph nodes.

Lymphoedema

Blockage of a lymph vessel leads to obstruction of flow of lymph which results in localized collection of fluids in the tissues, producing swelling. This clinical condition is called *lymphoedema*. Oedema can lead to tissue death and related complications.

5. **Lymphatic ducts:** These are the principal ducts of lymphatic drainage. They receive lymphatic drainage from the efferent lymphatic vessels and are two in number:
   (a) Lymph from the left side of the head and neck drains into the thoracic duct. This is the larger of the two, and it finally drains into the left subclavian vein.

(b) Lymph from the right side of the head and neck drains into the right lymphatic duct. This is smaller and drains into the right subclavian vein.

Lymphatic ducts contain valves that prevent backflow of lymph.

6. **Lymphoid tissue associated with lymphatic system:** Lymphoid tissue refers to tissues involved in immune functions. They comprise connective tissue filled with defence cells (lymphocytes). The lymphoid tissue may be primary or secondary, on the basis of the stage of lymphocyte development:
   (a) Primary lymphoid organs generate lymphocytes from immature progenitor cells (e.g. thymus, bone marrow)
   (b) Secondary lymphoid organs maintain mature lymphocytes and are sites of lymphocyte activation by antigen (e.g. lymph nodes [B lymphocytes], tonsils, spleen, adenoids)

SIGNIFICANCE OF THE LYMPHATIC SYSTEM

The lymphatic system performs the following three fundamental functions:

1. **Fluid homeostasis:** Lymphatic capillaries lie in close proximity to blood capillaries. When the circulatory blood reaches the tissues at the capillary level, a small quantity enters the surrounding tissues as tissue fluid. The lymphatic capillaries take up excess of tissue or interstitial fluid and return it to the bloodstream through lymphatic ducts (**Fig. 6.1**). Failure of uptake of tissue fluid by lymphatics can lead to stasis, thus impairing fluid balance.
2. **Defence:** Lymph nodes contain lymphocytes that help in defending the body against disease-causing agents. Nodes act as filters of microbes present in lymph.
3. **Fat assimilation:** The lymphatic capillaries (called *lacteals* in the intestinal villi) absorb fat from the digestive tract and carry it to the blood stream (through the thoracic duct) where they get acted upon by enzymes (**Fig. 6.1**). Later, they are taken to the liver for further digestion and assimilation.

ANATOMY OF LYMPH NODES

Gross Anatomy

Lymph nodes are small, bean-shaped anatomical structures usually present as clusters embedded in fibrofatty tissue along the course of lymphatic vessels. They are generally about 0.5–2.5 cm in size and not palpable (not felt by fingers under the skin) under normal circumstances. They become palpable when they become enlarged in some disease states. Palpation of lymph nodes provides valuable information regarding the presence or absence of disease and the prognosis.

Lymph nodes are encapsulated secondary lymphoid tissues which are major centres of lymphocyte differentiation.

Applied Anatomy

Clinical Examination of Lymph Nodes

This is done by digital palpation and is very important in diagnosing the diseases related to lymph nodes. Healthy lymph nodes are not palpable and not sensitive to touch; however, in some disease states, they increase in size and become painful, which can be appreciated by palpation. The enlargement of size is due to increased production of B lymphocytes. Changes observed in lymph nodes can indicate underlying disease processes. When the nodes are soft, tender and mobile, it usually denotes infection, whereas lymph nodes which are fixed and rubbery indicate malignancy or metastatic involvement. Matting of nodes is seen in conditions such as tuberculosis.

Microscopic Anatomy (Fig. 6.2)

On cross-section, lymph nodes contain two major parts:

1. **Cortex:** The outermost portion of the node that contains the lymphoid follicles.
2. **Medulla:** The innermost region of node which contains blood vessels and plasma cells which produce antibodies.

A depression called *hilum* is present on the surface of the lymph node, which makes the lymph node bean shaped. The afferent lymph vessels which bring tissue fluid from tissues are

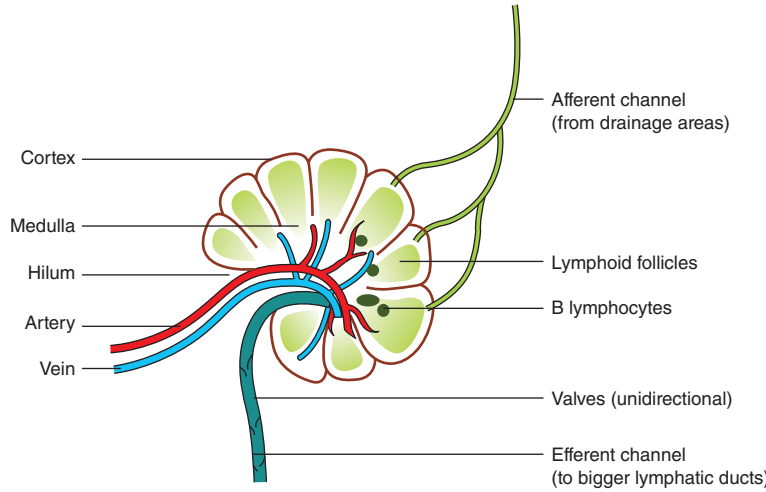


Figure 6.2 Lymph node architecture.

multiple in number and enter the nodes on their convex surface. The efferent lymph which drains the lymph node is single and emerges out through the hilum. The arteries and veins supplying the lymph node enter and exit through the hilum.

B lymphocytes are present in the lymphoid follicles and act against the microbes brought into the lymph node through lymph.

CLASSIFICATION OF LYMPH NODES

The lymphatic tissue of the head and neck is grossly divided into the adenoid tissue and lymph nodes:

1. **Adenoid tissue:** The adenoid tissue of the head and neck region is an aggregation of lymphoid tissue which protects the entrance of the alimentary and respiratory tracts. It is a circular arrangement referred to as the lymphatic or *Waldeyer's ring*. This is discussed in detail later in this chapter.
2. **Lymph nodes:** They are categorized on the basis of certain criteria stated below:
   (a) *On the basis of location* (**Figs 6.3** and **6.4**)
   - *Superficial/peripheral*: Nodes that drain anatomical regions superficial to the body; superficial nodes are further divided as nodes of the neck and nodes of the head
   - *Deep/central*: Nodes that drain deeper anatomical regions

   (b) *On the basis of the arrangement of nodes*
   - *Circular/horizontal*: Groups of interconnected nodes positioned as a ring

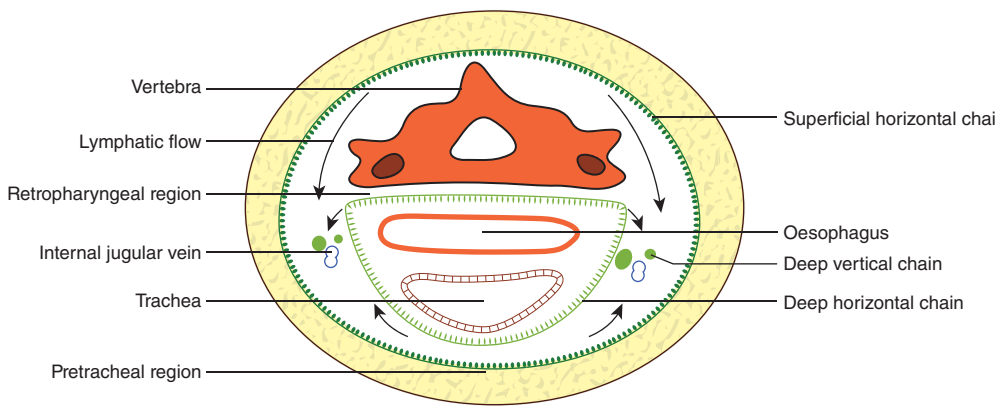


Figure 6.3 Cross-section showing lymph nodes at the level of the neck.

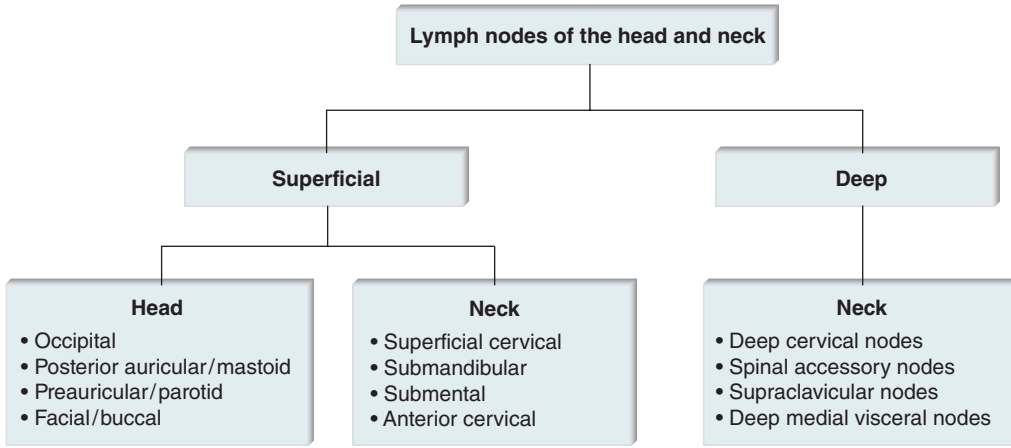


Figure 6.4 Lymph nodes of the head and neck—classification based on location.

- *Vertical*: Groups of nodes positioned as a vertical chain

(c) *On the basis of their drainage type*
- *Primary*: These are superficial nodes that receive drainage first from an anatomical site.
- *Secondary*: These are deeper nodes that receive drainage from primary nodes.
- *Sentinel*: These are the first nodes which receive lymphatic drainage from a malignant tumour. This term is generally used in relation to clinical management of cancers.

(d) *On the basis of clinical staging* (*see* **Fig. 6.6**): This is a classification used worldwide to represent nodes at different anatomic levels. Clinically, the involvement of nodes or changes in nodal architecture in cancer patients indicate the extent of disease and its progression. The status of the nodes also helps in determining the prognosis as well as treatment planning. The nodes are grouped into levels from 1 to 5 as stated below:
- *Level 1* (nodes in the submandibular triangle): These are nodes arranged in a triangle bounded by the anterior and posterior belly of the digastric muscle and inferior border of the mandible; submental nodes are also included in level 1.
- *Level 2* (nodes in the upper jugular region): These are the nodes that lie around the upper portion of the internal jugular vein and upper spinal accessory nerve; this level extends superoinferiorly from the skull base to the bifurcation of carotid artery.
- *Level 3* (nodes in the middle jugular region): These are the nodes that lie around the middle third of the internal jugular vein; these nodes are present from the inferior border of level 2 to the omohyoid muscle.
- *Level 4* (nodes in the lower jugular region): These are the nodes that lie around the inferior third of the internal jugular vein; these nodes are scattered from the inferior border of level 3 to the clavicle.
- *Level 5* (nodes in the posterior triangle): These nodes are present in the posterior triangle, bounded by the sternomastoid, trapezius and omohyoid muscles.

LYMPHATIC DRAINAGE OF THE HEAD AND NECK

For ease of understanding, the lymphatic drainage of the head and neck has been explained in the following text. The drainage is by two chains of lymph nodes (**Figs 6.3–6.5**):

1. **Circular chain**

(a) Superficial circular chain
- Submental
- Submandibular
- Superficial parotid

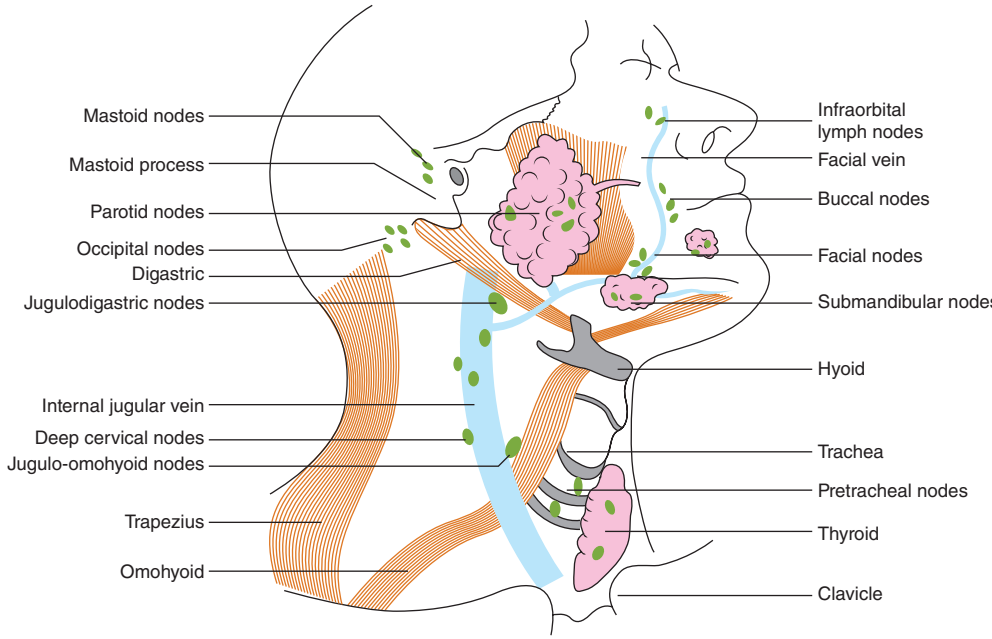


Figure 6.5 Lymph nodes of the face.

- Deep parotid
- Mastoid
- Occipital

(b) Deep circular chain
- Retropharyngeal
- Pretracheal and paratracheal
- Prelaryngeal

2. **Deep vertical chain:** These are the deep cervical nodes situated along the length of internal jugular vein.
   - Jugulodigastric
   - Jugulo-omohyoid
   - Other deep cervical nodes

To summarize, the entire lymph from the head and neck drains ultimately into deep cervical nodes, either directly or through superficial or peripheral nodes.

Submandibular Lymph Nodes (Fig. 6.5)

Submandibular lymph nodes lie in the submandibular triangle bounded by the anterior and posterior belly of digastric muscles (**Figs 6.6** and **6.7**). They are present over the surface of the gland; however, some are located within the gland substance.

Submental Nodes (Fig. 6.7)

Submental nodes are present in the submental triangle below the chin. They overlie mylohyoid and are situated between the two anterior bellies of the digastric muscle.

Jugulodigastric Nodes (Fig. 6.5)

Jugulodigastric nodes lie below the posterior belly of the digastric muscle, between the angle of the mandible and anterior border of the sternomastoid. They are the main nodes draining the tonsils.

Jugulo-Omohyoid Nodes (Fig. 6.5)

Jugulo-omohyoid nodes belong to the postero-inferior group of the deep cervical chain. They lie just above the intermediate tendon of the omohyoid, under the cover of the sternomastoid. These nodes constitute the main lymph nodes of tongue (**Fig. 6.8**).

Facial Nodes/Nodes of Stahr (Fig. 6.5)

This group of nodes encompasses three subgroups: infraorbital, buccal and mandibular (**Fig. 6.5**).

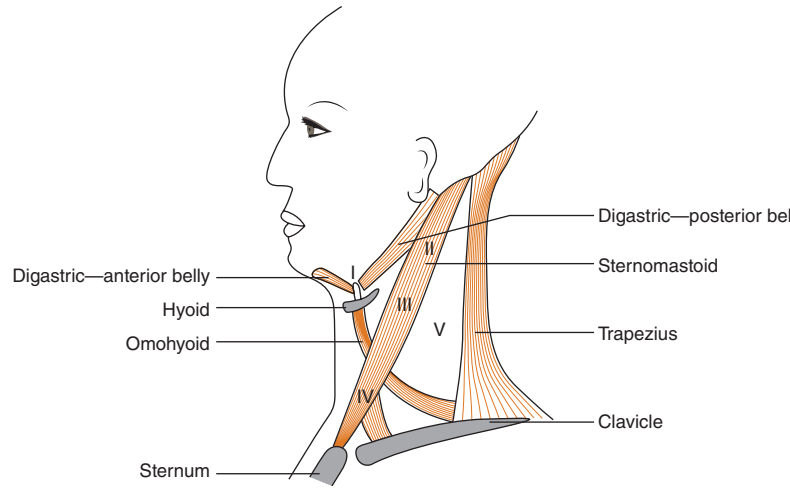


Figure 6.6 Clinical grouping of nodes.

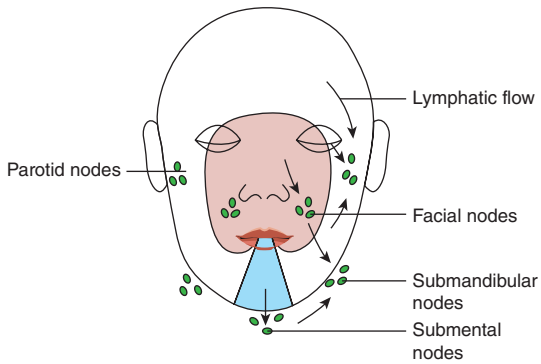


Figure 6.7 Lymphatic drainage of the face.

Infraorbital nodes are scattered near the infraorbital region. Buccal lymph nodes lie on the buccinator muscle. The mandibular nodes are at the lower border of the mandible, near the anterior inferior angle of the masseter, in close relation to the facial artery. They drain part of the cheek and lower eyelid. Their efferents pass to the anterosuperior group of deep cervical nodes.

Mastoid Nodes (Fig. 6.5)

Mastoid nodes lie over the mastoid process, superficial to the sternomastoid muscle. They drain the scalp just above and behind the auricle, upper half of the medial surface and margin of the auricle and posterior wall of external acoustic meatus. Efferents pass through posterior superior group of deep cervical nodes.

Occipital Nodes (Fig. 6.5)

Occipital nodes lie in the apex of the posterior triangle superficial to the attachment of

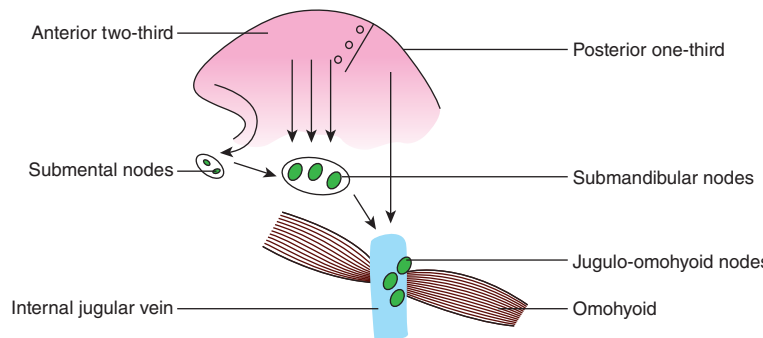


Figure 6.8 Lymphatic drainage of the tongue.

trapezius. They drain the occipital region of the scalp. Efferents pass through the supraclavicular member of the posteroinferior group of the deep cervical nodes.

Superficial and Deep Parotid Nodes (Fig. 6.7)

The superficial parotid nodes lie over the parotid capsule. They drain the eyelids, temples, prominence of the cheek and ears. The efferents drain into the deep parotid or deep cervical nodes. The deep parotid nodes are present within the gland and drain the middle ear, soft palate and posterior nasal cavity. The efferents drain into the deep cervical nodes.

Superficial Cervical Nodes

The superficial cervical nodes lie on the external jugular vein, superficial to the sternomastoid muscle. They drain the lobule of auricle, skin over the lower parotid region and the angle of jaw. Efferents reach upper and lower deep cervical nodes.

Retropharyngeal Nodes

The retropharyngeal nodes lie in front of the prevertebral fascia and drain the pharynx and hard palate. Efferents pass to the upper deep cervical nodes.

The lymphatic drainage of specific anatomical units of head and neck is described in **Table 6.1**.

Table 6.1 Lymphatic Drainage of the Face

Anatomical Site	Specific Site	Draining Lymph Nodes	
		Primary	Secondary
Eyelids	–	Superficial parotid	Deep cervical
Nose	Anterior region	Submandibular nodes	
	Posterior region	Deep cervical	
Soft palate	–	Deep parotid	
Tongue	Tip	Submental nodes	Jugulo-omohyoid
	Anterior two-third, lateral region	Submandibular nodes	
	Anterior two-third, medial region	–	
	Posterior one-third	Retropharyngeal nodes	
Tonsil	–	–	Jugulodigastric
Floor of mouth	–	Submandibular	Deep cervical
Face	Forehead	Superficial and deep parotid lymph nodes	
	Eyelids (lateral part)		
	Cheek (lateral part)		
	Conjunctiva		
	Face between eyes	Submandibular	
	Eyelids, medial part		
Lip	Upper lip	Submandibular	
	Lower lip (lateral part)	Submandibular	
	Lower lip (central part)	Submental	Submandibular
Scalp	–	Mastoid	Deep cervical
Larynx, pharynx, trachea, oesophagus	–	Pretracheal, paratracheal, prelaryngeal, infrahyoid	

WALDEYER'S RING

Waldeyer's ring refers to the anatomical unit comprising a group of lymphoid tissue arranged in the form of a ring and located in the pharynx as well as the posterior aspect of the oral cavity. Also called *Waldeyer–Pirogov tonsillar ring* or the MALT (mucosa-associated lymphoid tissue), this lymphoid tissue appears a few months after birth, becomes prominent during the growth phase and progressively involutes from the time of puberty.

Waldeyer's ring functions as the first level of defence against micro-organisms from the oral and nasal cavity and prevents the spread of infection into the deeper parts of respiratory tract such as the larynx, trachea and lungs.

The lymphoid ring consists of the following (**Fig. 6.9**):

1. Pharyngeal tonsil (also known as adenoids)
2. Two tubal tonsils: Right and left (where the Eustachian tube opens in the nasopharynx)
3. Two palatine tonsils: Right and left (commonly called 'the tonsils'/faucial tonsils)
4. Lingual tonsil

Applied Anatomy

Adenoids

Enlargement of the pharyngeal tonsils presenting in the posterior wall of pharynx is called adenoids. It occurs when there is hypertrophy of tonsils due to infection. This can lead to obstruction of airflow from the nose into the nasopharynx which eventually leads to difficulty in respiration.

Tonsillectomy

The tonsils are often infected in younger people and undergo reactive hypertrophy. Such cases are managed by excision of the tonsils by a procedure called tonsillectomy.

The arrangement of the lymphoid masses is as follows (**Fig. 6.10**):

1. **Superiorly:** The pharyngeal tonsil at the roof and the posterior wall of the nasopharynx
2. **Inferiorly:** The lingual tonsil on the dorsum of the posterior third of the tongue
3. **Laterally:** The palatine tonsils, in the crypt between the palatoglossal and palatopharyngeal arches

The efferent lymphatics from Waldeyer's ring drain into the upper deep cervical lymph nodes.

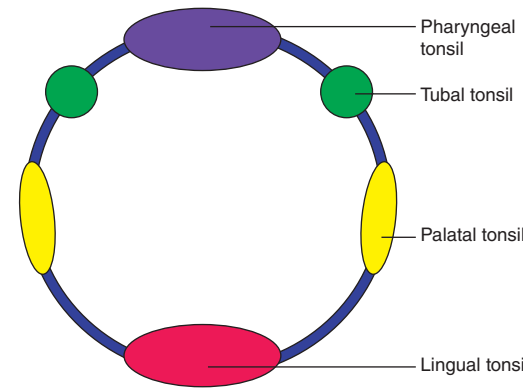


Figure 6.10 Waldeyer's ring showing arrangement of the lymphoid masses.

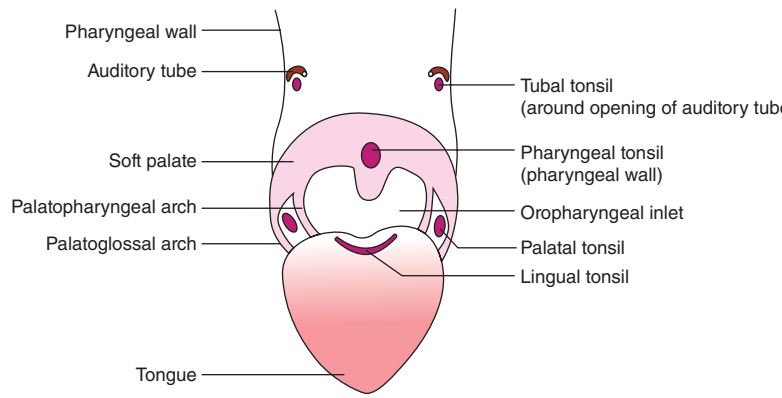


Figure 6.9 Schematic diagram of Waldeyer's ring.

CLINICAL CONSIDERATIONS

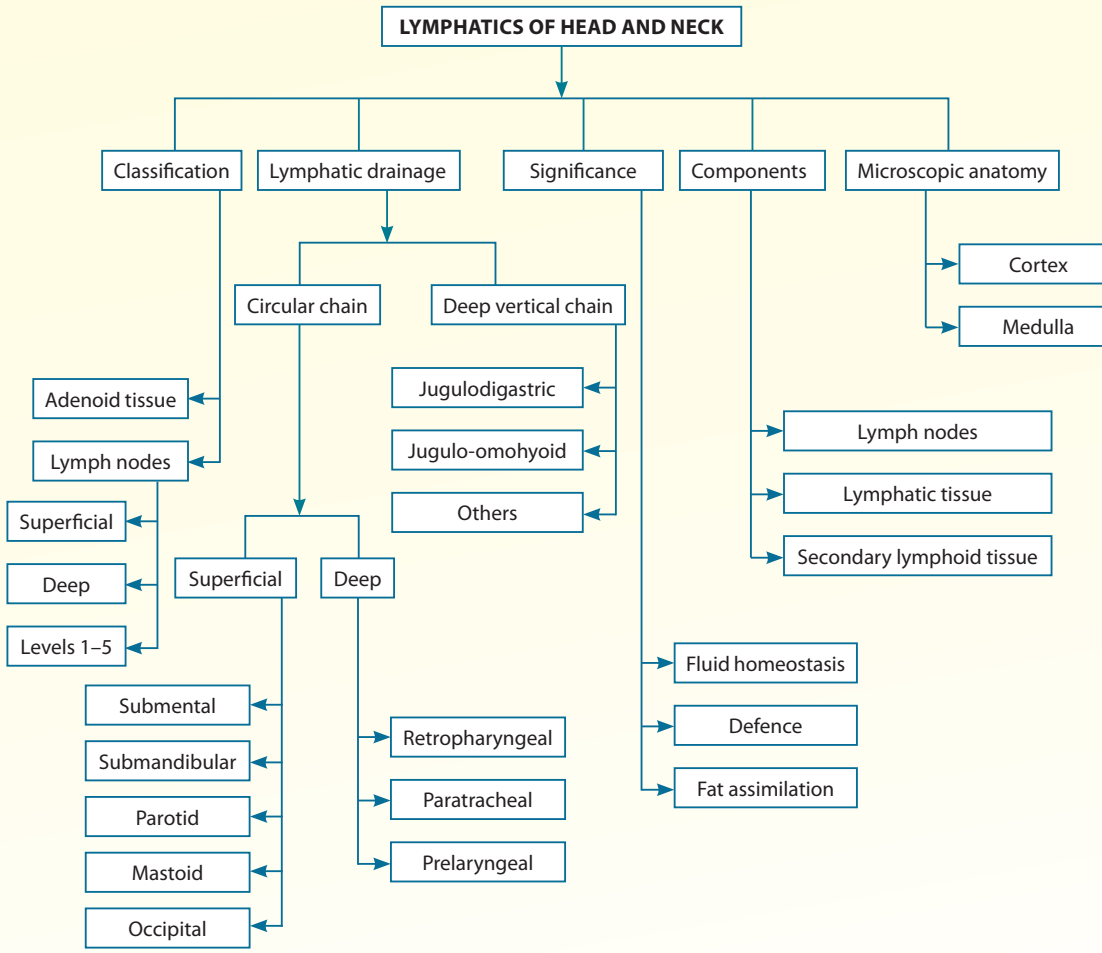
1. **Sentinel lymph node biopsy:** It is the examination of the first lymph node that receives lymphatic drainage from a tumour site by surgically obtaining tissues from nodes. It is a standard histopathologic technique done to determine whether the sentinel node is invaded by tumour cells. If the sentinel node contains tumour cells, removal of more nodes in the adjoining area becomes necessary. If the sentinel node is normal, it rules out the necessity for extensive dissection of the regional lymph nodes.
2. **Neck dissection:** Entry of cancer cells into the lymph nodes is the most important factor in the spread of the disease and in reducing the survival rate of patients. To control or cure spread of cancer cells, surgeries are performed to remove lymph nodes from the side of the neck into which cancer cells may have migrated. Such surgeries are called neck dissections. Submandibular lymph nodes are present over the surface of the gland and some within the gland substance. This is the reason behind removal of the submandibular gland during neck dissections, as removal of lymph nodes containing the tumour cells is the objective.

Key Points

1. Lymphatics carry tissue fluid from the tissues to the veins for recirculation. The lymphatic flow is unidirectional. Lymph channels possess valves that prevent backward flow of lymph. Lymphatic vessels begin as lymphatic capillaries and constitute a one-way system.
2. The movement of lymph within lymphatic capillaries is dependent on skeletal muscle contraction.
3. The lymphatic flow is as follows: lymph → lymphatic capillaries → small lymph vessels → afferent lymph vessel → lymph node → efferent lymph vessel → lymphatic duct → subclavian vein → heart.
4. Lymph nodes are secondary lymphoid organs and are the major sites of production of B lymphocytes.
5. The three major functions of lymphocytes are as follows:
   (a) Fluid balance
   (b) Defence against diseases
   (c) Fat absorption
6. Examination of lymph nodes plays a very important role in diagnosis and prognosis of diseases.
7. Lymph from the lymphatic vessels finally drains into bigger lymphatic ducts. To the left side of the head and neck is the thoracic duct and to the right side is the lymphatic duct.
8. The largest lymphoid organ is spleen.
9. The largest lymphatic vessel is the thoracic duct.
10. In the head and neck area, lymphatics are absent in the
    (a) Cornea
    (b) Central nervous system
    (c) Superficial skin
    (d) Bones
11. The lymph nodes of the head and neck area are divided into superficial and deep lymph nodes. Superficial nodes are submandibular, sublingual, parotid, mastoid and occipital nodes. Deep nodes are retropharyngeal, pretracheal, prelaryngeal and cervical nodes.
12. Knowledge of drainage areas of lymph nodes is very important because it helps in understanding the spread of infection or cancer. Also, it helps in localizing the origin and course of the disease process.

13. The entire lymph from the head and neck drains ultimately into deep cervical nodes either directly or through superficial or peripheral nodes.
14. The drainage areas of nodes of the head and neck are as follows:
    (a) *Teeth:* Submandibular nodes
    (b) *Upper lip:* Submandibular nodes
    (c) *Lower lip:* Submental nodes
    (d) *Tip of the tongue:* Submental nodes
    (e) *Anterior two-third of tongue—lateral region:* Submandibular nodes
    (f) *Anterior two-third of tongue—medial region:* Deep cervical nodes
    (g) *Posterior one-third of tongue:* Retropharyngeal nodes
    (h) *Anterior region of nasal cavity:* Submandibular nodes
    (i) *Posterior region of nasal cavity:* Deep cervical nodes
15. Waldeyer's ring protects the oropharynx and nasopharynx and includes the following lymph nodes: two palatine tonsils, two tubal tonsils, one lingual tonsil and one pharyngeal tonsil.

Mind Map



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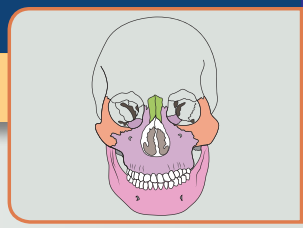
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Multiple Choice Questions

1. Lymphatic vessels on the left side of the head and neck finally drain into the
   (a) Thoracic duct
   (b) Artery
   (c) Submandibular gland
   (d) Lymphatic duct
2. One of the following is not a lymphoid organ:
   (a) Tonsils
   (b) Thymus
   (c) Spleen
   (d) Lungs
3. Functions of lymph nodes are all except
   (a) Fluid balance
   (b) Production of lymphocytes
   (c) Production of RBCs
   (d) Fat digestion
4. Normal lymph nodes are
   (a) Palpable
   (b) Not palpable
   (c) Painful
   (d) Not encapsulated
5. Lymph nodes
   (a) Are primary lymphoid tissue
   (b) Are secondary lymphoid tissue
   (c) Produce RBCs
   (d) Produce platelets
6. Level 1 nodes are found in
   (a) The submandibular triangle
   (b) The posterior triangle
   (c) Front of the parotid
   (d) Front of the trachea

7. Parotid nodes belong to the following chain of nodes:
   (a) Deep horizontal
   (b) Superficial circular
   (c) Waldeyer's ring
   (d) Vertical chain
8. The lymph nodes of the tongue are
   (a) Jugulodigastric
   (b) Jugulo-omohyoid
   (c) Submental
   (d) Parotid
9. The common name of 'nodes of Stahr' is
   (a) Submental nodes
   (b) Parotid nodes
   (c) Occipital nodes
   (d) Facial nodes
10. The group of nodes which does not form a part of Waldeyer's ring is the
    (a) Pharyngeal tonsil
    (b) Lingual tonsil
    (c) Tubal tonsil
    (d) Laryngeal tonsil
11. The total number of lymphoid components in Waldeyer's ring is
    (a) 4
    (b) 5
    (c) 6
    (d) 3
12. Palatine tonsils finally drain to the
    (a) Jugulodigastric nodes
    (b) Submandibular nodes
    (c) Submental nodes
    (d) Parotid nodes
13. The lymph nodes of the upper lip are
    (a) Parotid
    (b) Submandibular
    (c) Cervical
    (d) Buccal
14. When a lymph node is rubbery and fixed to the underlying structures, it is most likely to be
    (a) A tumour
    (b) An infection
    (c) A congenital defect
    (d) The presence of a foreign body
15. Enlargement of lymph nodes is called
    (a) Lymphadenitis
    (b) Lymphoma
    (c) Lymphadenopathy
    (d) Lymphoedema

CHAPTER 7



Anatomy of Salivary Glands

Overview

Salivary glands are compound, exocrine, tubuloacinous and merocrine in nature. They can be classified into mucous, serous or mixed glands based on the secretion. Based on the size and location, salivary glands are classified into major and minor salivary glands. Parotid, submandibular and sublingual glands constitute the major salivary glands. Anatomically, parotid gland and submandibular glands are characteristic with their own capsules and a major duct of excretion, namely Stenson's duct and Wharton's duct, respectively. Sublingual glands are devoid of its own capsule and possess multiple ducts namely ducts of Rivinus. Apart from the capsule and the ducts, each of the major salivary glands possess specific boundaries, anatomical relationships, neurovascular supply and lymphatic drainage. Through knowledge of the anatomy of these glands are prudent for a dental surgeon.

INTRODUCTION

Salivary glands constitute a set of organs that synthesize and liberate a fluid called saliva into the oral cavity that is of paramount importance for numerous physiologic functions. The salivary glands in humans have a wide range of activities from simple deglutition to more complex immune activities. These glands are a complex network of hollow tubes and sacs which comprise the basic secretory and storage units of saliva. They are of various types and present in multiple locations in and around the oral cavity.

A thorough understanding of the structural and functional anatomy of the glands enables accurate diagnosis and appropriate medical as well as surgical management of salivary gland disorders (**Table 7.1**).

Table 7.1 Study of Salivary Glands—Various Modalities

Type of Anatomical Study	Method/Armamentarium	Salivary Structures Studied
Macro/gross	Study by cadaveric/surgical dissection or palpation in living	Structures that may be observed or palpated beneath the skin, e.g. gland extent, related blood vessels, muscles, nerves
Micro	Study of specimens under a microscope	Acini, ducts (cells/tissues)
Radiologic	Study of glands in living using imaging techniques such as ultrasonography, magnetic resonance imaging, computed tomography and sialography	Salivary glands and related structures in deeper planes as in their natural position
Clinical	Correlating clinical symptoms to the gland anatomy	Functional anatomy, e.g. relating dryness of mouth to acinar atrophy
Comparative	Comparison of features in different species	Gross anatomy and microanatomy

GENERAL CHARACTERISTICS OF SALIVARY GLANDS

Salivary glands are of different types depending on the site, type of secretion and function. However, the following features are uniform to all types of salivary glands (**Box 7.1**):

1. **Compound:** Based on their structure, salivary glands are classified as compound because they are composed of branching duct systems. (Glands without branches are called simple glands, e.g. sweat glands and gastric glands.)
2. **Tubular:** Salivary glands have tube-shaped secretory units and are hence classified as tubular.
3. **Acinous:** Salivary glands are classified as acinous because they have secretory units in the form of a cluster or group.
4. **Exocrine:** Salivary glands are termed *exocrine* because their secretions are poured into the oral cavity through extraglandular ducts. (On the contrary, endocrine or ductless glands pour their secretions directly into the bloodstream, e.g. thyroid and adrenal glands.)
5. **Merocrine:** Salivary glands discharge only the secretory product and maintain the secretory cell intact and are hence known as merocrine glands. This is in contrast to other types of glandular secretions such as apocrine, in which the secretory products become concentrated at the free end of the secreting cell and are expelled along with a portion of the cytoplasm (e.g. mammary gland), or holocrine, in which the entire cell forms the secreted matter of the gland (sebaceous glands).

Box 7.1 Salivary Glands: General Features

- Compound
- Exocrine
- Tubuloacinous
- Merocrine

CLASSIFICATION OF SALIVARY GLANDS

Salivary glands are classified and named according to the:

1. Size and location
2. Nature of the secretion

On the basis of the size and location, the salivary glands are categorized as follows:

1. Major
2. Minor

Major salivary glands are larger in size and are located at a distance away from the oral cavity. They have a definite capsule, and their secretions are poured into the oral cavity through prominent extraglandular ducts. The volume of saliva secreted by these glands is more, about 90% of the total salivary volume.

The major salivary glands are three in number and are present as paired structures on either side of the face. They are the parotid, submandibular and sublingual glands (**Fig. 7.1**).

Minor salivary glands are smaller in size and contribute less to the overall quantity of saliva.

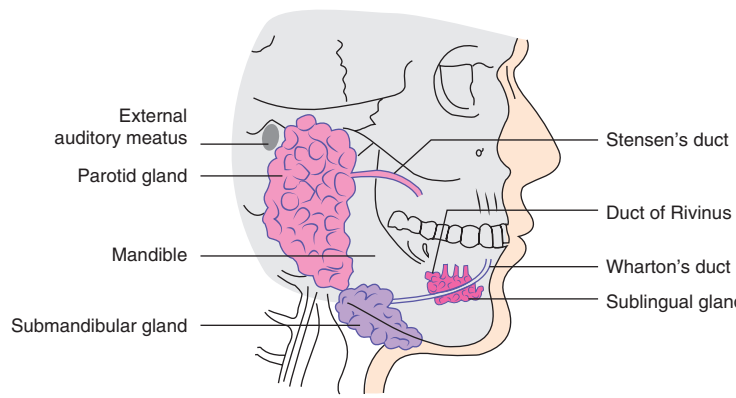


Figure 7.1 Major salivary glands.

Table 7.2 Differences Between Major and Minor Salivary Glands

Feature	Major Gland	Minor Gland
Size	Large	Small
Number	Three pairs	600–1,000
Structure	Extra glandular ducts	–
Capsule	Present	Absent
Location	At a distance from oral cavity	In oral mucosa/ sub-mucosa
Contribution to saliva	Greater percentage	Smaller percentage

Table 7.3 Development of Salivary Glands

Gland	Time Period	Tissue of Origin
Parotid	6th–8th week of gestation	Ectoderm
Submandibular	6th week	Ectoderm
Sublingual	8th–9th week	Ectoderm
Capsule of all major salivary glands	3rd month	Mesenchyme
Minor salivary glands	12th week IUL	Endoderm

IUL, intrauterine life.

They do not possess a well-defined capsule or an extraglandular duct. They are numerous; approximately 600–1,000 minor salivary glands line the oral cavity and oropharynx and these are named according to the site in which they are found as follows: buccal (buccal mucosa), lingual (tongue), labial (lip) and palatal (palate).

The features distinguishing major salivary glands from minor salivary glands are listed in **Table 7.2**.

On the basis of the type of secretion, glands may be classified as follows:

1. Mucous glands
2. Serous glands

Mucous glands are those glands that produce mucous secretions while *serous glands* liberate serous secretions.

EMBRYOLOGY

Although salivary glands exhibit diversity in their appearance, molecular mechanisms involved in their development are strikingly similar. The formation of major salivary glands is initiated by ectodermal–mesenchymal interaction. Differentiation of the gut and its derivatives depends on reciprocal interactions between the gut endoderm (epithelium) and its surrounding mesoderm. *HOX* genes in the mesoderm are induced by *sonic hedgehog* (*SHH*) secreted by gut endoderm.

The major salivary glands start developing from the sixth to the eighth week of gestation as outpouchings of the oral ectoderm into the surrounding mesenchyme (**Table 7.3**). The first indication is a thickening of the epithelium on the side of the tongue, outside the anlage (*anlage*, foundation) of the dental arch. The development of salivary glands consists of five main stages as tabulated in **Table 7.4** and shown in **Figure 7.2**.

Table 7.4 Features of the Developmental Stages of the Salivary Gland

Stage	Development
Pre-bud	• Epithelial thickening in the floor of mouth
Bud	• Invagination of epithelial thickening into the underlying mesenchyme • Formation of a thick solid epithelial stalk terminated by a bulge
Pseudoglandular	• *Branching morphogenesis:* An initial single epithelial bud is turned into an array of epithelial branches that eventually differentiate into a network of ducts, each terminating in a secretory end piece
Canalicular	• Hollowing out of branches and buds in their centre by a process of cavitation • De novo formation of lumen to create epithelial tubes/future ducts
Terminal differentiation	• Maturation of the acini and intercalated ducts • Diminishing prominence of interstitial connective tissue

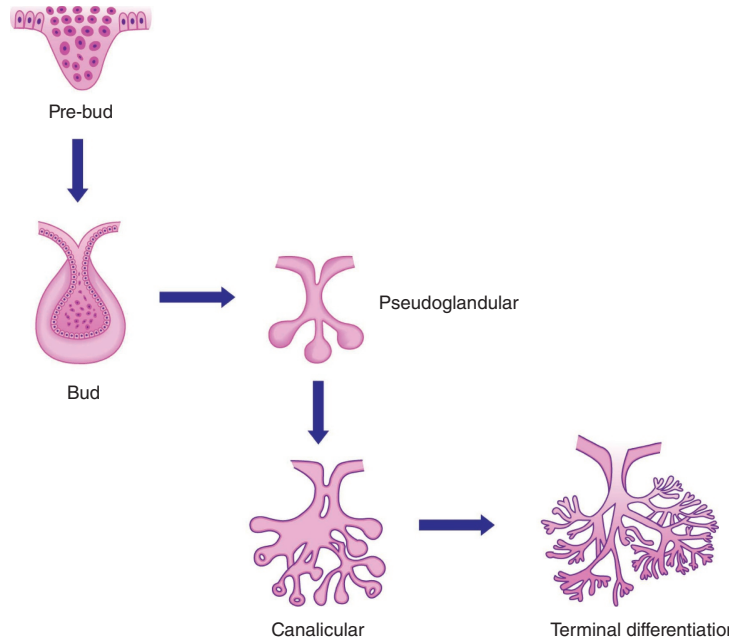


Figure 7.2 Development of salivary glands.

The minor salivary glands arise from the endoderm and the capsules of the major salivary glands are contributed by the surrounding mesenchyme.

During development of the glands, involvement of the autonomic nervous system is crucial; sympathetic nerve stimulation leads to acinar differentiation, whereas parasympathetic stimulation is needed for overall glandular growth.

GROSS ANATOMY OF THE SALIVARY GLANDS

Significance

Applied Anatomy

Gross anatomy of the salivary glands provides information about structures that may be observed with the naked eye or palpated beneath the skin. In addition to providing landmarks concerning the superficial structures, it helps in gauging the position and anatomy of the associated deeper tissues; therefore, it is of great importance in diagnosing the anatomical origin of lesions and planning of surgeries, i.e. the placement of incisions or approaches.

Major Salivary Glands

The term *major salivary glands* denotes the three-paired salivary glands that are larger in size and provide greater contribution to the overall volume of saliva in humans (**Box 7.2**). These glands are named according to their location, structure, size and secretion. The major salivary glands are as follows:

1. Parotid
2. Submandibular
3. Sublingual

The location of salivary glands is indicated by their names. *Parotid* means 'near the ears', *submandibular* refers to 'under the mandible' and *sublingual* denotes 'under the tongue'. Although

Box 7.2 Major Salivary Glands: Common Features

- Larger size
- Presence of a capsule
- Located at a distance from the oral cavity
- Larger quantity of secretion (90% of total saliva)
- Presence of extraglandular ducts

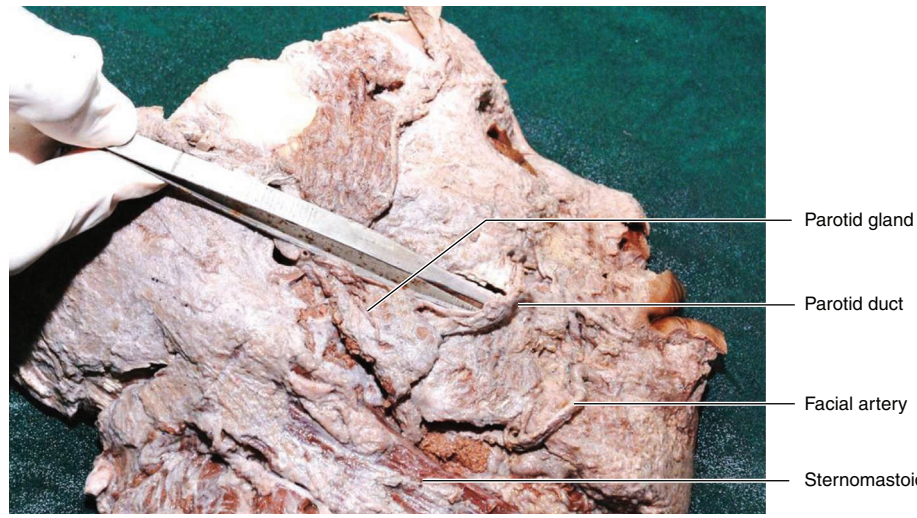
the functional anatomy of all the salivary glands is common, they are distinct in their gross and regional anatomy.

Parotid Gland

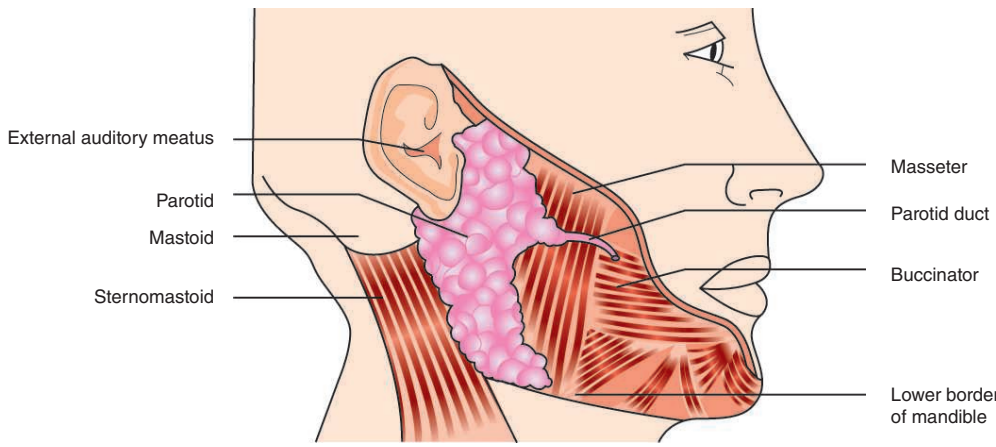
The parotid glands are the largest of the salivary glands, averaging about 5.5 cm in the craniocaudal dimension, 3.5 cm in the ventral–dorsal dimension and weighing about 15 grams. They are flat structures following the facial contour under the skin, one in front of each ear (*para*, around; *otic*, ear). The gland lies in the parotid bed, which is the region between the ramus of the mandible and the mastoid process (**Fig. 7.3**). It has a considerable impact on the posterolateral contour of the face, the extent of its contribution being particularly obvious after its surgical removal.

Capsule The parotid gland is encased by a tough, less-resilient covering called the parotid sheath or capsule, which is derived from the investing layer of deep cervical fascia (**Fig. 7.3**).

Boundaries The parotid gland is approximately pyramidal in shape with the apex pointing downwards. The boundaries of the gland are as follows (**Fig. 7.3**):



(a)



(b)

Figure 7.3 Parotid gland: (a) dissected specimen and (b) schematic diagram.

1. **Superior border:** Zygoma
2. **Inferior border:** Posterior belly of digastric
3. **Posterior border:** External auditory canal
4. **Medial border:** Styloid process, musculature related to styloid process, internal carotid artery, jugular veins
5. **Anterior border:** Masseter

Surfaces and Relations The parotid gland has four surfaces:

1. Superior
2. Superficial
3. Anteromedial
4. Posteromedial (**Fig. 7.4**)

The *superior surface* is the base of the pyramid. It is small, concave and lies close to the external acoustic meatus and the posterior surface of the temporomandibular joint.

Superficial surface faces the skin and is covered by (i) skin, (ii) superficial fascia containing the superficial parotid lymph nodes and posterior fibres of platysma, (iii) parotid fascia and (iv) few deep parotid lymph nodes within the gland.

The *anteromedial surface* lies against the posterior border of ramus. The structures associated with this surface are masseter, medial pterygoid and emerging branches of the facial nerve (**Fig. 7.4**).

The *posteromedial surface* is adapted to the mastoid and styloid processes and the structures attached to them.

Lobes The parotid gland has multiple projections called lobes (**Fig. 7.5**) which are named according to their location such as glenoid lobe, pterygoid lobe, carotid lobe and socia parotidis.

Parotid Duct It is the excretory duct of the parotid gland measuring about 4–6 cm in length and 5 mm in diameter. It is also known as Stensen's duct. It lies midway between the zygomatic arch and the corner of the mouth along a line between the upper lip philtrum and the tragus (**Fig. 7.3**). The duct originates at the anterior border of the parotid gland and parallels the zygomatic arch, runs on the masseter, winds around the anterior margin of the masseter and opens lateral to the second upper molar tooth. Before it opens into the oral cavity, it pierces through the buccal fat pad, the buccopharyngeal fascia and the buccinator muscle. It runs obliquely through the buccinator which avoids inflation of the duct while blowing the mouth. The duct opens intraorally on the inner surface of the cheek. A small mucosal elevation called parotid papilla identifies this opening. The diameter of the parotid duct is

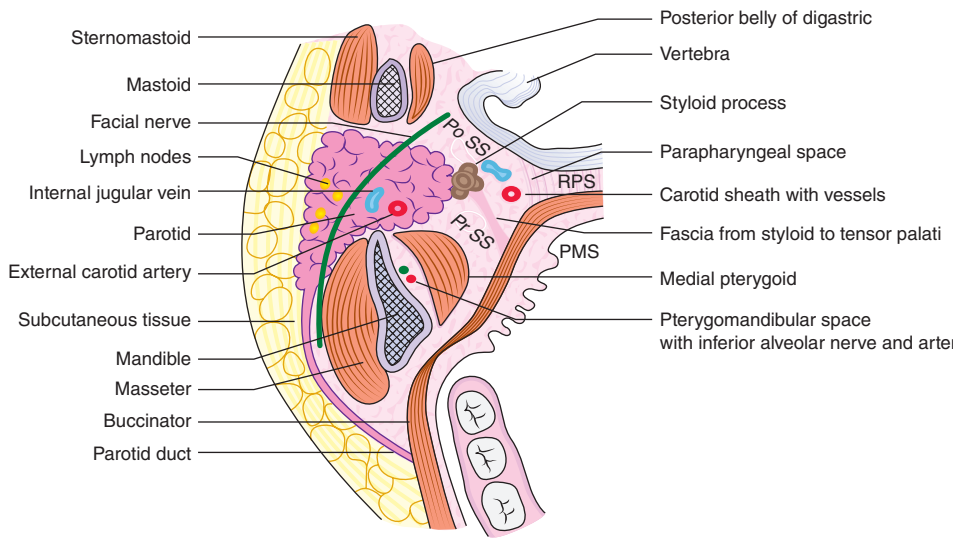


Figure 7.4 Axial section of parotid gland. *PMS*, pharyngeal mucosal space; *Po SS*, post-styloid space; *Pr SS*, pre-styloid space; *RPS*, retropharyngeal space.

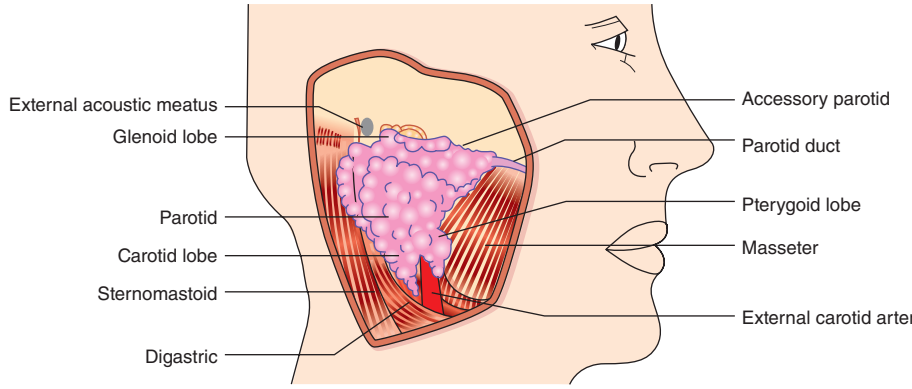


Figure 7.5 Lobes of the parotid gland.

smaller at the opening when compared with the diameter elsewhere in the duct.

Accessory Parotid Gland In 20% of people, a portion of the parotid gland is detached from the main gland and located on the masseter muscle between the parotid duct and the zygomatic arch. Ducts arise from the accessory gland to join the parotid duct. The accessory duct typically lies superior to Stensen's duct.

Structures Related to the Parotid Gland The structures can be studied under the following two divisions:

1. **Structures within the parotid gland:** The structures present within the substance of the parotid gland may be divided into four compartments for ease of understanding. The components from superficial to deep are as follows:
   (a) Parotid lymph nodes, in the parotid fascia as well as the gland (**Fig. 7.4**)
   (b) Parotid plexus of the facial nerve (CN VII) and its branches (**Fig. 7.6**)
   (c) Retromandibular vein
   (d) External carotid artery (**Fig. 7.6**)
2. **Structures adjacent to the parotid gland**
   (a) *Auriculotemporal nerve:* It is a branch of mandibular nerve (CN V_3) closely related to the parotid gland and passes superior to it with the superficial temporal vessels (**Figs 7.6** and **7.7**).
   (b) *Great auricular nerve:* It is a branch of the cervical plexus composed of fibres from C2 and C3 spinal nerves. It provides sensory supply to the parotid sheath as well as the overlying skin.

Relationship to the Adjacent Spaces The parotid gland is closely related to two potential spaces which are crucial in the spread of lesions:

1. **Parapharyngeal space:** This is a potential space lateral to the upper pharynx and anteromedial to the deep lobe of parotid (**Fig. 7.4**). This space deserves mention because the retromandibular portion of the deep lobe of the parotid gland and lymph nodes associated with the parotid gland are present in the pre-styloid compartment, in addition to various other vital structures.
2. **Pterygomandibular space** (**Fig. 7.4**): The parotid gland forms the posterior boundary of this space that lies medial to the mandibular ramus. It contains the inferior alveolar nerve and artery, which provide sensory innervation to the lower teeth. Anaesthesia of the inferior alveolar nerve requires administration of local anaesthetic (LA) solution into this space, closer to the nerve.

Applied Anatomy

Pain on Mastication in Patients with Parotitis

Patients with parotitis frequently have pain during mastication because the gland is enlarged and is trapped between the mandible and mastoid process on opening the mouth.

(Continued)

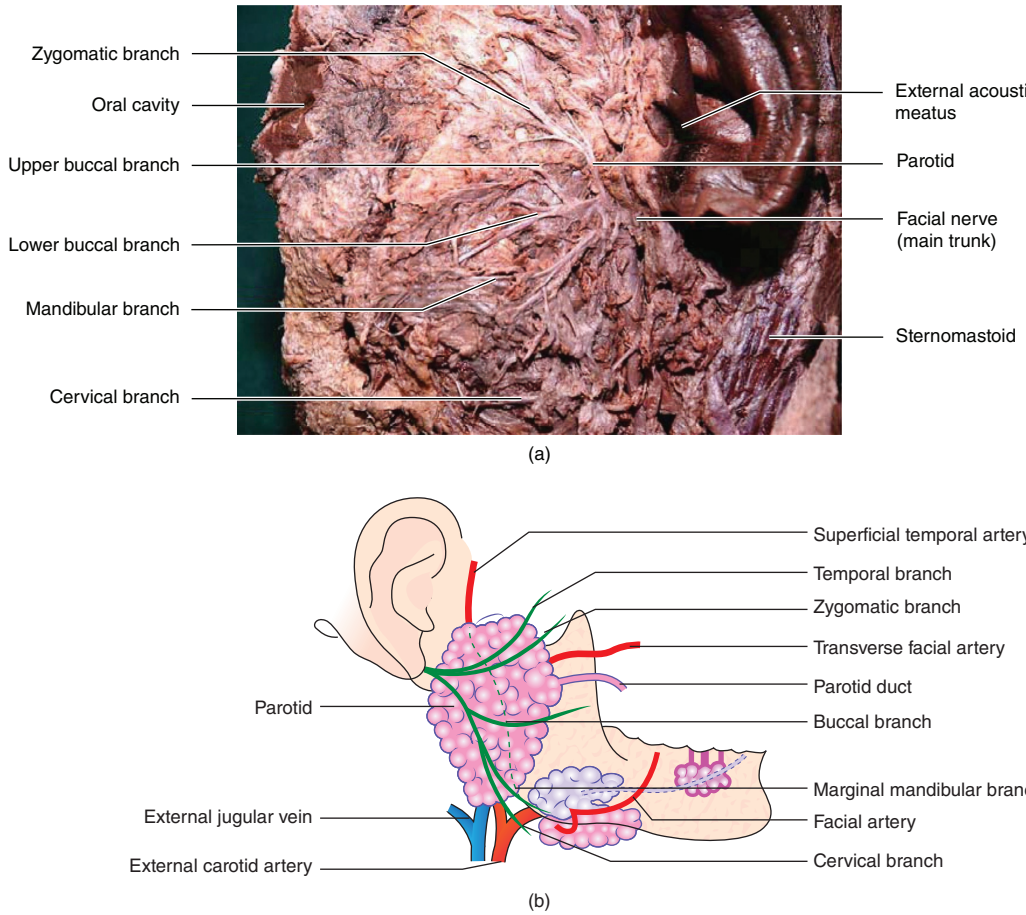


Figure 7.6 Parotid plexus of the facial nerve and its branches: (a) dissected specimen and (b) schematic diagram.

(Continued)

Painful Parotid Swellings

This is due to the richly innervated and unyielding capsule that resists expansion of the gland during inflammation.

Spread from Parotid

Tumours arising from the deep lobe of the parotid gland commonly extend into the prestyloid compartment. It is necessary to differentiate a primary prestyloid lesion from a lesion originating from the parotid. Also, parotitis can progress to parapharyngeal cellulitis through the fascial barrier.

Infection of Parotid Glands

Infection of parotid glands can arise from retrograde entry of microorganisms from the oral cavity through the parotid ducts. It is necessary to differentiate whether a swelling of cheek is because of an infection of the parotid or because of an abscess of dental origin. Infection of the parotids is generally associated with inflamed papilla.

Nerve Supply

1. **Parasympathetic fibres** are constituted by the postganglionic fibres from otic ganglion. These are carried by the auriculotemporal nerve. Stimulation of the parasympathetic fibres produces thin, watery saliva.

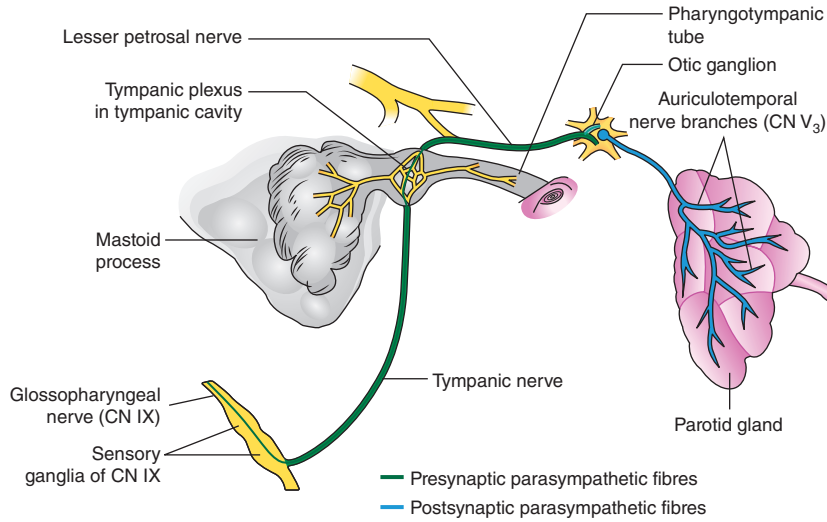


Figure 7.7 Nerve supply to the parotid gland.

2. **Sympathetic fibres** are derived from the cervical ganglia through the external carotid nerve plexus on the external carotid artery (Fig. 7.7). The vasomotor activity of these fibres may reduce secretion from the gland.
3. **Sensory nerve fibres** pass to the gland through the great auricular (parotid fascia) and auriculotemporal nerves.

Applied Anatomy

Local Anaesthesia Injection Producing Facial Paralysis

Anaesthesia of the mandible is achieved by injecting LA solution into the pterygomandibular space which contains the inferior alveolar nerve that innervates the teeth of the lower jaw. The parotid gland encompassing the terminal branches of the facial nerve which innervate the facial muscles lies just posterior to the pterygomandibular space. Improperly orientated LA needle can penetrate the parotid space and injure the facial nerve leading to paralysis.

Frey's Syndrome/Baillarger's Syndrome/ Du-Puy's Syndrome

It is a complication that arises if the auriculotemporal nerve is cut inadvertently either surgically or traumatically. The clinical features are perspiration in the parotid region while eating. This occurs due to aberrant regeneration of the cut auriculotemporal nerve.

The new fibres of the auriculotemporal nerve, whose function is to supply the secretomotor fibres to the parotid, join the fibres of the great auricular nerve that supply the sweat glands; therefore, while eating, a stimulus meant for saliva production alternately produces sweat.

Blood Supply A branch of the external carotid artery (Fig. 7.8), the superficial temporal artery, provides arterial supply.

Venous Drainage (Fig. 7.8) Venous drainage is carried out by the retromandibular vein, which finally drains into the external jugular vein.

Lymphatic Drainage The parotid lymphatics drain into the superficial and deep cervical lymph nodes.

Submandibular Glands

The submandibular gland lies in the submandibular triangle formed by the anterior and posterior bellies of the digastric muscle and the inferior margin of the mandible (Fig. 7.9). It is lodged in a small depression on the medial surface of that bone called

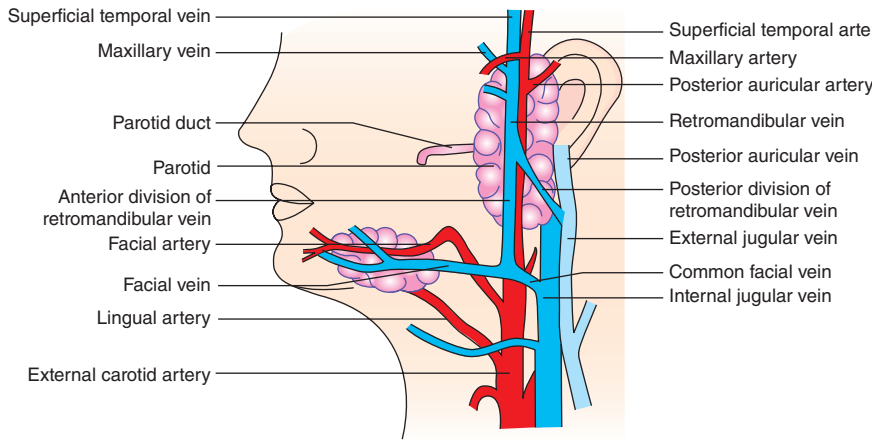


Figure 7.8 Parotid—vascular compartment.

the submandibular fossa. It is often referred to as the submaxillary gland because some anatomists refer to the mandible as the *submaxilla*. It is separated from the parotid gland by the stylomandibular ligament. The submandibular glands are mixed salivary glands with a predominant serous secretion and account for 70% of the total salivary volume. The gland is walnut sized, J shaped and weighs about 15 grams. The unique features of submandibular glands are listed in **Box 7.3**. Each submandibular gland is divided by the posterior border of mylohyoid muscle (**Figs 7.9** and **7.10**) into two lobes:

1. Large superficial lobe (inferior to the muscle and facing the extraoral side)
2. Small deep lobe (superior to the muscle and facing the intraoral side)

The gland is positioned medial and inferior to the posterior border of mandibular ramus and forms a 'C' around the anterior margin of the mylohyoid muscle.

Capsule Similar to the parotid gland, the submandibular gland also has a capsule of its own, derived from the investing layer of deep cervical fascia.

Box 7.3 Submandibular Gland: Unique Features

- Mixed gland, predominantly serous
- Major contribution to saliva
- Major site of salivary calculi

Surfaces and Relations

1. **Superficial part:** It lies below the mylohyoid line on the medial surface of the mandible. It has three surfaces: inferior, lateral and medial.
   (a) *Inferior surface*: It is covered from the outer to the inner by skin, platysma, cervical branch of facial nerve, deep fascia, facial vein and submandibular lymph nodes (**Fig. 7.8**).
   (b) *Lateral surface*: It is associated with the submandibular fossa, medial pterygoid muscle and facial artery.
   (c) *Medial surface:* It is related to the mylohyoid muscle, lingual nerve, submandibular ganglion and hypoglossal nerve anteriorly, and the styloglossus muscle, stylohyoid ligament and hypoglossal nerve posteriorly (**Fig. 7.11**).
2. **Deep part:** This lies sandwiched between the mylohyoid muscle on one side and the hyoglossus and styloglossus on the other side. It extends anteriorly till the posterior end of the sublingual gland (**Fig. 7.11**).

The marginal mandibular branch of the facial nerve CN VII courses superficial to the submandibular gland and deep to the platysma (**Fig. 7.6**).

Submandibular Duct The excretory duct of submandibular salivary gland is also called Wharton's duct. The duct is about 5 cm long and

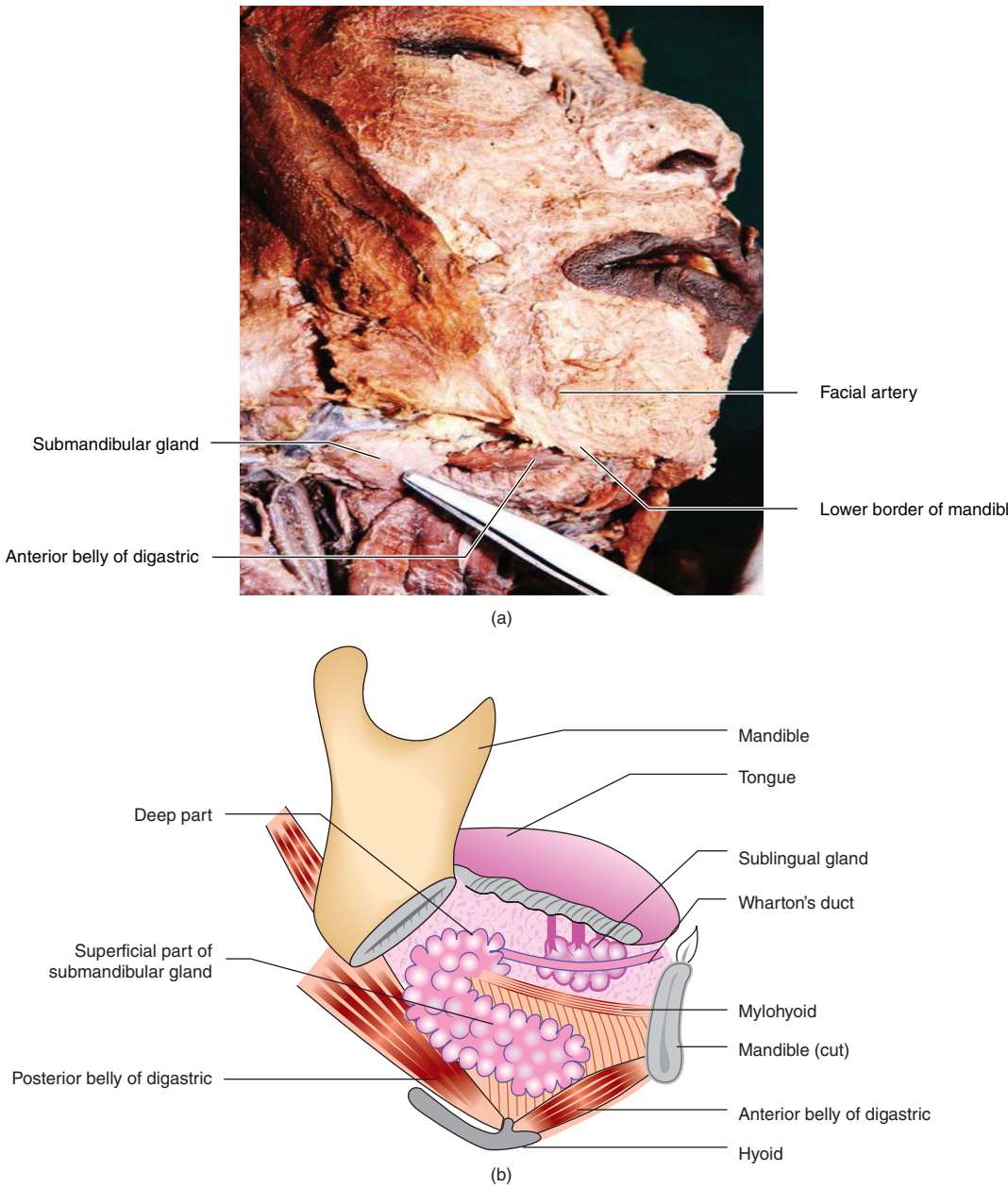


Figure 7.9 Submandibular triangle: (a) dissected specimen and (b) schematic diagram.

extraglandular. It arises at the anterior end of the deep part of the salivary gland. From the point of origin, it courses across the hyoglossus muscle accompanied by the lingual nerve superiorly and the hypoglossal nerve inferiorly (**Fig. 7.11**). The lingual nerve wraps around Wharton's duct; it lies lateral to the duct posteriorly and medial to it anteriorly, while CN XII parallels the submandibular duct, running just inferior to it. Finally, it opens into the floor of the mouth at the summit of the sublingual papilla called *caruncula sublingualis* (a small mucosal eminence on either side of the frenulum) which is present on the lateral aspect of the base of the lingual frenulum. The orifice is easily identified intraorally (**Fig. 7.12**). The duct slopes upwards, against gravity.

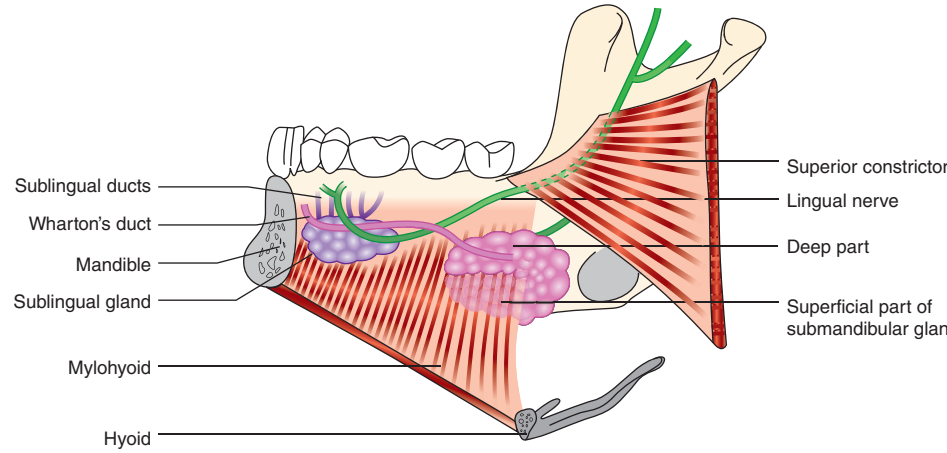


Figure 7.10 Submandibular gland.

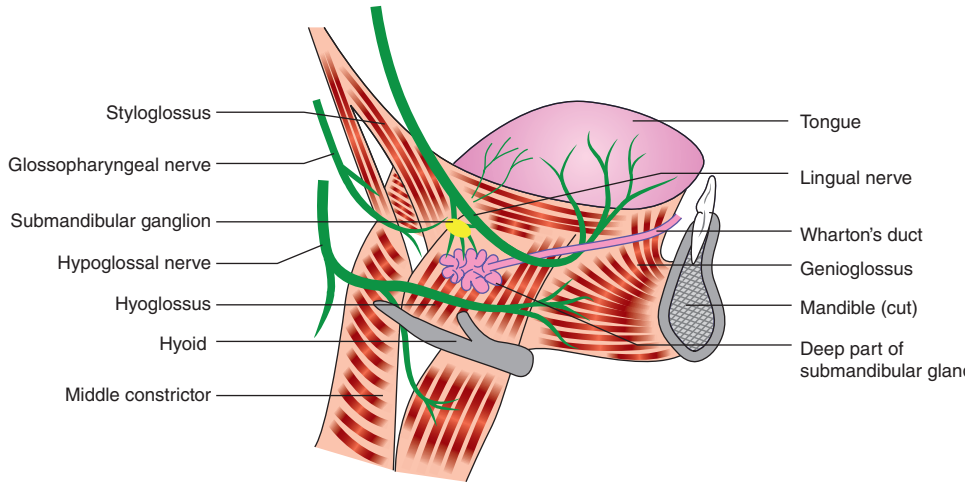


Figure 7.11 Submandibular glands—relations.

Applied Anatomy

Salivary calculi are more common in the submandibular gland (80% of all salivary calculi): This is because of two reasons:

1. Viscid saliva
2. Opening of the duct is at a higher level than the gland, against gravity

Nerve Supply The submandibular gland is innervated by three important sources:

1. **Sympathetic innervation** is from the superior cervical ganglion via the plexus around the facial artery. The sympathetic nervous system regulates submandibular secretions through vasoconstriction of the arteries that supply it. Increased sympathetic activity reduces glandular blood flow, thereby decreasing salivary secretions and producing an enzyme-rich mucous saliva.
2. **Parasympathetic innervation** to the submandibular glands is provided by the superior salivatory nucleus via the chorda tympani (branch of the facial nerve) and the lingual nerve which synapse in the submandibular ganglion. Post-ganglionic fibres supply the gland. Increased parasympathetic activity promotes the secretion of saliva.

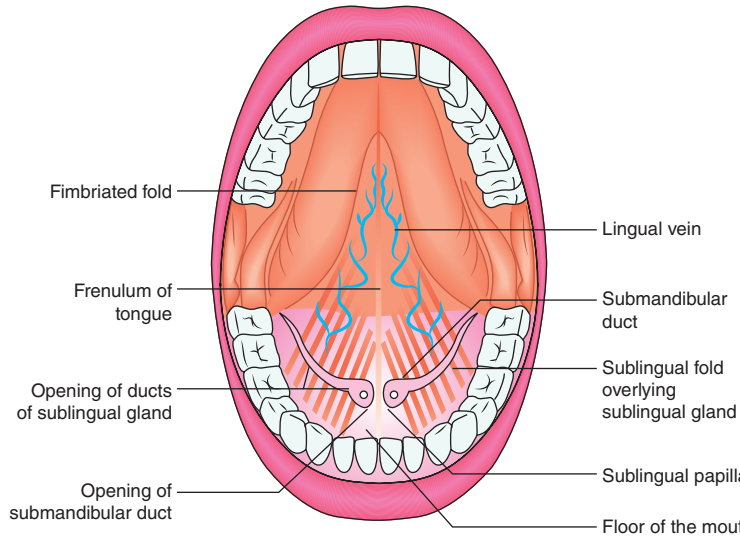


Figure 7.12 Ventral aspect of the tongue and the floor of the mouth.

3. **Sensory innervation** is through the lingual nerve.

Applied Anatomy

Excision of the Submandibular Salivary Gland

Some pathologic changes such as tumours or intraglandular calculi/stone necessitate removal of the submandibular gland. In such cases, it is approached by a skin incision which, as a rule, is placed more than 2.5 cm below the angle of the jaw to avoid injuring the mandibular branch of the facial nerve which lies about 1 inch away from the angle of the jaw and angles upwards to supply the lip. Injury of this nerve may lead to unsightly asymmetry and deviation of lips.

The identification of CN XII, the lingual nerve and Wharton's duct is absolutely essential before excision of the gland.

Perivascular lymph nodes near the facial artery are often involved with cancer originating in the submandibular gland, and these nodes should be removed with submandibular excision.

Blood Supply Arterial supply to the submandibular gland comes from the submental branch of the facial artery (branch of the external carotid artery). The facial artery forms a groove in the deep part of the gland and then curves up around the inferior margin of the mandible to supply the face (**Figs 7.6** and **7.8**). The facial artery and vein are the first blood vessels encountered when excising the submandibular glands as they cross superficially over the inferior border of the mandible. The facial vein traverses over the lateral surface of the submandibular gland.

Venous Drainage The venous drainage is provided by the anterior facial vein (**Fig. 7.8**), which lies deep to the marginal mandibular branch of CN VII.

Lymphatic Drainage The lymphatics drain into the deep cervical and jugular chains of nodes.

Sublingual Gland

The sublingual glands are the smallest of the salivary glands. They are almond shaped and lie in the sublingual fossa on the inner surface of the mandible. They produce a distinct ridge under the tongue on either side called the sublingual fold (**Fig. 7.12**).

They are mucous-secreting glands that lie just deep to the floor of mouth between the mandible and the genioglossus muscle. The sublingual gland is clinically important because of its position,

Box 7.4 Sublingual Gland: Unique Features

- A row of ducts (not a single duct)
- No true fascial capsule
- Mixed gland, more mucous

especially in the events of injuries and infections in the anterior part of the sublingual region. Some unique features of sublingual glands are listed in **Box 7.4**.

Boundaries The sublingual glands are bound inferiorly by the mylohyoid muscle and superiorly by the mucous membrane of the floor of the mouth. The superior wall is clinically the most significant. It consists of the sublingual mucosa and a sublingual fold. This wall represents the main surgical access to the gland. In edentulous mandibles, this mucous fold may be at the level of the upper mandibular border which may hinder the use of the lower dental prosthesis. The medial boundary is formed by the genioglossus muscle. The two sublingual glands meet at the midline of the floor of the mouth.

The following structures are present between the gland and the genioglossus muscle: submandibular duct, lingual nerve, hypoglossal nerve and the sublingual artery (**Fig. 7.13**).

Applied Anatomy

Spread of Sublingual Lesions

The sublingual gland lies against the sublingual fossa on the medial surface of the mandible. There is no posterior fascial limit to the sublingual space and the floor formed by mylohyoid is dehiscent in some areas. This permits lesions of the sublingual gland to exit the sublingual space and enter into the submandibular or parapharyngeal space.

Surgical Relevance

The superior wall of the sublingual gland represents the main surgical access to the gland.

Sublingual Fold and Edentulousness

In edentulous mandibles, sublingual mucosa and a sublingual fold mucous fold may be at the level of the upper mandibular border which may hinder the use of the lower dental prosthesis.

Capsule Unlike the parotid and submandibular glands, the sublingual gland has no true fascial capsule.

Sublingual Duct In contrast to the parotid and submandibular glands, the sublingual gland lacks a single dominant duct. Instead, it is drained by approximately 10 small ducts (the ducts of Rivinus), which exit the superior aspect of the gland and open along the sublingual fold on the floor of mouth. Sometimes, several of the more anterior ducts may join to form a common duct (Bartholin's duct), which typically empties into Wharton's duct.

1. **Major sublingual duct/Bartholin's duct:** It is the main drainage duct of the sublingual gland. It opens at the sublingual caruncle next to the submandibular duct.

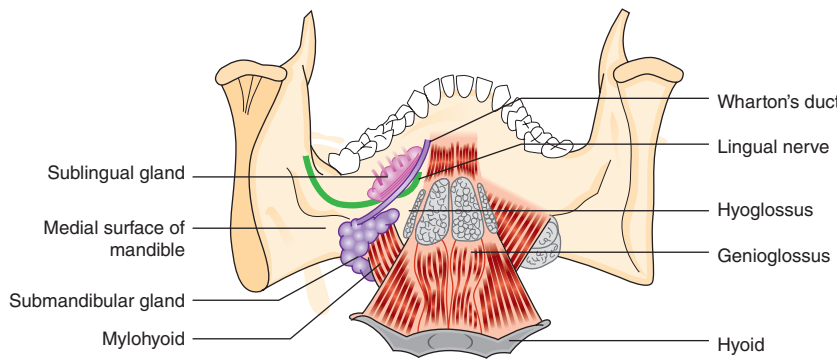


Figure 7.13 Sublingual gland—boundaries.

2. **Minor sublingual ducts/duct of Rivinus:** About 40 small ducts drain the sublingual gland and open along the sublingual fold and the sublingual caruncle.

Nerve Supply Innervation to the sublingual gland is derived from the following:

1. **Sympathetic innervation** is from the cervical chain ganglia via the plexus around the facial artery.
2. **Parasympathetic innervation,** as in the submandibular gland, is derived from the submandibular ganglion.
3. **Sensory innervation** is through the lingual nerve.

Blood Supply Arterial supply to this gland is twofold:

1. Sublingual branch of the lingual artery
2. Submental branch of the facial artery

Venous Drainage The venous drainage is done by the vessels accompanying the arteries.

Lymphatic Drainage The lymphatics drain into the submandibular nodes.

Applied Anatomy

Submandibular Nodes Versus Submandibular Salivary Gland

Often, the submandibular lymph nodes are enlarged during an infection in head and neck. Because of proximity of site, it may be confused with swelling of the gland. The differentiating factor is the bimanual palpation of the salivary gland.

Minor Salivary Glands

Minor salivary glands are the salivary glands of the oral cavity that are smaller in size. There are about 600–1,000 such glands present in the submucosa of the oral cavity. Unlike in the major salivary glands, the minor salivary glands do not possess prominent draining ducts. Instead, each salivary unit has its own simple duct. The minor salivary glands are concentrated in the buccal, labial, palatal and lingual regions. In addition, minor salivary glands may be found at the superior pole of the tonsils (Weber's glands), the tonsillar pillars, base of tongue (von Ebner's glands), paranasal sinuses, larynx, trachea and bronchi (**Box 7.5**).

Box 7.5 Minor Salivary Glands: Common Features

- Smaller size
- Absence of a capsule
- Located in the submucosa of the oral cavity
- Smaller quantity of secretion

The minor salivary glands are named according to the location in which they are found. Characteristically, minor salivary glands are not present in the gingival, dorsal surface of the anterior part of the tongue and anterior hard palate.

The glands are named thus:

1. **Labial glands:** Glands at the inner aspect of the lips
2. **Buccal glands:** Glands at the inner aspect of the cheeks
3. **Molar glands:** Glands at the level of the molar teeth
4. **Palatine glands:** Glands beneath the mucosa of the palate (**Fig. 7.14**)
5. **Lingual glands:** Glands in the lateral and posterior areas of the tongue
6. **Anterior lingual glands (Nuhn's glands):** Glands near the apex of the tongue
7. **Von Ebner's glands:** Glands around the circumvallate papillae

Nerve Supply

Most of the minor glands receive parasympathetic innervation from the lingual nerve, except the minor glands of the palate which receive their parasympathetic fibres from the palatine nerves, fed by the sphenopalatine ganglion.

RADIOGRAPHIC ANATOMY

A radiographic study of the salivary gland enables demonstration of deeper structures that cannot be identified on clinical examination of the patient. This is especially very useful in patients in whom normal anatomy is altered as a result of disease

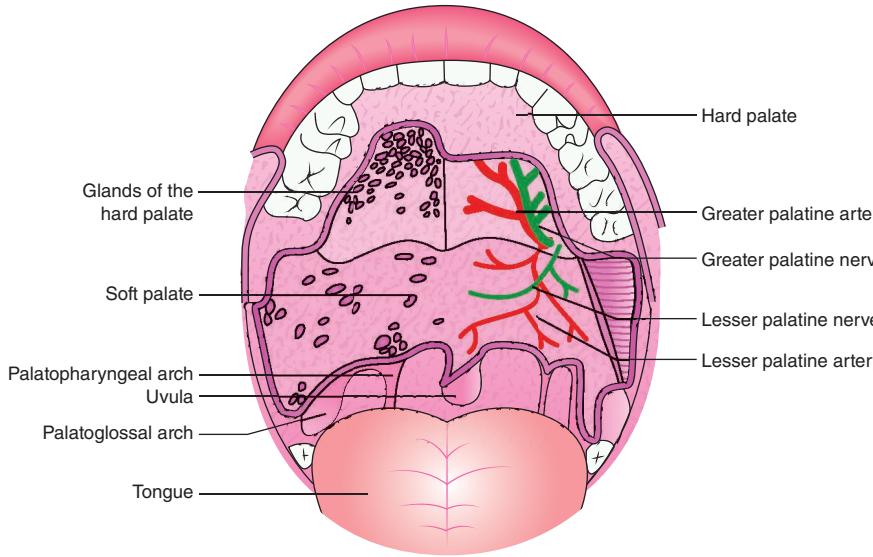


Figure 7.14 Minor salivary glands in the hard and soft palates.



Figure 7.15 Sialogram of the parotid gland.

processes or congenital/developmental disorders. This method of studying anatomical structures is of great use in the diagnosis and treatment of various conditions (**Fig. 7.15**). Examples of diagnostic techniques used to study salivary glands are computed tomography (CT), magnetic resonance imaging (MRI), sialography and ultrasound.

AGE-RELATED CHANGES

Salivary gland dysfunction is more prevalent in the older population. But controlled studies in humans have shown that although the amount of salivary tissue decreases with ageing, salivary function is well-preserved across the human lifespan. Various observations made in relation to the ageing glands are as follows:

1. The submandibular glands are more sensitive to metabolic and physiologic changes.
2. Salivary flow in the unstimulated state is more greatly affected by such changes.
3. A decreased salivary function in older individuals is not a result of age per se but of the greater use of drugs and more chronic illnesses which impact salivation.
4. In healthy, older, non-medicated individuals, there is no decrement in salivary function when compared with younger persons.
5. There are no differences in ageing between sexes.

CLINICAL CONSIDERATIONS

1. **Pain on mastication in patients with parotitis:** Patients with parotitis frequently have pain during mastication because the gland is enlarged and is trapped between the mandible and mastoid process on opening the mouth.
2. **Painful parotid swellings:** This is due to the richly innervated and unyielding capsule

that resists expansion of the gland during inflammation.

3. **Local anaesthesia injection producing facial paralysis:** Anaesthesia of the mandible is achieved by injecting LA solution into the pterygomandibular space which contains the inferior alveolar nerve that innervates the teeth of the lower jaw. The parotid gland encompassing the terminal branches of the facial nerve which innervate the facial muscles lies just posterior to the pterygomandibular space. Improperly orientated LA needle can penetrate the parotid space and injure the facial nerve leading to paralysis (**Fig. 7.4**).
4. **Spread from the parotid gland:** Tumours arising from the deep lobe of the parotid gland commonly extend into the prestyloid compartment. It is necessary to differentiate a primary prestyloid lesion from a lesion originating from the parotid. Also, parotitis can progress to parapharyngeal cellulitis through the fascial barrier.
5. **Infection of parotid glands:** Infection of parotid glands can arise from retrograde entry of micro-organisms from the oral cavity through the parotid ducts. It is necessary to differentiate whether a swelling of cheek is because of an infection of the parotid or because of an abscess of dental origin. Infection of the parotids is generally associated with inflamed papilla.
6. **Frey's syndrome/Baillarger's syndrome/ Du-puy's syndrome:** It is a complication that arises if the auriculotemporal nerve is cut inadvertently either surgically or traumatically. The clinical features are perspiration in the parotid region while eating. This occurs due to aberrant regeneration of the cut auriculotemporal nerve. The new fibres of the auriculotemporal nerve, whose function is to supply the secretomotor fibres to the parotid, join the fibres of the great auricular nerve that supply the sweat glands; therefore, while eating, a stimulus meant for saliva production alternately produces sweat.
7. **Excision of the submandibular salivary gland:** Some pathologic changes like tumours or intraglandular calculi/stone necessitate removal of the submandibular gland. In such cases, it is approached by a skin incision which, as a rule, is placed more than 2.5 cm below the angle of the jaw to avoid injuring the mandibular branch of the facial nerve which lies about 1 inch away from the angle of the jaw and angles upwards to supply the lip. Injury of this nerve may lead to unsightly asymmetry and deviation of lips.

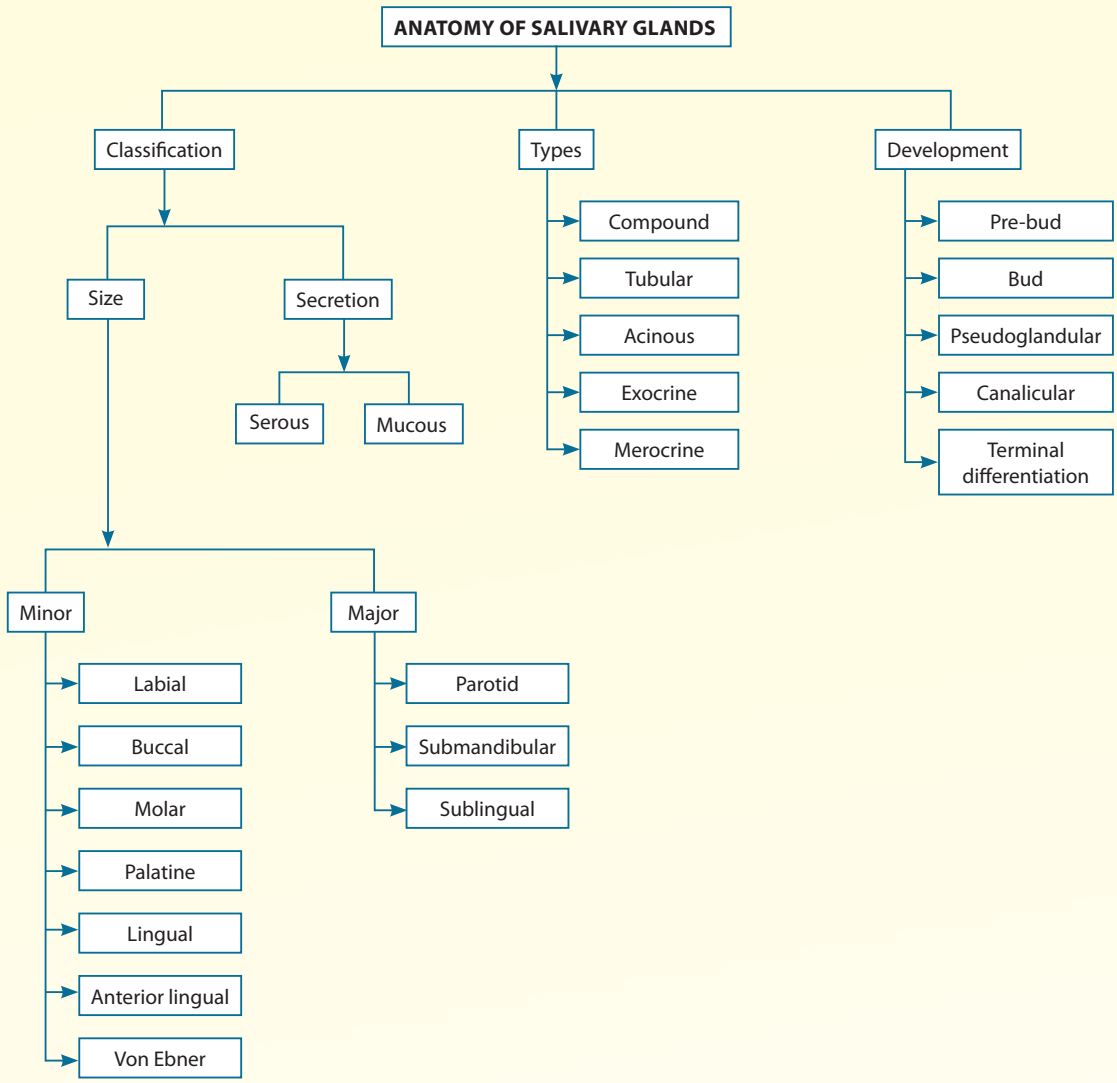
   The identification of CN XII, the lingual nerve and Wharton's duct is absolutely essential before excision of the gland.

   Perivascular lymph nodes near the facial artery are often involved with cancer originating in the submandibular gland, and these nodes should be removed with submandibular excision.
8. **Spread of sublingual lesions:** The sublingual gland lies against the sublingual fossa on the medial surface of the mandible. There is no posterior fascial limit to the sublingual space and the floor formed by mylohyoid is dehiscent in some areas. This permits lesions of the sublingual gland to exit the sublingual space and enter into the submandibular or parapharyngeal space.
9. **Submandibular nodes versus submandibular salivary gland:** Often, the submandibular lymph nodes are enlarged during an infection in head and neck. Because of proximity of site, it may be confused with swelling of the gland. The differentiating factor is the bimanual palpation of salivary gland.
10. **Salivary calculi are more common in the submandibular gland (80% of all salivary calculi):** This is because of two reasons:
    (a) Viscid saliva
    (b) Opening of the duct is at a higher level than the gland, against gravity

Key Points

1. The features uniform to all types of salivary glands are as follows:
   (a) Compound and tubuloacinous structure
   (b) Exocrine and merocrine secretion
2. There are five stages in the development of salivary glands, namely pre-bud, bud, pseudoglandular, canalicular and terminal differentiation.
3. The major salivary glands develop from ectoderm and the minor salivary glands from endoderm.
4. The common features of major salivary glands include larger size, presence of a capsule, location at a distance from the oral cavity, large quantity of secretion (90% of total saliva) and presence of extraglandular ducts.
5. The largest of the salivary glands is the parotid gland.
6. The parotid gland is a unique gland in that it is the first to develop and the last to get encapsulated and flattened, producing serous secretion and having intraparenchymal lymph nodes.
7. The excretory ducts of the major salivary glands are named as follows:
   (a) Stensen's duct (parotid)
   (b) Wharton's duct (submandibular)
   (c) Duct of Rivinus (sublingual)
8. The parotid gland is closely related to two potential spaces which are of clinical importance:
   (a) Pterygomandibular space
   (b) Parapharyngeal space
9. The facial nerve gives off five branches within the parotid:
   (a) Temporal
   (b) Zygomatic
   (c) Buccal
   (d) Marginal mandibular
   (e) Cervical
10. The submandibular gland is a mixed salivary gland which is predominantly serous. It is the main site of salivary calculi.
11. The submandibular gland is J shaped and is divided into superficial and deep parts by the mylohyoid muscle.
12. Developmental disorders of salivary glands may fall into one of the following categories:
   (a) Agenesis
   (b) Atresia
   (c) Heterotopia
   (d) Cysts

Mind Map


ANATOMY OF SALIVARY GLANDS
Classification
Types
Development
Size
Secretion
Serous
Mucous
Compound
Tubular
Acinous
Exocrine
Merocrine
Pre-bud
Bud
Pseudoglandular
Canalicular
Terminal differentiation
Minor
Major
Labial
Buccal
Molar
Palatine
Lingual
Anterior lingual
Von Ebner
Parotid
Submandibular
Sublingual

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Multiple Choice Questions

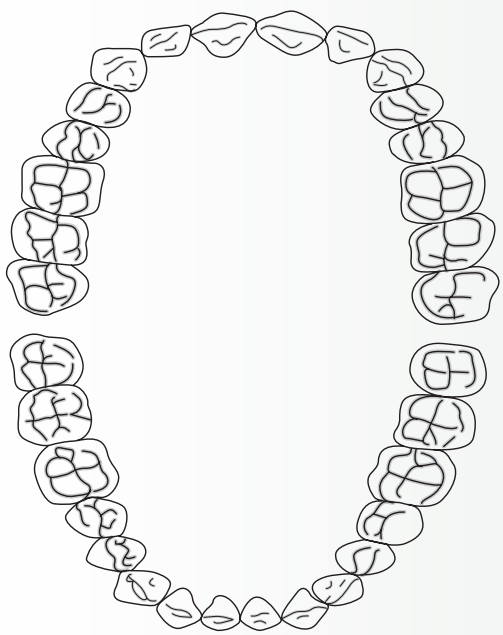
1. Salivary glands develop during the
   (a) Second to fourth week of IUL
   (b) Second month of IUL
   (c) Sixth to eighth week of IUL
   (d) Sixth to eighth month of IUL
2. The capsule of the parotid gland is derived from
   (a) The investing layer of the deep cervical fascia
   (b) The subcutaneous tissue
   (c) Fat
   (d) The masseter
3. Stensen's duct opens
   (a) At the floor of the mouth, adjacent to the lower second molar
   (b) At the angle of the mouth
   (c) Below the tongue
   (d) At the buccal vestibule opposite the upper second molar
4. Intraparenchymal lymph nodes are found in the
   (a) Parotid gland
   (b) Sublingual gland
   (c) Submandibular gland
   (d) von Ebner's gland
5. The space associated with parotid gland is the
   (a) Buccal space
   (b) Submandibular space
   (c) Pterygomandibular space
   (d) Sublingual space
6. The salivary gland most commonly affected by salivary calculi is the
   (a) Sublingual salivary gland
   (b) Submandibular salivary gland

(c) Parotid salivary gland
(d) Palatal salivary gland

7. The structure that divides the parotid gland from submandibular gland is the
   (a) Stylomandibular ligament
   (b) Sphenomandibular ligament
   (c) Lateral ligament
   (d) Capsular ligament
8. The excretory duct of the submandibular gland is known as
   (a) Wharton's duct
   (b) Duct of Rivinus
   (c) Bartholin's duct
   (d) Stensen's duct
9. The nerve that loops around the submandibular duct is the
   (a) Hypoglossal nerve
   (b) Auriculotemporal nerve
   (c) Lingual nerve
   (d) Inferior alveolar nerve
10. The salivary gland that does not have a capsule of its own is
   (a) Parotid
   (b) Submandibular
   (c) Sublingual
   (d) Palatal
11. Sialography is useful to study
   (a) Ductal architecture
   (b) Lymph nodes
   (c) Tumours of the salivary gland
   (d) Blood vessels of the salivary gland
12. Parotid swellings are painful because
   (a) The gland is richly innervated
   (b) It is covered by an unyielding capsule
   (c) The abscess cannot be drained
   (d) They do not allow penetration of drugs
13. Frey's syndrome means
   (a) Salivating while eating
   (b) Sweating while eating
   (c) Paralysis of one side of face
   (d) Lack of secretion on the affected side
14. Secretomotor fibres for the submandibular gland are carried by the
   (a) Olfactory nerve
   (b) Hypoglossal nerve
   (c) Vagus nerve
   (d) Auriculotemporal nerve
15. Extraoral incision to reach the submandibular gland is placed 2.5 cm below the inferior border of the mandible to protect the
   (a) Lingual nerve
   (b) Cervical branch of the facial nerve
   (c) Mandibular branch of the facial nerve
   (d) Nerve to mylohyoid

SECTION II

Tooth Morphology



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CHAPTER 8

Evolution of Teeth and Comparative Dental Anatomy

Overview

Diversity in tooth number is an important contributor for mammalian diversification. The evolutionary path in the phylogeny ranging from fish to reptiles to mammals is characterized by a modification in the number of teeth. Dentition is a unique characteristic of vertebrates. From the time of evolution of more than 360 million years, teeth play a vital role in survival in terms of food acquisition, processing and defence. Morphological data of teeth have played an important role in the field of dental anthropology and dental forensics. Teeth are well suited for the investigation of developmental processes. In addition, since teeth are composed of hard-mineralized tissues, primarily apatite, that are readily preserved, the evolution of mammals is well documented through their teeth in the fossil record.

INTRODUCTION

Heterogeneity or variance in tooth number is a principal contributor of mammalian diversity.

Evolutionary advancements from primitive phylogeny to highly evolved species range from having many functional teeth at a particular time period (polyodont) to a single set of teeth (oligodont). Diversity with different species also exists in number of dentitions and with an increase in complex morphological features. Advanced species have always had complex dentition for defence and apprehension of food.

Comparative dental anatomy deals with a comparative study of morphology of teeth and their related structures in different animals and also between members of the same species. Dentition is a unique characteristic of vertebrates. From the time of evolution of more than 360 million years, teeth play a vital role in survival in terms of food acquisition, processing and defence. Morphological data of teeth have played an important role in the field of dental anthropology and dental forensics. For example, the tooth form is useful in elucidating the evolutionary changes from fossil hominids to modern humans, reconstructing life history from archaeological human remains and analysing the population history of recent human groups.

EVOLUTION OF TEETH

Modern day human dentition has undergone a considerable evolutionary change. The general tendency observed in these changes is that the jaw and dentition size have become smaller. Evolutionary studies have shown that from about 35,000 years ago until 10,000 years ago, the tooth size has decreased on average by about 1% every 2000 years to a 1% decrease every 1000 years. Factors related to evolution, environment and culture have determined this change.

Functional demands and diet are regarded as core factors in evolution of teeth. The evolutionary progress in mammals from reptilian ancestors is represented by the presence of two openings on each side of the skull behind the orbit. This is being used as a site of rigid attachment of masticatory muscles. Advanced species require the more calorific energy due to increased physical activity. Mammal-like reptiles (cynodonts) exhibited development of a more complex dentition which could assist in improved mastication of food with molar-like teeth. Such masticatory apparatus presented with enamaloid extensions called cusps. Morphology of the cusps in terms of number, morphology, topology and orientation is unique to each species.

Development of the mammalian complex occlusal surface was of a great aid in breaking down a variety of foods. The triconodont type presents with teeth consisting of three major cusps arranged in a straight line and the minor cusps on the external surface.

Cuspal patterns in symmetrodont organisms (extinct mammals) presented with a central cusp that was separated from the other two outer cusps so that a triangle was formed on the occlusal surface of the upper molars. Similar patterns were also observed in lower molars, thus also increasing the masticatory prowess.

PHYLOGENETIC CLASSIFICATION OF DENTITION AND CUSP FORMS

1. **Based on succession or replacement of teeth:** According to succession or replacement, the teeth can be divided into three categories:
   (a) Monophyodont
   (b) Diphyodont
   (c) Polyphyodont

   Among mammals, the first two categories are found.

   Monophyodont teeth appear only once in lifetime. If they are lost, they are never again replaced by new ones.

   Examples: In some mammals, only one set of teeth develops in their lifetime and this condition is called monophyodont, for example, marsupials retain all their milk teeth except last premolars, toothed whales (Odontoceti), some rodents (e.g. squirrels) and certain insectivores (e.g. moles). The platypus, sirenians and toothless whales develop only one set of teeth. These teeth may not erupt (some whales) or, if these develop, are usually shed shortly afterwards.

   Diphyodont type has two sets of dentition. The first temporary set of teeth is called deciduous teeth or milk teeth or lacteal teeth. They are lost and replaced by a second permanent teeth. It is characteristic of mammals in which milk teeth appear in the young ones but as they grow and jaw becomes larger, milk teeth are replaced by larger permanent ones to fit in the larger jaw bone.

   Examples: In mammals, bats and guinea pigs, the milk teeth are lost even before birth.

   Polyphyodont dentition involves teeth that are replaced continuously throughout life. It is seen in lower vertebrates which lose teeth while feeding and capturing prey and needs teeth to be replaced for survival.

   Example: Vertebrates such as dogfish, snakes and mice

2. **Based on the kinds of teeth found—form and function of dentition:** According to the form and function of teeth, there are three categories of dentition:
   (a) Homodont or isodont
   (b) Specialized homodont
   (c) Heterodont

   Homodont or isodont dentition has teeth which are functionally and anatomically of the same type, although their size may be variable depending on the location.

   Example: Fishes, amphibians, reptiles

   Specialized homodont occurs in homodont dentition where a functional specialization is required like a venomous fang in the anterior teeth.

   Example: Venomous snakes

   Heterodont dentition occurs in mammals in which there are four functionally different types of teeth, namely incisors for cutting, canines for tearing flesh and large and broad premolars and molars with a flat grinding surface.

   Example: This condition is the usual feature in mammals and mammal like reptiles, i.e. the teeth are distinguished according to their shape, size and function.

3. **Based on the type of attachment of teeth on the jaw bone**, the following three types are found in vertebrates (**Fig. 8.1**):
   (a) Acrodont
   (b) Pleurodont
   (c) Thecodont

   Acrodont teeth are attached on the top surface of the jaw bone. These have no roots and are attached to the edge of the jawbone by a fibrous membrane. This type of attachment is not very strong and teeth are lost easily and are replaced by new ones.

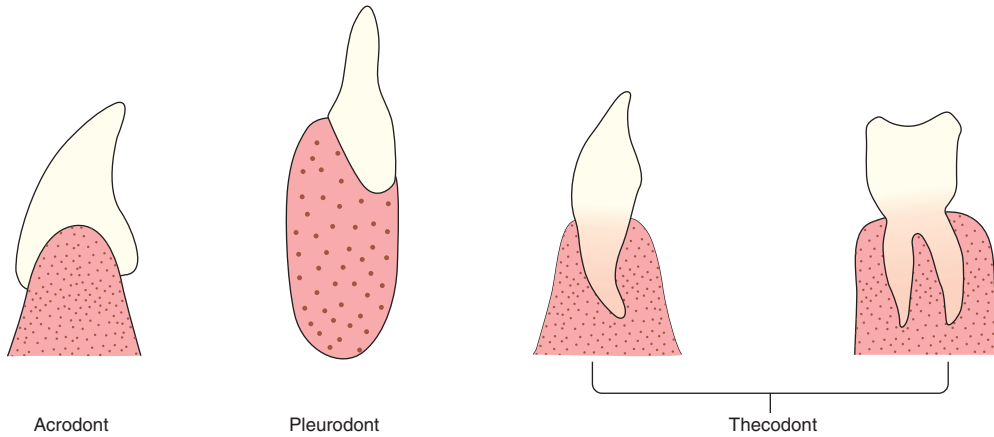


Figure 8.1 Attachment of teeth to the jaw bone.

Example: Fishes, amphibians and some reptiles

Pleurodont teeth are attached on the inner side and upper side of the jawbone that brings a larger surface area of tooth in contact with jawbone and hence attachment is stronger.

Example: Lizards and amphibians

Thecodont dentition is found in mammals in which the root of the tooth is firmly fixed in a socket of the jawbone, making the attachment strongest in vertebrates. This is a peg-and-socket attachment with the help of cementum that surrounds the root portion of the tooth. Capillaries and nerves enter the jaw bone and the pulp cavity through the open tips of the hollow roots.

Example: Except mammals, the codont types of teeth are found in crocodiles and in some fishes (Haddock, Garpike and Barracuda).

ORIGIN AND EVOLUTION OF MOLARS IN MAMMALS

The origin of the complex posterior teeth of mammals has been a controversial issue for a long time. The simple and single-rooted incisor and canine show little modifications through ages and are not taken into consideration. Two theories have been put forward to explain the origin of the complex posterior teeth:

1. **Concrescence theory:** Kukenthal and Rose postulated this theory in the year 1890. This theory urges that the posterior teeth originated by the fusion of two or more conical-shaped teeth. This was supported with an evidence in the animal dugong were several enamel organs fuse to form the molar teeth. However, there were no embryological evidences and the condition found in dugong is considered as exception, so this theory was not considered.
2. **Differentiation theory:** Cope and Osborn postulated this theory in the year 1880 and was further updated by Gregory in 1934. This theory suggests that a conical tooth's additional projections or buds develop giving rise to the triconodont shape. These cones further shift to give rise to separate tubercles or cusps arranged in a triangle called tritubercular position. Later forms additional cusps or folds, giving rise to the varied types of mammalian posterior teeth.

   Due to abundant embryological and palaeontological evidences, this theory has been in favour.

STRUCTURE OF CUSPS IN THE POSTERIOR TEETH

Understanding cusp homology among mammals is integral to deciphering their evolutionary history. Homologizing cusps in taxa that are highly derived has been a difficult task as the remnants of a primitive tribosphenic pattern have been overprinted by millions of years of evolution.

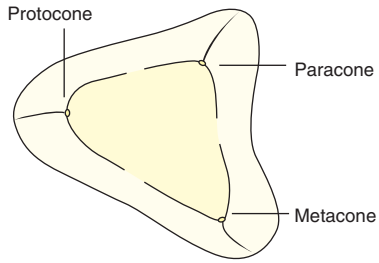


Figure 8.2 Different cones of teeth.

The basic rules of naming a **cusp** is that it is called a **cone**. Different cones are identified by different prefixes, the major ones being **proto-**, **para-**, **meta-**, **hypo-** and **ento-** (Fig. 8.2). Minor cusps may have been added with a suffix **-ule** to the name of the major cust. A suffix **-id** is added to cusps in the lower jaw.

Tribophenic Type

The earliest therian mammals (placentals and marsupials) had the tribophenic or triangular pattern with three cusps: paracone and metacone on the buccal aspect and protocone on the lingual aspect. Two important features of the tribosphenic molars is the **trigonid**, or shearing end, and the **talonid**, or crushing heel. In highly evolved tribosphenic molars, the trigonid is towards the front of the jaw and the talonid towards the rear.

Quadrate Type

The quadrate type is also called quadritubercular and has an additional fourth cusp on the lingual side called the hypocone. Quadrate molars are found in primates and humans. Additional cusps termed conules are found between the larger cusps. Paraconule is located between a paracone and a metacone and hypoconulid is located between a hypoconid and an entoconid (Fig. 8.3).

Secodont Type (Fig. 8.4)

Secodont teeth have sharp cutting edges that act like scissors to severe flesh in carnivores.

Bunodont Type (Fig. 8.5)

Bunodont teeth are small with smaller cusps or tubercles on their surface. Animals with bunodont teeth have a wide range of diet consisting of different consistencies. This type is observed in man and monkeys.

Brachydont Type

Brachydont teeth are small and low crowned with crescent-shaped cusps. The crown of the tooth is located above the gingiva and has a constricted neck at the gum line and a root embedded in the jawbone. This type is observed in man, carnivores such as dogs and cats, and pigs.

Hypsodont Type (Fig. 8.6)

Hypsodont teeth have a large crown and short open roots that can resist wear and tear of feeding on tough and fibrous diet. These teeth extend unusually far above the gum line, providing lots of extra material for wear and is seen in horse and incisor of elephants.

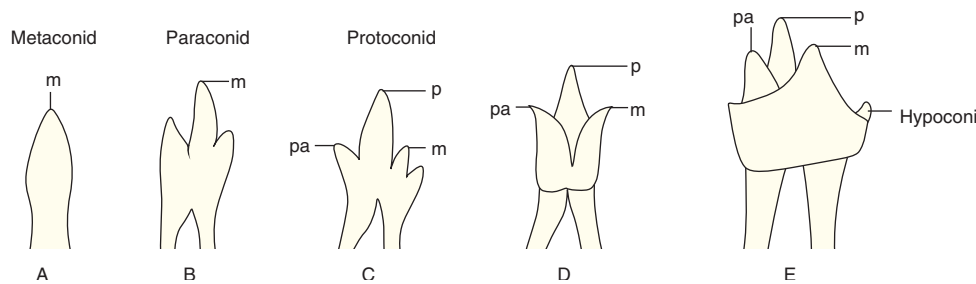


Figure 8.3 Evolution of mammalian teeth from primitive conical teeth.

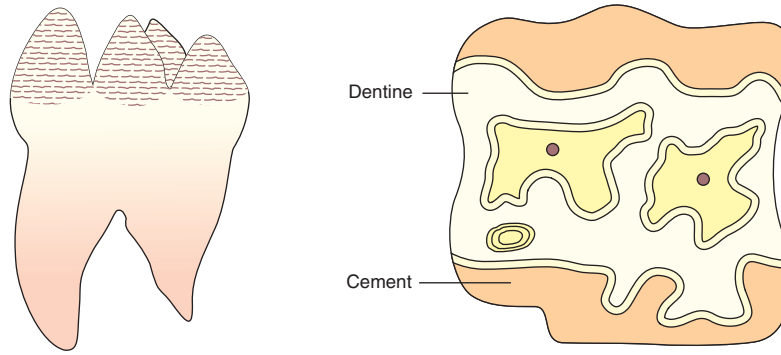


Figure 8.4 Secodont type of teeth.

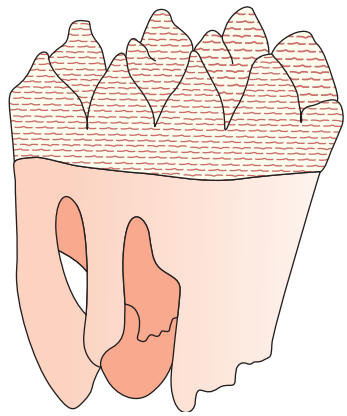


Figure 8.5 Bunodont type of teeth.

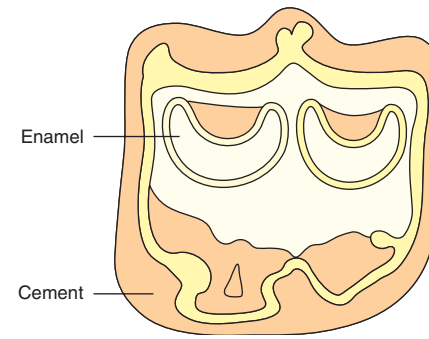


Figure 8.7 Selenodont type of teeth.

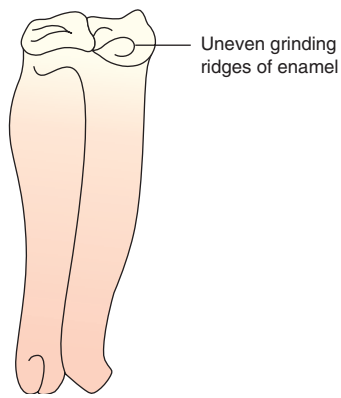


Figure 8.6 Hypsodont type of teeth.

Selenodont Type (Fig. 8.7)

Selenodont teeth have cusps in the form of crescent shaped in which silica deposits are seen to prevent wearing away of teeth. They are seen in horses and other ungulates such as cow and sheep.

Lophodont Type (Fig. 8.8)

Lophodont teeth have ridges on the occlusal surface which are in the shape of elongated ridges termed lophs and the depressions are filled with silica. They are found in elephants which feed on the roughest diet that any mammal can feed on.

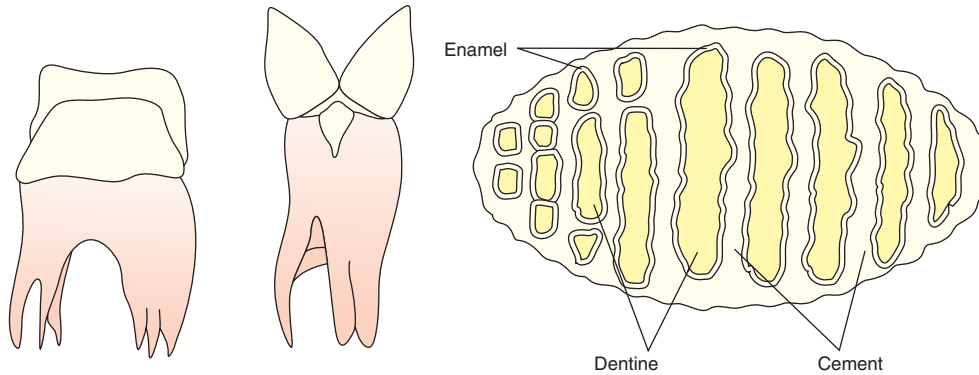


Figure 8.8 Lophodont type of teeth.

DENTAL FORMULA

The total number of teeth in a particular species remains constant but variations are seen in different species. Knowledge about the dental formula in different species helps as a quick source of reference in forensic dentistry and tooth morphology.

The modified Triadan system provides a consistent method of numbering teeth across different animal species. The system is based on the permanent dentition of the pig, which has 11 teeth in each quadrant: three incisors, one canine, four premolars and three molars. The grand total is 44 teeth. The maximum number of teeth in heterodont mammals is 44. The first digit of the modified Triadan system denotes the quadrant. The second and third digits denote the tooth position within the quadrant, with the sequence always starting at the midline. A typical primitive mammal possesses 44 teeth and it is expressed as

I⅜, c1/1, Pm4/4, m⅜ = 22 × 2 = 44

Or 3.1.4.3/3.1.4.3 = 22 × 2 = 44

The dental formula for different species are given in the following text where **I** = incisors, **C** = canines, **P** = premolars and **M** = molars:

Man (Adult)

I – ⅔ **C** – 1/1 **P** – ⅔ **M** – ⅜ = 16 × 2 = 32

Dog

(a) Puppy (temporary teeth). Not present at birth but complete by 60 days.

I – ⅜ **C** – 1/1 **P** – ⅜ **M** – % = 14 × 2 = 28

(b) Adult (permanent teeth). Emerge at about 4 months of age.

I – ⅜ **C** – 1/1 **P** – 4/4 **M** – ⅜ = 21 × 2 = 42

Cat

(a) Kitten (temporary teeth). Not present at birth but complete by 60 days.

I – ⅜ **C** – 1/1 **P** – ⅜ **M** – % = 13 × 2 = 26

(b) Adult (permanent teeth). Emerge at about 4 months of age.

I – 3/3 **C** – 1/1 **P** – ⅜ **M** – 1/1 = 15 × 2 = 30

Horse

(a) Temporary teeth

I – ⅜ **C** – 0/0 **P** – ⅜ **M** – % = 12 × 2 = 24

(b) Adult (permanent teeth)

I – ⅜ **C** – 1/1 **P** – 3 or ⅘ **M** – ⅜ = 20 (or 21) × 2 = 40 (or 42)

Cattle

(a) Temporary teeth

I – 0/4 **C** – % **P** – ⅜ **M** – % = 10 × 2 = 20

(b) Permanent teeth

I – 0/4 **C** – % **P** – ⅜ **M** – ⅜ = 16 × 2 = 32

In cattle, the permanent teeth are not fully erupted until 3.5–4 years of age.

Sheep

(a) Temporary teeth

I – 0/4 **C** – % **P** – ⅜ **M** – % = 10 × 2 = 32

(b) Permanent teeth

I – ¾ **C** – % **P** – ⅔ **M** – ⅔ = 16 × 2 = 32

In sheep, the permanent teeth are not completely erupted until 3.5–4 years of age

Pig

(a) Temporary teeth

I – ⅔ **C** – ⅟₁ **P** – ¾ **M** – % = 16 × 2 = 32

(b) Permanent teeth

I – ⅔ **C** – ⅟₁ **P** – ¾ **M** – ⅔ = 22 × 2 = 44

In pigs, the permanent teeth are not completely erupted until 16–20 months of age.

ADDITIONAL READING

Ever-Growing Teeth in Mammals and Dental Stem Cell Maintenance

Dentition in a mammal is categorized as Heterodont with different types of teeth (incisor, canine, premolar and molar) and a diverse tooth morphology. Animals classified as polyphyodonts have their teeth replaced continuously throughout their life. Early mammalian ancestors like the Morganucodon and Sinoconodon had one of their teeth types being replaced during their lifespan. The Morganucodon species had their canines replaced for about four times and Sinoconodon species had their molars replaced. However, during the process of evolution the placental mammalian lineage lost this phenomenon and had a diphyodont type of dentition. Exceptions to this pattern were wallaby (*Petrogale concinna*), manatees and African mole-rat (*Heliophobius argenteocinereus*) which exhibited a type of polyphyodont by replacing their molars. The new molar develops in a posterior position and replaces the first in order molar in a horizontal treadmill like the tooth replacement mechanism (excerpts from Renvoisé and Michon 2014).

Animal Bite Marks

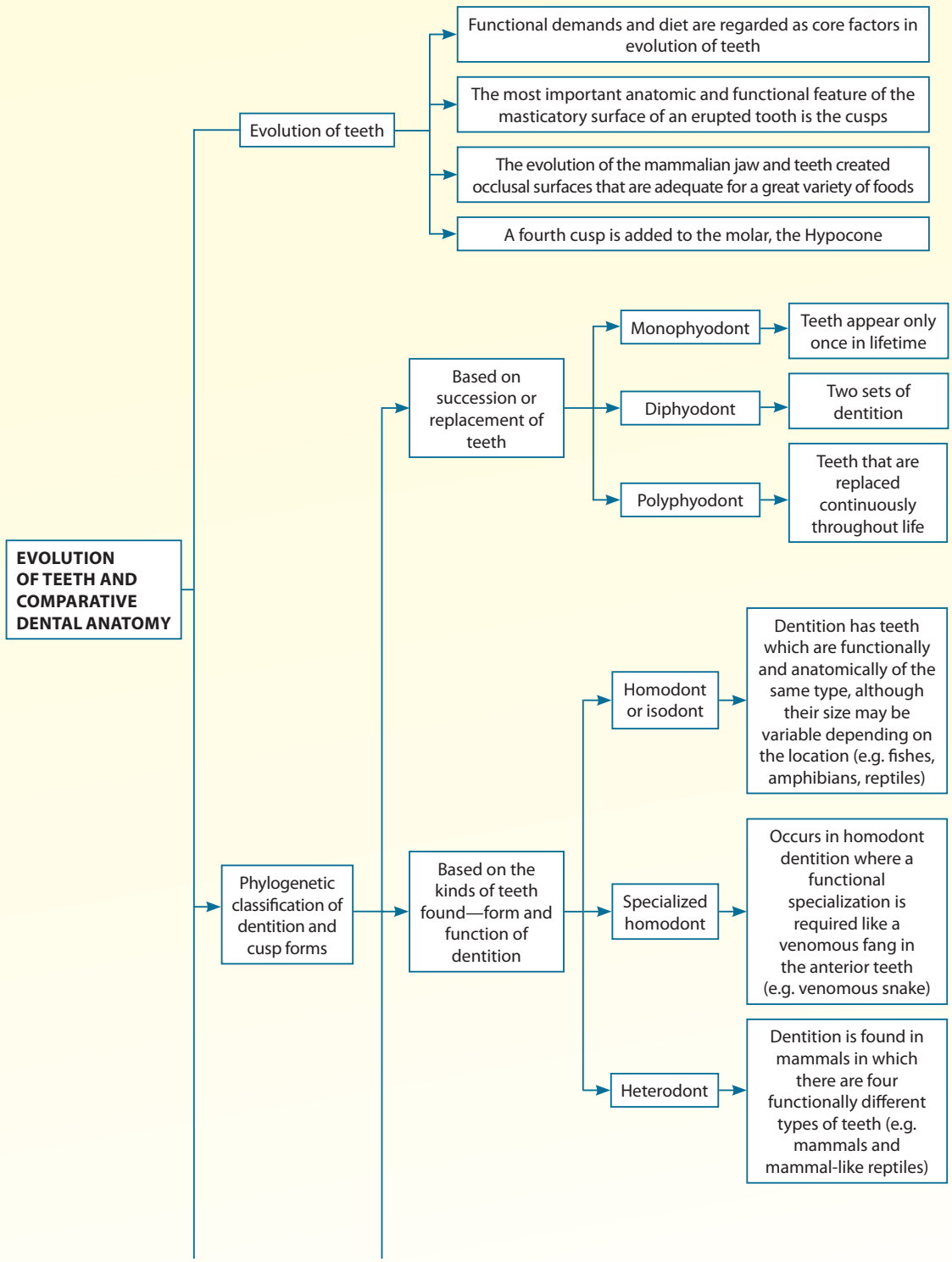
Bite marks are important in forensic identification. The major consideration in bite mark analysis is to determine the type of origin of the bite mark—animal or human. Categorization of the origin of the bite mark decides the course of the investigation process. In depth analysis is required to differentiation into self-inflicted bites, caused by an aggressor or an animal. Excluding the suspect can be done after a careful bite mark analysis. The procedure of bite mark analysis is carried out by an expert who determines the size and configuration of the affected site. A comparison with human and animal bite marks is made. Factors such as resistance of the affected tissue, anatomical location and position of the victim are given due consideration during bite mark analysis (excerpts from Tedeschi-Oliveira et al. 2011).

SECTION II

Key Points

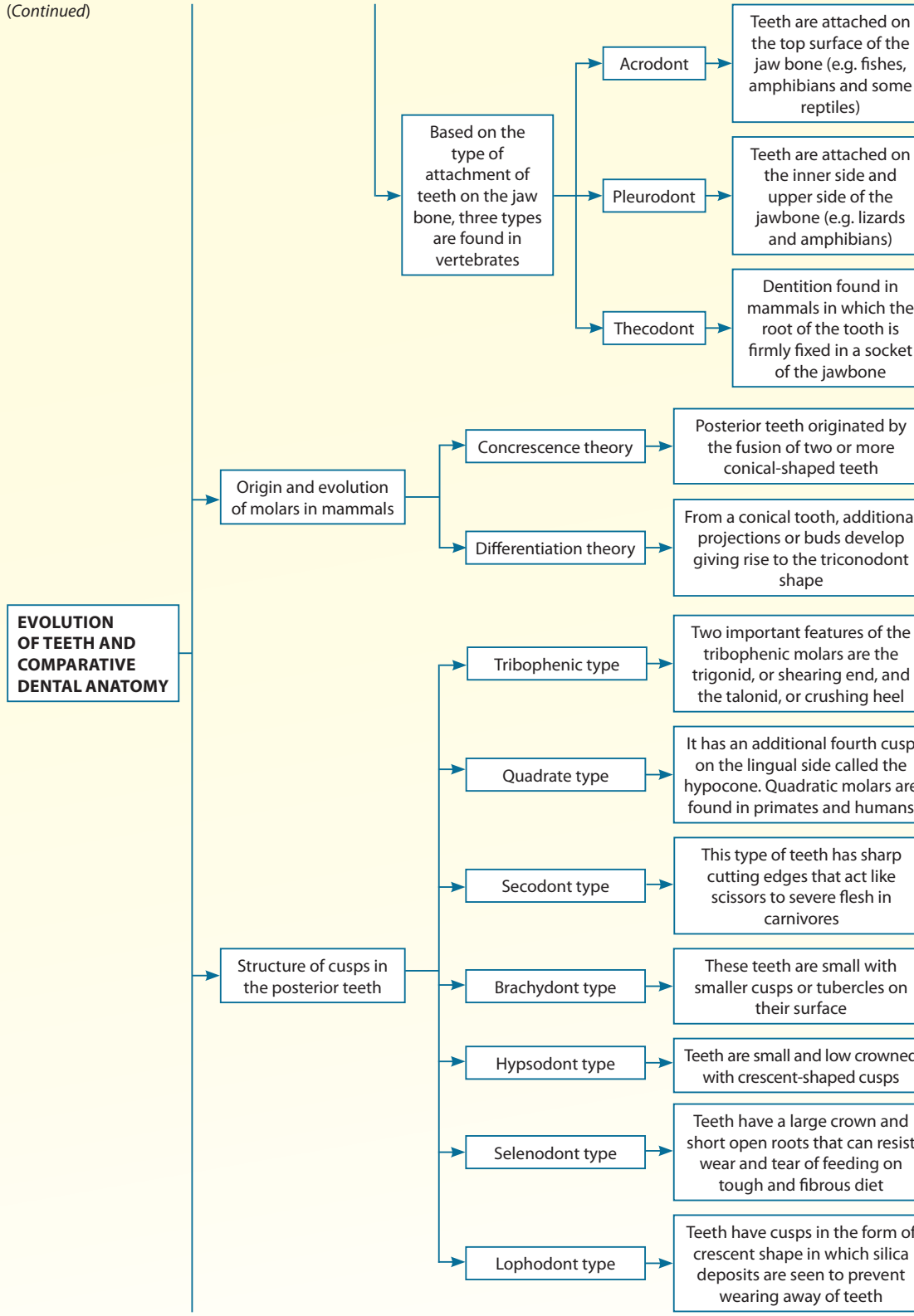
1. Teeth can be divided into three categories based on succession or replacement of teeth: monophyodont, diphyodont and polyphyodont.
2. Based on the form and function of dentition teeth, they are categorized into the following:
   (a) Homodont or isodont
   (b) Specialized homodont
   (c) Heterodont
3. Vertebrates show three types of attachment of teeth to the jaw bones: acrodont, pleurodont and thecodont.
4. Two theories that explain the origin of posterior teeth are concrescence theory and differentiation theory.
5. Major cusps are named by adding prefixes **proto-**, **para-**, **meta-**, **hypo-** and **ento-**. Minor cusps may have been added with a suffix **-ule** to the name of the major cust. A suffix **-id** is added to cusps in the lower jaw.

Mind Map



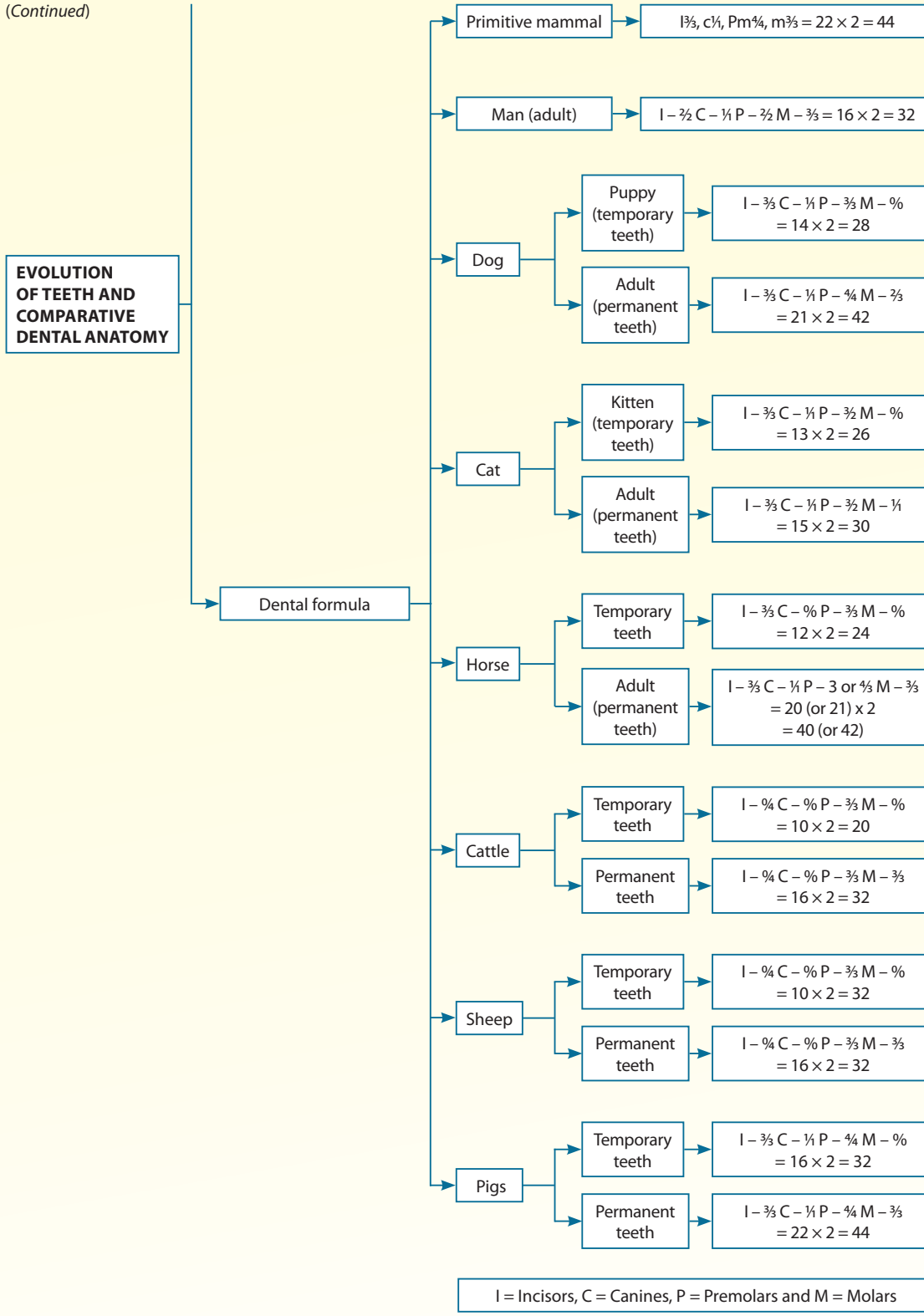
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EVOLUTION OF TEETH AND COMPARATIVE DENTAL ANATOMY
Dental formula
Primitive mammal
I⅔, c1/1, Pm4/4, m3/3 = 22 × 2 = 44
Man (adult)
I – 2/2 C – 1/1 P – 2/2 M – 3/3 = 16 × 2 = 32
Dog
Puppy (temporary teeth)
I – 3/3 C – 1/1 P – 3/3 M – 0/0 = 14 × 2 = 28
Adult (permanent teeth)
I – 3/3 C – 1/1 P – 4/4 M – 2/3 = 21 × 2 = 42
Cat
Kitten (temporary teeth)
I – 3/3 C – 1/1 P – 3/2 M – 0/0 = 13 × 2 = 26
Adult (permanent teeth)
I – 3/3 C – 1/1 P – 3/2 M – 1/1 = 15 × 2 = 30
Horse
Temporary teeth
I – 3/3 C – 0/0 P – 3/3 M – 0/0 = 12 × 2 = 24
Adult (permanent teeth)
I – 3/3 C – 1/1 P – 3 or 4/3 M – 3/3 = 20 (or 21) x 2 = 40 (or 42)
Cattle
Temporary teeth
I – 0/4 C – 0/0 P – 3/3 M – 0/0 = 10 × 2 = 20
Permanent teeth
I – 0/4 C – 0/0 P – 3/3 M – 3/3 = 16 × 2 = 32
Sheep
Temporary teeth
I – 0/4 C – 0/0 P – 3/3 M – 0/0 = 10 × 2 = 32
Permanent teeth
I – 0/4 C – 0/0 P – 3/3 M – 3/3 = 16 × 2 = 32
Pigs
Temporary teeth
I – 3/3 C – 1/1 P – 4/4 M – 0/0 = 16 × 2 = 32
Permanent teeth
I – 3/3 C – 1/1 P – 4/4 M – 3/3 = 22 × 2 = 44
I = Incisors, C = Canines, P = Premolars and M = Molars

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2. Renvoisé E, Michon F. An Evo-Devo perspective on ever-growing teeth in mammals and dental stem cell maintenance. Front Physiol. 2014;5:324.
3. Tedeschi-Oliveira SV, Trigueiro M, Oliveira RN, Melani RF. Intercanine distance in the analysis of bite marks: a comparison of human and domestic dog dental arches. J Forensic Odontostomatol. 2011;29(1):30–36.

Multiple Choice Questions

1. Polyphyodont dentition means teeth that are
   (a) Replaced continuously throughout life
   (b) Replaced
   (c) Replaced once in life
   (d) None of the above
2. Isodont dentition refers to teeth that are
   (a) Functionally and anatomically dissimilar
   (b) Functionally and anatomically similar
   (c) Both a and b
   (d) None of the above
3. Concrescence theory was put forward by
   (a) Gregory
   (b) Osborn
   (c) Kukenthal and Rose
   (d) All of the above
4. Differentiation theory was formulated by
   (a) Cope
   (b) Osborn
   (c) Gregory
   (d) All of the above
5. The first digit of the Triadan system denotes
   (a) Tooth position
   (b) Proximity to midline
   (c) Quadrant
   (d) All of the above

CHAPTER 9



Terminologies in Tooth Morphology

Overview

Each tooth has two parts—crown and root—separated by a cervical line or cementoenamel junction. Each tooth is composed of the following surfaces: facial (labial/buccal), proximal (mesial/distal), masticatory (incisal/occlusal) and palatal/lingual surfaces. The crown and root are traditionally classified into three-third cervico-occlusally, faciolingually and mesiodistally for description purposes. The anatomical landmarks in the crown are cusp, tubercle, lobe, cingulum, ridge, fossa, groove, sulcus and pits while anatomical landmarks in the root are the apex, apical foramen, root trunk and furcation area.

INTRODUCTION

The subject *Tooth Morphology* involves the study of the anatomical topography of teeth. Learning about the terminologies is important to understand the subject in a better manner.

PARTS OF A TOOTH

Each tooth has two parts—crown and root—separated by a cervical line or cementoenamel junction (CEJ).

Crown

The crown is the portion of the tooth which is covered by enamel. The crown portion may have an incisal ridge or edge in the case of an incisor or a single or two or more cusps in the cases of canines, premolars and molars.

On the basis of the position of the crown in the oral cavity, two types of crown terminologies are used (**Fig. 9.1**) which are as follows:

1. **Anatomical crown:** It refers to the crown (entire) which is covered by enamel, regardless of whether it is completely erupted or not. The size of the anatomical crown remains constant throughout the lifetime of the tooth, except in cases of attrition or any other physical wearing of tooth surface.

Applied Morphology

If sufficient anatomical crown is not present for placing full restorative crowns, pins or posts can be placed in the root following root canal treatment to build up the crown height with restorative materials.

2. **Clinical crown:** It refers to the crown which is visible clinically, and it is what one sees when looking into the mouth. The height of the clinical crown is determined by the position of the gingival margin. The clinical crown may be smaller than the anatomical crown, such as in a newly erupted tooth where only a part of the anatomical crown is visible and the cervical portion of the crown is still covered by gingiva. The clinical crown can also be larger than the anatomical crown in cases where there has been recession of the gingiva with root exposure.

Root

The portion of the tooth covered by cementum is known as the root. The tooth may have either a single root or multiple roots. Single roots are seen in anterior teeth, mandibular premolars and maxillary second premolars. Multiple roots are seen in molars and premolars. In maxillary first premolars and mandibular molars, two roots are present, and in maxillary molars, three roots are present. *Bifurcation* or *trifurcation* is the term used for the division of the root into two or three segments, i.e., bifurcation is seen in maxillary first premolars and

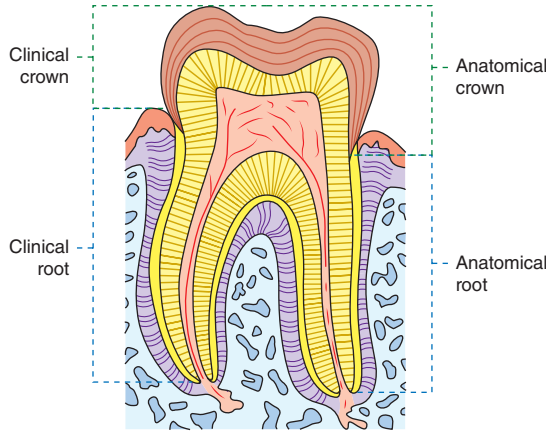


Figure 9.1 Posterior tooth showing clinical and anatomical crown and clinical and anatomical root.

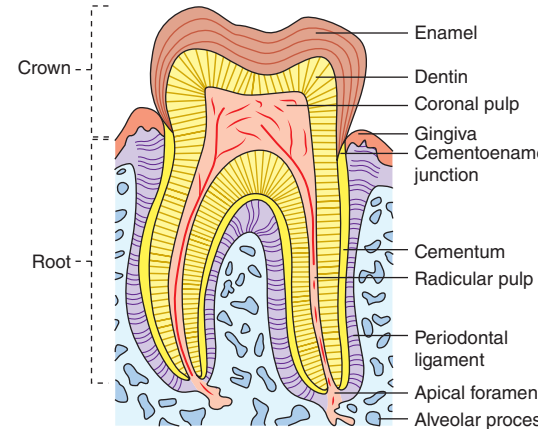


Figure 9.2 Section of a tooth, same as Figure 9.1, showing supporting structures.

mandibular molars and trifurcation is seen in maxillary molars.

On the basis of whether the root is visible in the oral cavity, two types of root terminologies are used (**Fig. 9.1**):

1. **Anatomical root:** It refers to the root that is below the CEJ and is covered with cementum, a bone-like substance that facilitates anchorage of the tooth in its bony socket (the alveolus). The size of the anatomical root remains constant throughout the lifetime of the tooth, except in cases of resorption of the root.

Applied Morphology

Root resorption can lead to reduction in the height of the anatomical root.

2. **Clinical root:** It refers to the part of tooth that is under the gingiva and not exposed to the oral cavity. The height of the clinical root is determined by the position of the gingival margin. It may be longer than the anatomical root such as in newly erupted teeth where the part of the crown that is not erupted is considered part of the clinical root. It may also be shorter than the anatomical root in elderly persons, where there is gingival recession and part of the anatomical root is exposed to the oral cavity.

Cervical Line

The cervical line separates the anatomical crown from the anatomical root. It is the junction between two tissues of the tooth, enamel and cementum, and hence is known as the cementoenamel junction or simply the CEJ (**Fig. 9.2**). This region of the tooth is also called the cervix of the tooth because it appears constricted between the crown and the root portions.

STRUCTURE OF THE TOOTH

The tooth comprises three hard-tissue and one soft-tissue components. The hard-tissue components are enamel, dentin and cementum. The soft-tissue component is the pulp tissue. The hard tissues are mostly inorganic or calcified, with a large mineral content; they surround the soft tissue as a protective covering except at the apical foramen area.

Enamel

Enamel is the hard, highly mineralized, protective, white, shiny structure covering the outermost layer of the anatomical crown (**Fig. 9.2**). It is the hardest substance in the human body. It does not contain living cells, so it is incapable of remodelling or repairing.

Enamel is composed of 95% mineral content (calcium hydroxyapatite), 4% water and 1%

enamel matrix (organic matrix). The colour of the enamel depends on two factors—mineralization and thickness of the enamel—and can range from greyish white to yellowish white. Enamel develops from the enamel organ (ectoderm) by formation of a specialized type of epithelial cell called *ameloblast*, and the process of enamel formation is known as *amelogenesis*.

Dentin

Dentin is the hard, mineralized, yellowish tissue present in both the crown and the root. It makes up the major bulk of the tooth, is present beneath the enamel and cementum and lines the pulp cavity (**Fig. 9.2**). The *dentinoenamel junction* separates the enamel and dentin and the *cementodentinal junction* (CDJ) separates the cementum and dentin.

Dentin is composed of 70% mineral content (calcium hydroxyapatite), 12% water and 18% dentin matrix (organic matrix) and hence is softer than enamel. Dentin develops from the *odontoblasts* which are specialized cells that develop from the dental papilla. The process of formation of dentin is known as *dentinogenesis*. Odontoblasts line the pulp and are capable of remodelling or repairing by forming secondary and reparative dentin.

Cementum

Cementum is the mineralized, dull, yellowish tissue covering the outermost layer of the anatomical root extending from the cervical line (**Fig. 9.2**). The *CEJ* is the junction between the enamel and the cementum. The cementum protects and anchors the tooth in the alveolus through the attachment of the periodontal fibres.

Cementum is composed of 65% mineral content (calcium hydroxyapatite), 12% water and 23% organic matrix and is thus softer than enamel and dentin. Cementum is developed from the dental sac (mesoderm) by a specialized type of cell called *cementoblast,* and the process of cementum formation is known as *cementogenesis*.

Pulp

Pulp is the soft tissue present in the central, innermost portion of the tooth called the pulp cavity (**Fig. 9.2**). It is completely covered by the dentin layer except near the apical foramen. Apical foramen is the opening of the pulp cavity near the apex of the tooth through which the blood vessels and nerves enter the pulp. The pulp is divided into two parts: coronal pulp, which is present in the crown portion, and radicular pulp, which is present in the root portion (**Fig. 9.2**).

Pulp develops from the dental papilla (mesoderm) and is composed of connective tissue, nerves and blood vessels. It has formative, sensory, nutritive and protective functions during the life of the tooth.

SUPPORTING STRUCTURES OF THE TOOTH

The supporting structures of the teeth are collectively known as the periodontium, which helps in attaching the tooth to surrounding tissues as well as allowing the sensation of touch and pressure. The periodontium consists of the cementum, periodontal ligament, alveolar bone and gingiva. Of these, the cementum is the only structure that is a part of the tooth.

Alveolar Bone

The root portion of the tooth is fixed firmly within the tooth socket of the jaws called the *alveolus* with the help of the *periodontal ligament*. The portion of the jaw (maxillary or mandibular) which anchors and supports the teeth is known as the *alveolar process* or the *alveolar bone.*

Periodontal Ligament

The periodontal ligament develops from the dental sac (mesoderm) and is composed of periodontal ligament fibres attached to the alveolar bone on one side and the cementum of the tooth on the other side.

Gingiva

The crown portion, and sometimes part of the cervical cementum, is partly covered by the soft tissue of the mouth known as the *gingiva* or the *gums* (**Fig. 9.2**).

SURFACES OF THE TEETH

In addition to identifying and naming teeth, it is important to name the tooth's individual surfaces. The surfaces are named according to their position in the oral cavity and also their uses. The number of surfaces of a tooth is different for anterior and posterior teeth.

Anterior teeth are those closer to the midline and comprise central incisor, lateral incisor and canine. Anterior teeth have four surfaces—labial, palatal/lingual, mesial and distal—and one ridge—incisal ridge.

Posterior teeth are those away from the midline and comprise premolars and molars. Posterior teeth have five surfaces: buccal, palatal/lingual, mesial, distal and occlusal.

Facial Surface

The surface of the tooth nearest to the cheeks or lips is referred to as the facial surface. The facial surface can be subdivided into labial surface and buccal surface (Fig. 9.3):

1. **Labial surface:** It is the facial surface closest to the lips and is present in anterior teeth.
2. **Buccal surface:** It is the facial surface closest to the cheeks and is present in posterior teeth.

Applied Morphology

Abrasion is most commonly seen in the facial surfaces of the teeth mostly in relation to canines, premolars and molars which may be the result of abnormal brushing habits.

Palatal Surface

In the maxillary arch, the surface of the tooth closest to the palate is termed *palatal surface* (Fig. 9.3).

Lingual Surface

In the mandibular arch, the surface of the tooth closest to the tongue is termed *lingual surface* (Fig. 9.3).

Applied Morphology

Erosion is seen in the lingual aspect of anterior teeth because of the effect of acids present in soft drinks.

Proximal Surface

The surface of a tooth that is towards another tooth in the dental arch is termed proximal surface. The proximal surface can be subdivided into two surfaces on the basis of position in relation to the median line of the face. The median line is an imaginary line on the median sagittal plane that

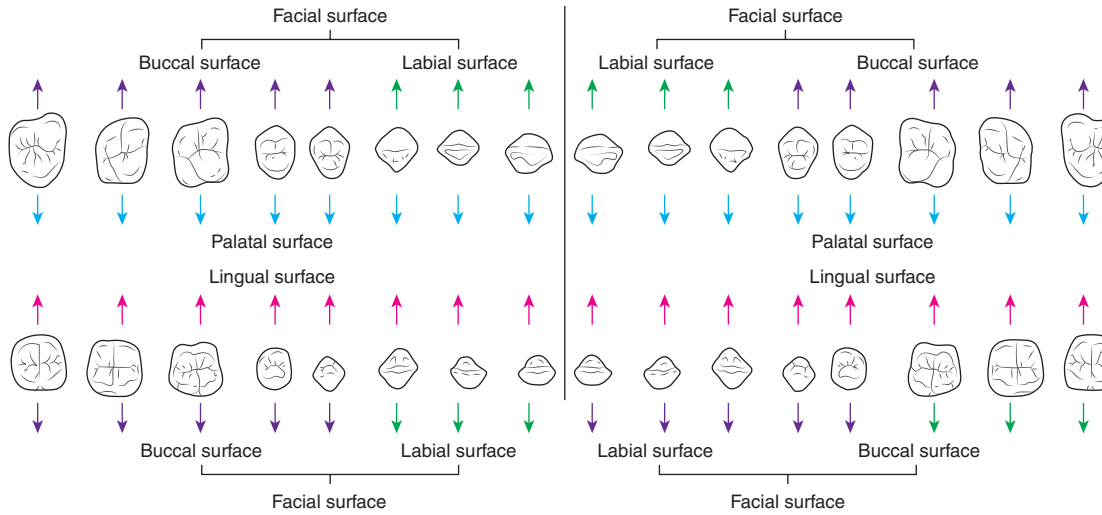


Figure 9.3 Facial (labial and buccal), palatal and lingual surfaces of the teeth.

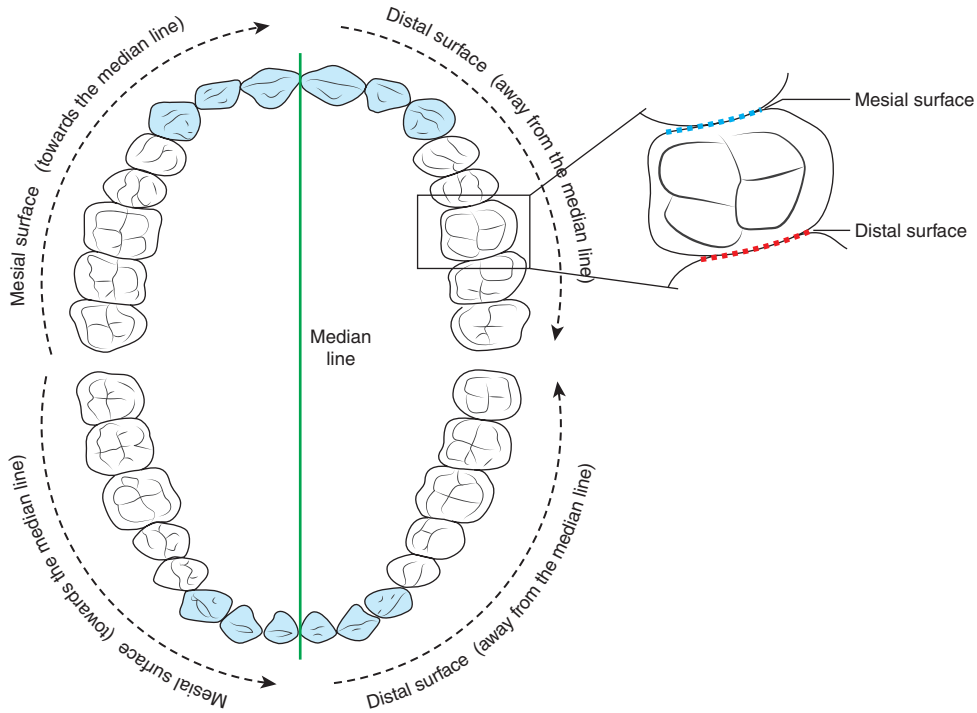


Figure 9.4 Proximal (mesial and distal) surface of the teeth.

bisects the dental arch at the centre. Each tooth has two proximal surfaces: mesial and distal (Fig. 9.4):

1. **Mesial surface:** The surface that is towards or closer to the median line of the face.
2. **Distal surface:** The surface that is away or distant from the median line of the face.

The mesial surfaces of all teeth contact the distal surface of the adjacent teeth, except between the central incisors where the mesial surface contacts the adjacent mesial surface. In the permanent third molars and deciduous second molars, the distal surface has no contact with any other tooth.

Masticatory Surface

The surface that aids in chewing is known as the masticatory surface. The masticatory surface is subdivided into the occlusal surface in the posterior teeth and the incisal surface in the anterior teeth (Fig. 9.5):

1. **Occlusal surface:** It is the chewing surface of the posterior teeth that articulates with an antagonist tooth in the opposing arch.
2. **Incisal surface:** It is the cutting surface of the anterior teeth. In newly erupted teeth, the incisal surface appears rounded and narrow and is termed *incisal ridge* instead of incisal surface. When the incisal ridge becomes flat due to wear and tear, it is termed *incisal edge*.

Applied Morphology

Increased attrition at a younger age is seen in the masticatory surface of the teeth which may be the result of bruxism/night grinding habit.

DIVISION OF THE SURFACES OF THE TEETH

For purposes of description and for locating the various areas on a specific tooth surface, the crowns and roots are arbitrarily divided into thirds and are named according to their location.

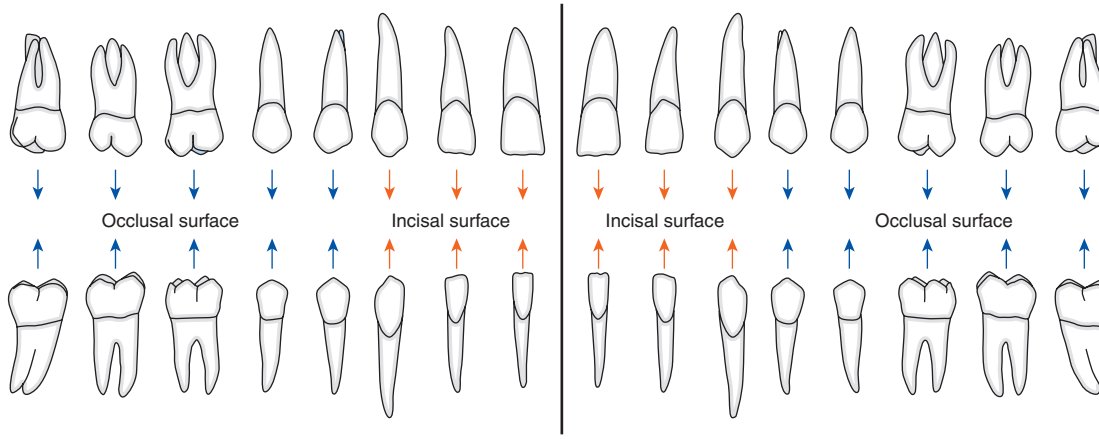


Figure 9.5 Masticatory (occlusal and incisal) surface of the teeth.

Division of the Crown into Thirds

The crown can be divided into thirds in three ways:

1. **Cervico-occlusally/cervicoincisally:** The facial, lingual/palatal and proximal surfaces of the crown can be divided into thirds (**Fig. 9.6**) cervico-occlusally/cervicoincisally by equally spaced horizontal lines. They are divided into the following:
   (a) Occlusal/incisal third
   (b) Middle third
   (c) Cervical third
2. **Faciolingually:** The proximal surfaces of the crown can be divided into thirds (**Fig. 9.7**) faciolingually by equally spaced vertical lines. The divisions are as follows:
   (a) Facial (labial/buccal) third
   (b) Middle third
   (c) Palatal/lingual third
3. **Mesiodistally:** The facial and lingual/palatal surfaces of the crown can be divided into thirds (**Fig. 9.8**) mesiodistally by equally spaced vertical lines. The divisions are as follows:
   (a) Mesial third
   (b) Middle third
   (c) Distal third

Division of the Root into Thirds

The root can be divided into thirds in the following three ways:

1. **Cervicoapically:** The facial, lingual/palatal and proximal surfaces of the root can be divided into thirds (**Fig. 9.6**) cervicoapically by equally spaced horizontal lines. The divisions are as follows:
   (a) Cervical third
   (b) Middle third
   (c) Apical third

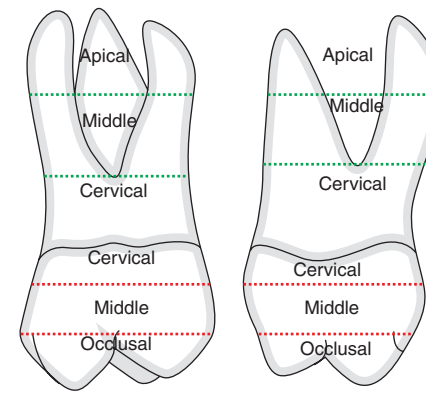


Figure 9.6 Division of the crown cervico-occlusally and root cervicoapically.

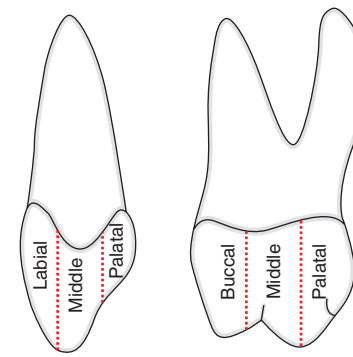


Figure 9.7 Division of the crown faciolingually.

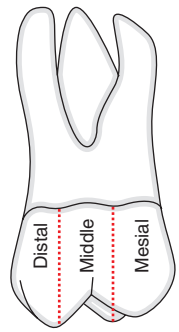


Figure 9.8 Division of the crown mesiodistally.

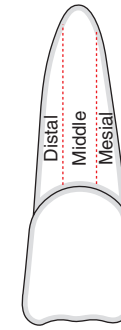


Figure 9.10 Division of the root mesiodistally.

2. **Faciolingually:** The proximal surfaces of the root can be divided into thirds (**Fig. 9.9**) faciolingually by equally spaced vertical lines. The divisions are as follows:
   (a) Facial (labial/buccal) third
   (b) Middle third
   (c) Palatal/lingual third
3. **Mesiodistally:** The facial and lingual/palatal surfaces of the root can be divided into thirds (**Fig. 9.10**) mesiodistally by equally spaced vertical lines. The divisions are as follows:
   (a) Mesial third
   (b) Middle third
   (c) Distal third

LINE ANGLES

A line or a point where two or more surfaces or borders meet is known as an *angle*. A line angle is an angle formed by the junction or union of two surfaces and the name is derived from both the surfaces. For example, the junction between labial and distal surfaces is termed *distolabial line angle*.

The anterior teeth have six line angles and the posterior teeth have eight line angles (**Fig. 9.11**; **Table 9.1**).

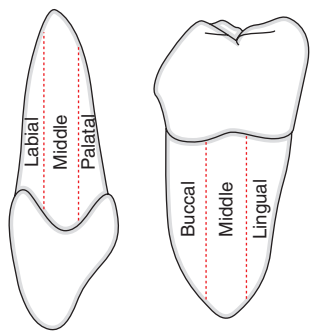


Figure 9.9 Division of the root faciolingually.

POINT ANGLES

A point angle is an angle formed by the junction or union of three surfaces, and the name is derived from the three surfaces. For example, the junction between labial, mesial and incisal surfaces is termed *mesio-labio-incisal point angle*.

The anterior and posterior teeth have four point angles each (**Table 9.2**; **Fig. 9.12**).

Table 9.1 Line Angles

Line Angles of Anterior Teeth[a]	Line Angles of Posterior Teeth
• Mesiolabial	• Mesiopalatal/ mesiolingual
• Mesiopalatal/ mesiolingual	• Distobuccal
• Distolabial	• Distopalatal/distolingual
• Distopalatal/distolingual	• Bucco-occlusal
• Labio-incisal	• Linguo-occlusal
• Linguo-incisal	• Mesio-occlusal
• Mesiobuccal	• Disto-occlusal

[a]Since the mesioincisal and distoincisal line angles are rounded, they are not considered line angles.

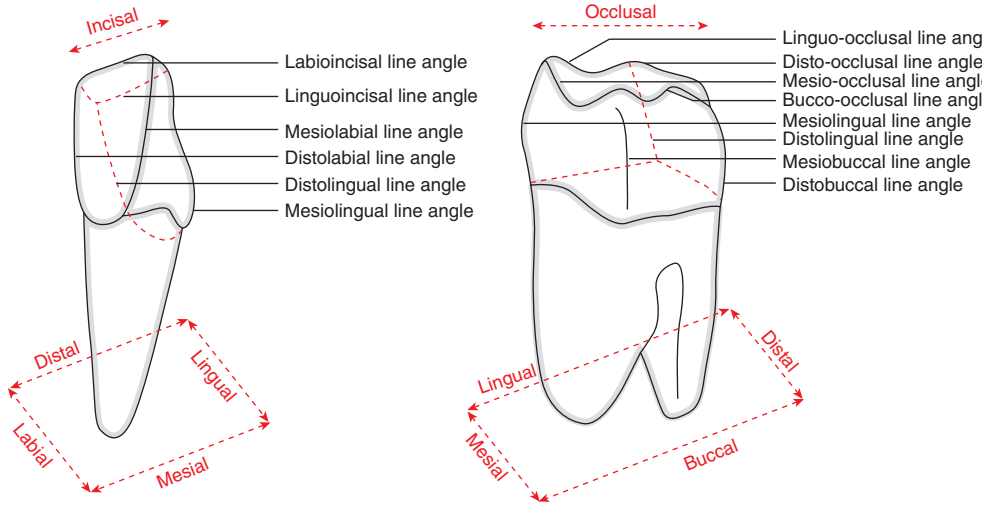


Figure 9.11 Line angles of the anterior and posterior teeth.

Table 9.2 Point Angles

Point Angles of Anterior Teeth	Point Angles of Posterior teeth
• Mesio-labio-incisal • Mesio-palato-incisal/ mesio-linguo-incisal • Disto-labio-incisal • Disto-palato-incisal/ disto-linguo-incisal	• Mesio-bucco-occlusal • Mesio-palato-occlusal/ mesio-linguo-occlusal • Disto-bucco-occlusal • Disto-palato-occlusal/ disto-linguo-occlusal

ANATOMICAL LANDMARKS ON THE TOOTH SURFACE

Elevations, depressions and grooves are present on the surfaces of teeth, and different terminologies are used to describe these landmarks. Some landmarks may be used to identify a particular tooth. Hence, it is necessary to know about the individual landmarks on the tooth surface.

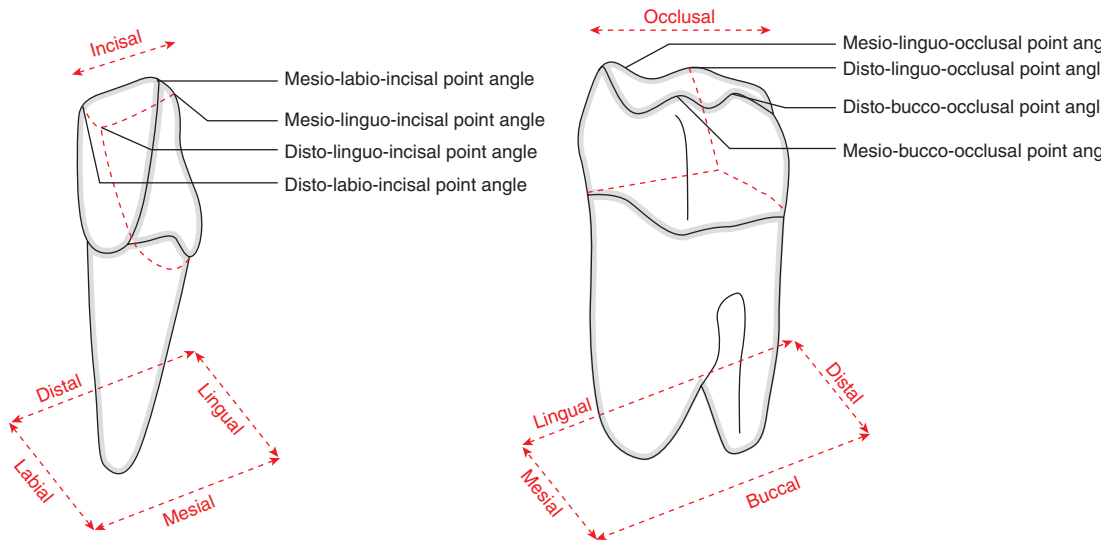


Figure 9.12 Point angles of the anterior and posterior teeth.

Anatomical Landmarks on the Crown Surface

Cusp

A cusp is an elevation on an occlusal surface of posterior teeth and canines. It contributes to a significant portion of the tooth surface and divides the occlusal surface of posterior teeth. It is present on the occlusal surface of molar and premolar teeth and on the incisal edges of canines. Each cusp represents the developmental lobes of a tooth. The cusp contributes to a significant portion of the tooth's surface. Each cusp has four cusp slopes/ridges and an apex.

The cusps are named according to the location on the tooth surface. The number of cusps may vary according to the type of teeth—canines have one cusp, maxillary premolars and mandibular first premolars usually have two cusps, mandibular second premolars may have either two or three cusps, maxillary molars have four and mandibular molars may have four or five cusps (**Fig. 9.13**).

Tubercle

Tubercle is a small, rounded prominence on the surface of tooth resulting from the extra formation of enamel (**Fig. 9.14**). Tubercles are usually deviations from the normal form. For example, the cusp of Carabelli is a tubercle.

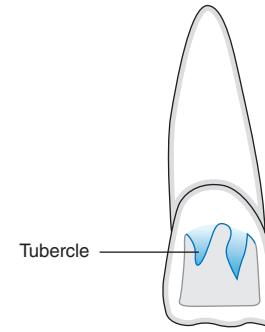


Figure 9.14 Permanent maxillary lateral incisor with tubercles.

The *cusp of Carabelli* is a fifth cusp present on the palatal surface of the maxillary first molars.

Applied Morphology

One or more tubercles may be present on the cingulum of permanent maxillary lateral incisors, which are termed Talon's cusps.

The presence of an accessory cusp or a globule of enamel on the occlusal surface of premolars is termed dens evaginatus/Leong's premolar.

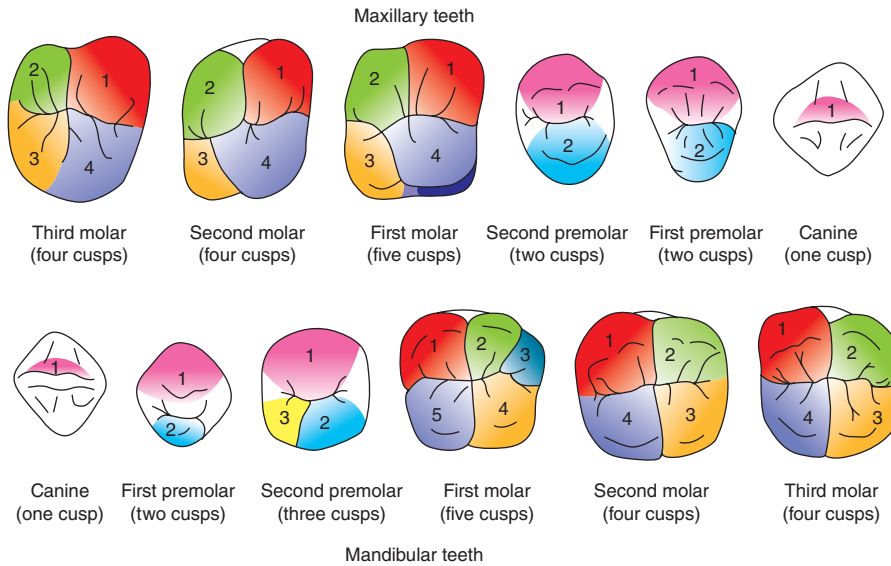


Figure 9.13 Number of cusps in maxillary and mandibular teeth.

Cingulum

Cingulum is a bulge or elevation on the lingual surface of incisors or canines (Fig. 9.15). It is the lingual lobe of the anterior teeth and makes up the bulk of the cervical third of the lingual surface. The term *cingulum* comes from a Latin word meaning *girdle*, since it encircles the lingual surface of the tooth mesiodistally in the form of a girdle.

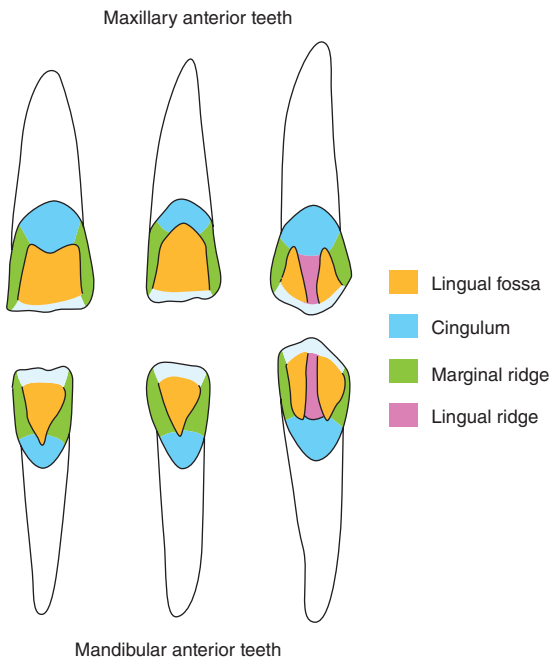


Figure 9.15 Lingual aspect of the anterior teeth.

Lobe

Developmental lobe is the growth centre in the development of the crown of the tooth (Fig. 9.16). Each tooth begins to develop from four or more developmental lobes, and they appear as cusps and mamelons on the tooth surface. Deciduous incisors develop from one lobe and deciduous molars develop from five lobes (three facial and two lingual). Permanent anterior teeth, maxillary premolars and mandibular first premolars develop from four lobes (three labial and one lingual). Permanent mandibular second premolars and permanent mandibular molars develop from five lobes (three buccal and two lingual). Permanent maxillary molars develop from four lobes (two buccal and two lingual).

Mamelons

Mamelons are the protrusions seen in the incisal ridges of newly erupted permanent incisor teeth (Fig. 9.17). They represent the three lobes from which the labial surface forms, and they are separated by developmental grooves.

Applied Morphology

Mamelons wear off because of attrition which leads to the formation of the incisal edge.

Ridges

Ridges are any linear, flat elevations on teeth, and they are named according to their location or form.

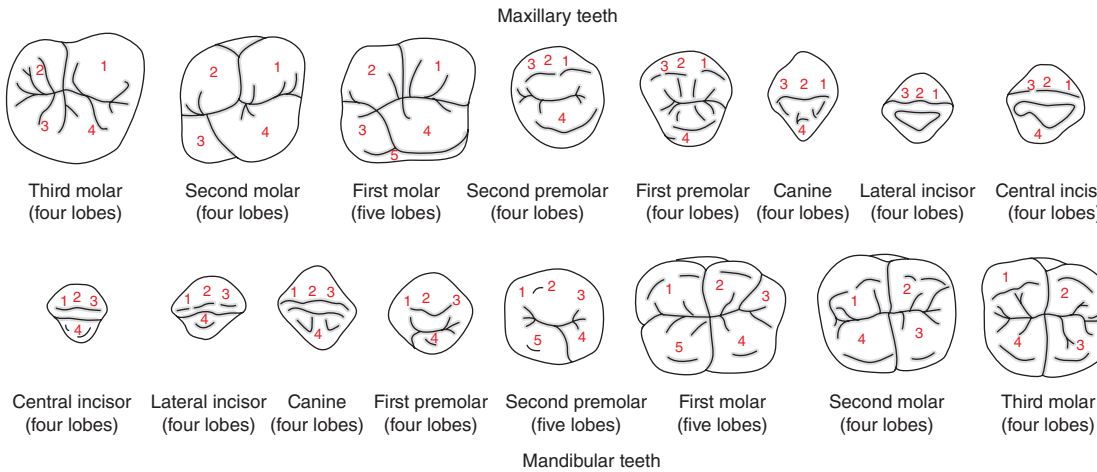


Figure 9.16 Developmental lobes.

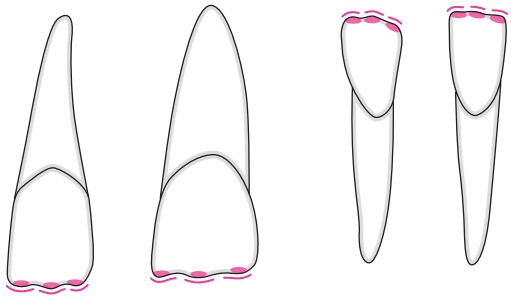


Figure 9.17 Mamelons in the anterior teeth.

Several specific types of ridges can be identified as follows:

1. **Labial ridge:** It is the ridge running cervicoincisally, approximately at the centre of the labial surface of the canines (**Fig. 9.18**). It extends from the cusp tip to the cervical region of the tooth. This ridge is very prominent in maxillary canines as compared to mandibular canines.
2. **Buccal ridge:** It is the ridge running cervico-occlusally, approximately at the centre of the buccal surface of the premolars (**Fig. 9.19**). It extends from the cusp tip to the cervical region of the tooth. This ridge is very prominent in the first premolar compared with the second premolars.
3. **Incisal ridge:** It is present in the incisal portion of newly erupted incisors, where the incisal surface is rounded and merges with the mesioincisal and distoincisal angles and the labial and lingual surfaces (**Fig. 9.20**).
4. **Lingual ridge:** It is the ridge running cervicoincisally, approximately at the centre of the lingual surface of the canines (**Fig. 9.15**). It extends from the cusp tip to the cingulum in the cervical third, thereby dividing the lingual fossa into two parts. This ridge is also more prominent in maxillary canines than in mandibular canines.
5. **Linguoincisal ridge:** It is the ridge running mesiodistally in the lingual surface at the incisal third level (**Fig. 9.21**).

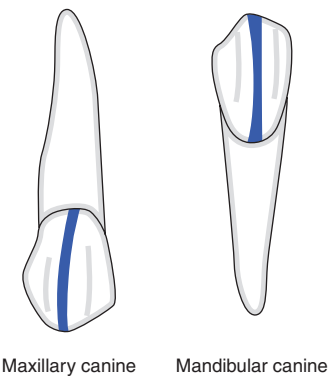


Figure 9.18 Labial ridge.

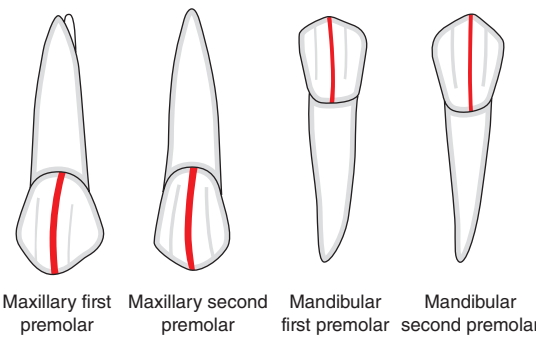


Figure 9.19 Buccal ridge.

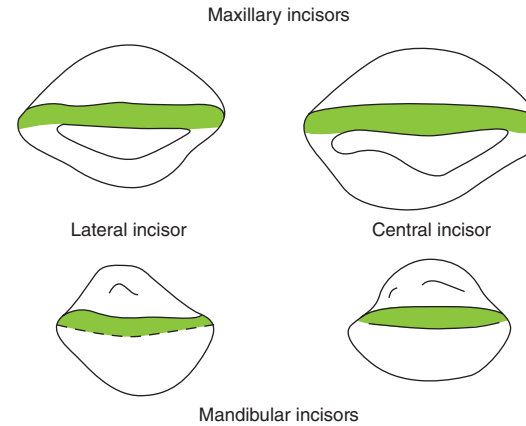


Figure 9.20 Incisal ridge.



Figure 9.21 Linguoincisal ridge.

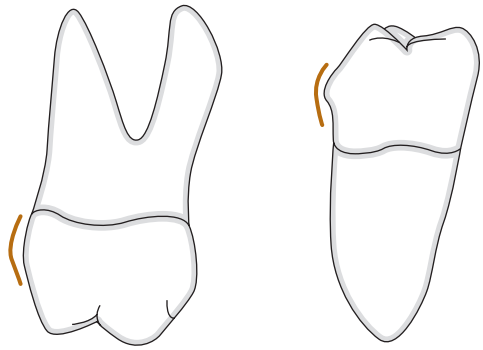


Figure 9.22 Buccal cervical ridge.

6. **Cervical ridge:** It is the ridge running mesiodistally on the cervical third of the buccal surface of the crown (**Fig. 9.22**). It is found on all primary teeth and on permanent molars.
7. **Marginal ridge:** It is a linear, rounded border of enamel that forms the mesial and distal margins of occlusal surfaces on posterior teeth and the mesial and distal margins of the incisors and canines lingually. In anterior teeth, the marginal ridges run vertically in the cervicoincisal direction (**Fig. 9.15**) and in posterior teeth, these run horizontally in the buccolingual direction (**Fig. 9.23**).
8. **Cusp ridge:** It refers to the inclined surface or ridge that forms an angle at the cusp tip (**Fig. 9.24**). Cusp ridges are also termed *cusp arms*.

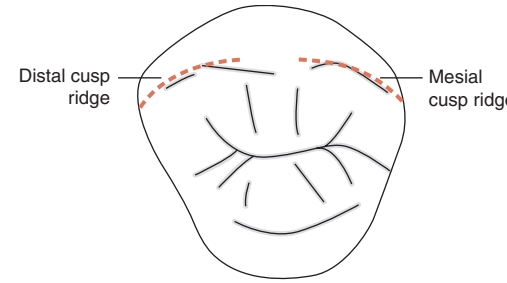


Figure 9.24 Cusp ridge in the maxillary first premolar.

9. **Triangular ridge:** It is the ridge descending from the tips of the cusps of molars and premolars towards the central part of the occlusal surface (**Fig. 9.25**). In cross-section, these ridges are more or less triangular and hence are termed *triangular ridges*. These are named according to the cusp to which they belong.
10. **Transverse ridge:** It is a type of ridge that crosses the occlusal surface of posterior teeth transversely and is created when the buccal and lingual triangular ridges join (**Fig. 9.26**).
11. **Oblique ridge:** It is the ridge that crosses the occlusal surface of the maxillary molars obliquely. It extends from the triangular ridge of the distobuccal cusp to the distal cusp ridge of the mesiopalatal cusp (**Fig. 9.27**).

Fossa

Fossa is an irregular, rounded depression or concavity found on the lingual surface of anterior

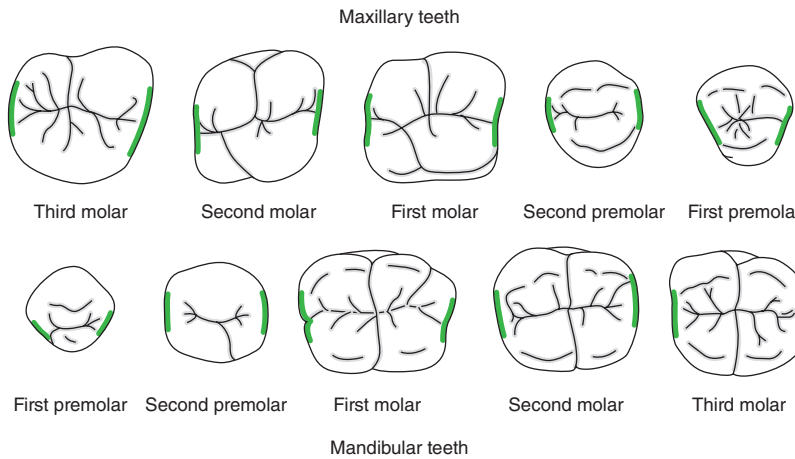


Figure 9.23 Marginal ridge in the posterior teeth.

SECTION II

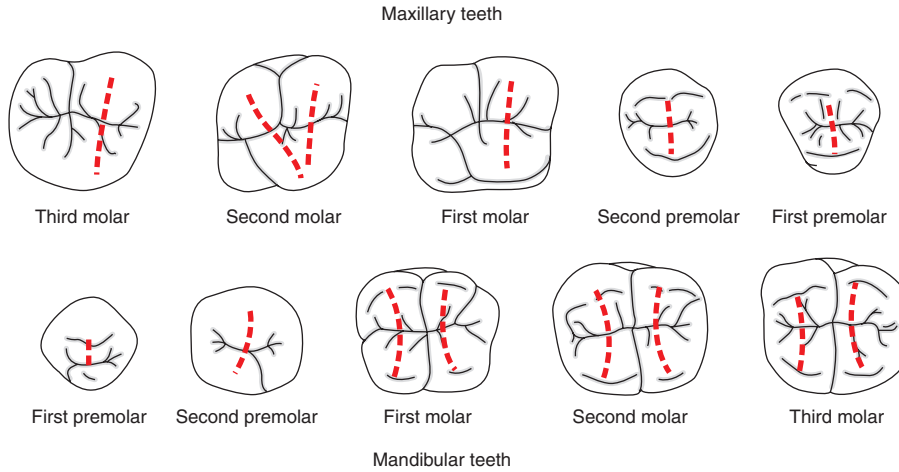


Figure 9.25 Triangular ridge.

teeth and occlusal surface of posterior teeth. The point of convergence of the ridges and the junction of the grooves form the depression or fossa in posterior teeth. Different types of fossa are as follows:

1. **Lingual fossa:** It is found on the lingual surface of the anterior teeth. It is bound by the linguoincisal ridge, cingulum and marginal ridges. In canine teeth, the lingual fossa is divided into two by the lingual ridge running cervicoincisally (**Fig. 9.15**).
2. **Central fossa:** It is a major fossa found on the occlusal surface of the molar teeth (**Fig. 9.28**).
3. **Distal fossa:** It is a major fossa found distal to the oblique ridge in the occlusal surface of the maxillary molars (**Fig. 9.28**).
4. **Triangular fossa:** It is a minor fossa found mesial as well as distal to the marginal ridges on the occlusal surface of premolars and molars and is termed *mesial triangular fossa* or *distal triangular fossa* depending on its location. Mesial triangular fossa is seen distal to the mesial marginal ridge and distal triangular fossa is seen mesial to the distal marginal ridge (**Fig. 9.29**).

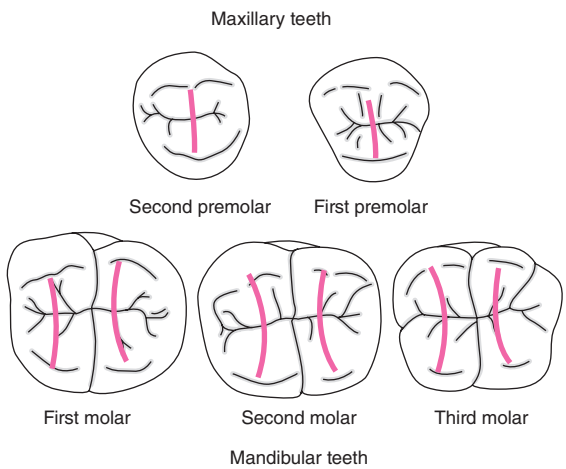


Figure 9.26 Transverse ridge.

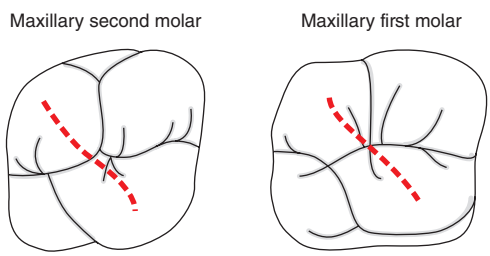


Figure 9.27 Oblique ridge.

Sulcus

Sulcus is a long, linear depression or valley in the occlusal surface of the posterior teeth, the inclines of which meet at an angle to form a developmental groove.

Developmental Groove

The developmental groove is a sharply defined, narrow and linear depression formed during tooth

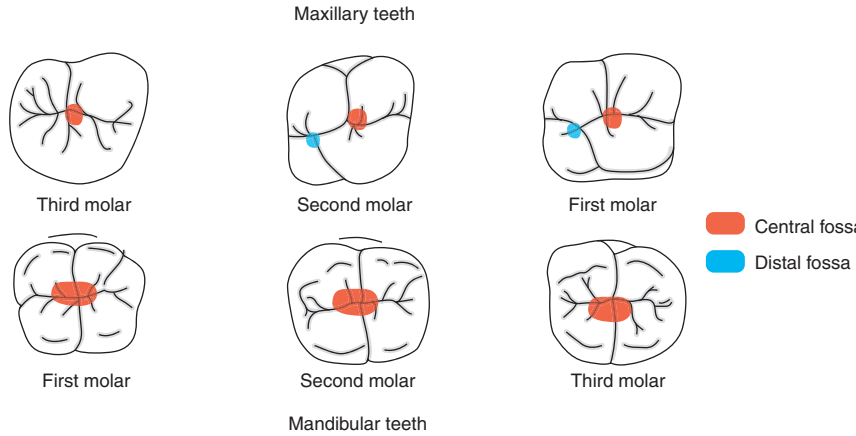


Figure 9.28 Central and distal fossa.

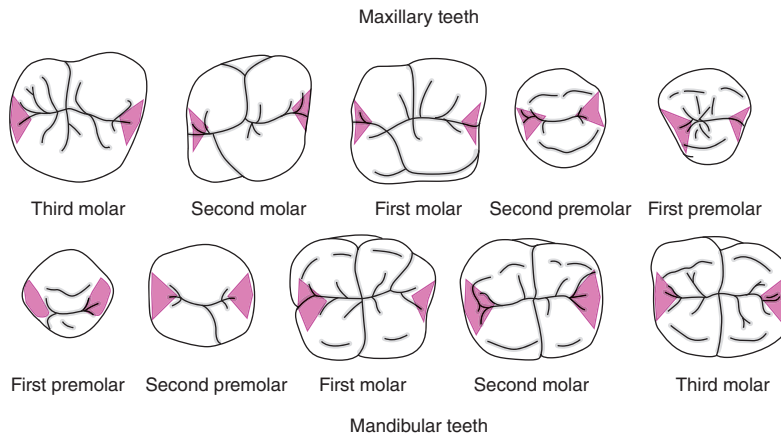


Figure 9.29 Mesial and distal triangular fossa.

development, usually separating the lobes or the major portions of a tooth (Fig. 9.30). The various types are as follows:

1. **Central developmental groove:** It is a groove separating the occlusal aspect of posterior teeth.
2. **Buccal developmental groove:** It is a groove separating the buccal cusps on the occlusal aspect of molar teeth and extending onto the buccal surface for a short distance.
3. **Lingual developmental groove:** It is a groove separating the lingual cusps on the occlusal aspect of maxillary and mandibular molars and mandibular second premolars and extending onto the lingual surface for a short distance.
4. **Supplemental groove:** It is a shallow linear depression, usually less distinct and more variable than a developmental groove; it does not mark the junction of the lobes or the major portions of a tooth (Fig. 9.31).

Pits

Pits are small, pinpoint depressions usually seen in the fossa of the posterior teeth. They are found at the ends or cross-sections of the developmental

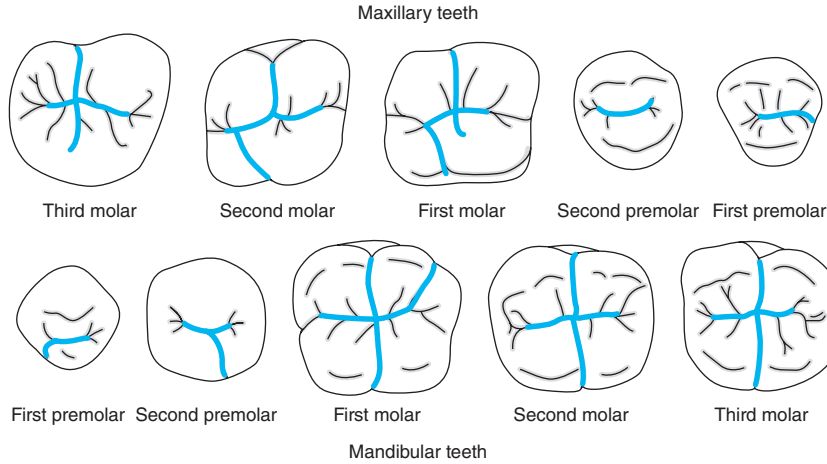


Figure 9.30 Developmental grooves.

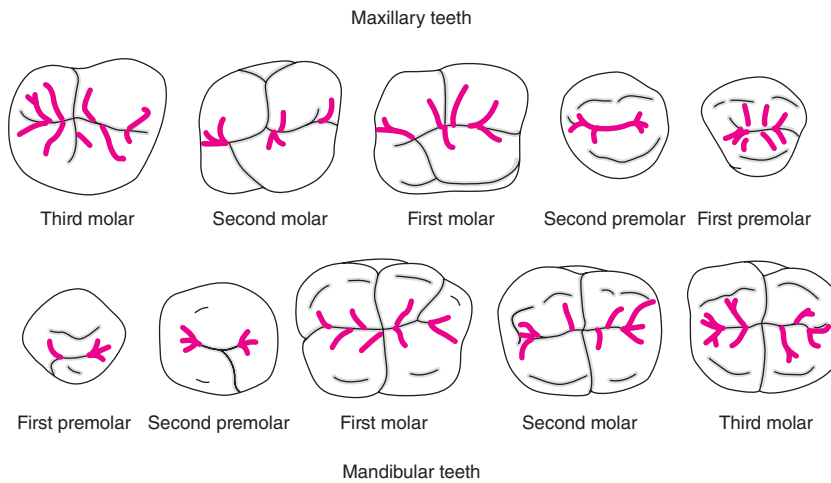


Figure 9.31 Supplemental grooves.

grooves (**Fig. 9.32**). Pits are named according to their location.

1. **Central pit:** It is found in the central fossa on the occlusal surfaces of molars where developmental grooves join.
2. **Buccal pit:** It is found on the buccal surface of molars where the buccal developmental groove terminates.
3. **Lingual pit:** It is found on the lingual surface of molars where the lingual developmental groove terminates.
4. **Mesial pit:** It is found in the mesial triangular fossa on the occlusal surface of premolars and molars.
5. **Distal pit:** It is found in the distal triangular fossa on the occlusal surface of premolars and molars.

Fissures

A fissure is a sharp crevice between cusp and ridges, formed because of the faulty union of the enamel of the different lobes; it is formed at the bottom of the developmental grooves.

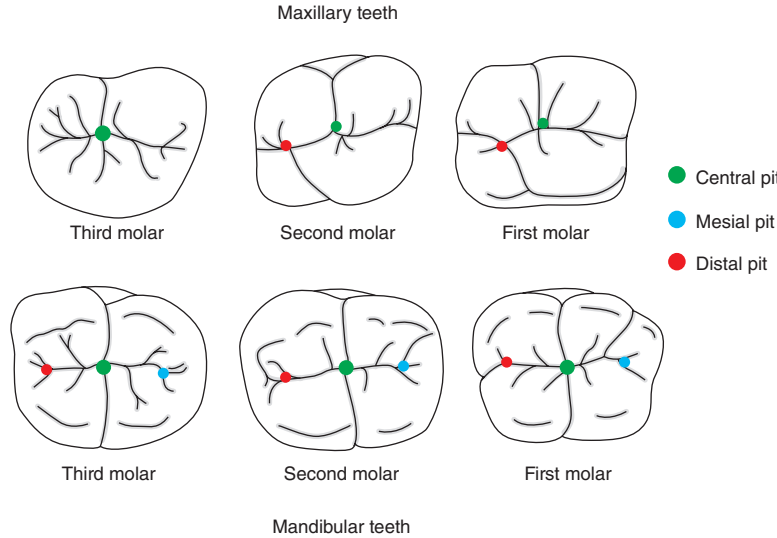


Figure 9.32 Developmental pits.

Applied Morphology

Pits, fissures and grooves are the sites of initiation of dental caries. This can be prevented by sealing the pits and fissures using pit and fissure sealants.

Contact Area

Contact areas/points are the crests of curvature on the proximal surface of two adjacent teeth in the same dental arch that come in contact with each other. In newly erupted teeth, the contact is small in size and is termed *contact point*. As age advances, because of constant rubbing of the proximal surface, the contact becomes broad and is termed *contact area* (**Fig. 9.33**).

Each tooth has two contact points—mesial and distal—except for deciduous second molars and permanent third molars, which have only one contact point (mesial). In each tooth, the position of the

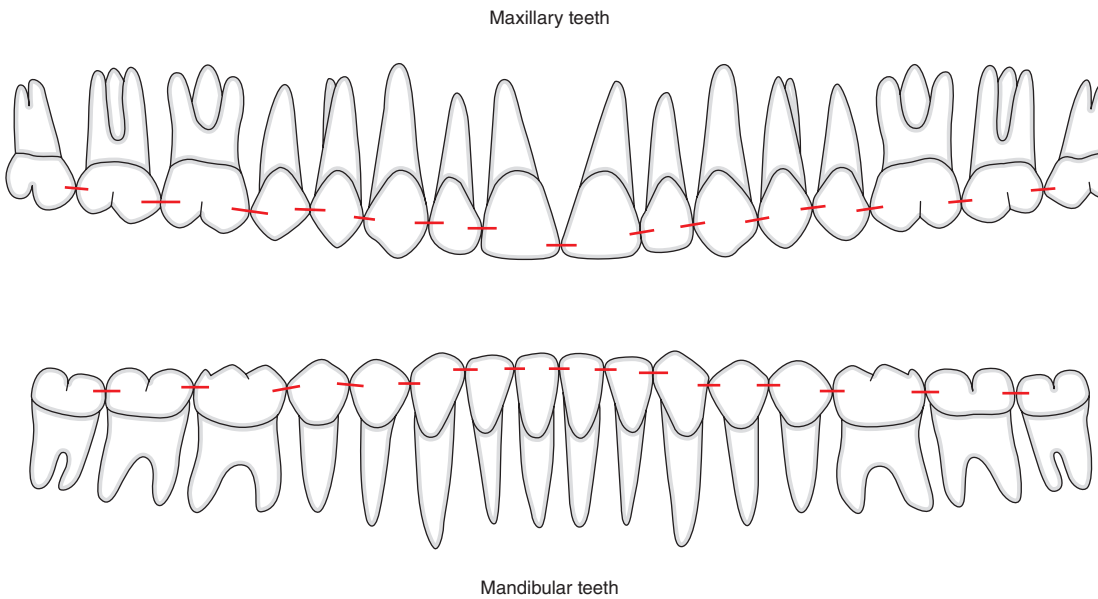


Figure 9.33 Contact areas of the permanent teeth.

contact point varies—incisal/occlusal third, middle third or the junction of middle and incisal third.

Contact points/areas have specific functions:

1. Stabilize the tooth within the alveolus
2. Prevent food impaction
3. Protect the interdental papilla

Interproximal Space

The interproximal space is the triangular or V-shaped space cervical to the contact area. The proximal surface of the adjacent teeth form the sides of the triangle, the contact area forms the apex and the alveolar bone forms the base of the triangle (**Fig. 9.35**). This space is usually filled by the interdental papilla from the gingiva. In case of gingival recession, the interproximal space transforms into a cervical embrasure as the interdental bone and the interdental papilla do not fill up that space.

Embrasures

When two teeth in the same arch are in contact, their curvatures adjacent to the contact areas form V-shaped spillway spaces or triangular spaces known as embrasures. The main difference between the interproximal spaces and the embrasures is that interproximal spaces are filled with the interdental gingiva, whereas embrasures are empty spaces adjacent to the teeth. These embrasures are formed occlusal or adjacent or cervical to the contact areas.

On the basis of their positions, there are four embrasures for every contact area (**Figs 9.34** and **9.35**):

1. Facial (labial or buccal) embrasure widens out facially from the contact area.
2. Lingual/palatal embrasure widens out lingually from the contact area.

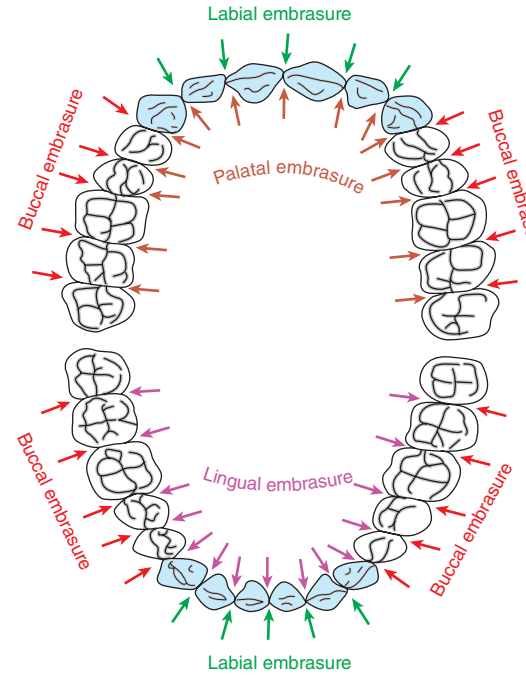


Figure 9.34 Occlusal/incisal embrasure and interproximal space.

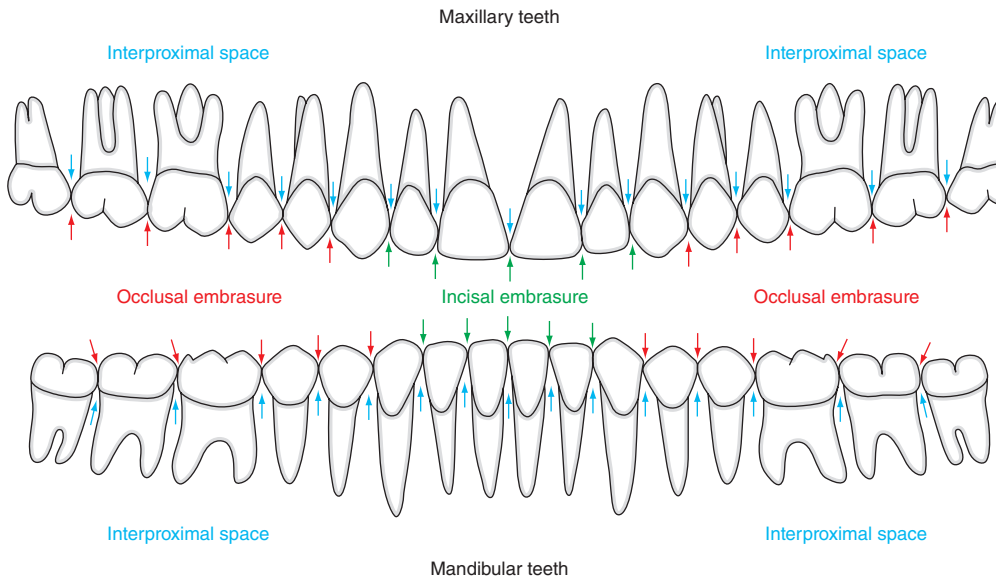


Figure 9.35 Facial and lingual/palatal embrasure.

3. Occlusal or incisal embrasure widens out occlusally/incisally from the contact area.
4. Gingival embrasure, otherwise known as cervical embrasure, is seen cervical to the contact area in the region of the interproximal space. This space is usually not present except in cases where the interdental gingiva and the bone do not fill up the interproximal space.

Embrasures have specific functions as follows:

1. Form spillways between teeth to direct food away from the gingiva
2. Provide a mechanism for teeth to be more self-cleansing
3. Protect the gingiva from undue frictional trauma by providing the proper degree of stimulation to the tissues

Anatomical Landmarks on the Root Surface

Apex

The terminal end of the root portion of the tooth is termed the *apex*.

Apical Foramen and Accessory Foramen

The apical foramen is the opening of the pulp canal at the apical end of the root through which blood and nerve supply pass into the pulp canal (**Fig. 9.2**). The accessory foramen is a channel leading from the root pulp laterally through the dentin to the periodontal tissue; it may be found anywhere in the tooth root but is more common in the apical third of the root.

Applied Morphology

In case of root canal treatment, improper cleaning of the accessory canals can lead to the failure of the treatment.

Accessory canals can cause spread of infection from one site to another. Infection from the tooth pulp can be transmitted to the periodontal space, or infection from the periodontium can pass into the pulp tissue.

Root Trunk

In multirooted teeth, the undivided cervical portion of the root is termed *root trunk* (**Fig. 9.36**).

Furcation

In multirooted teeth, the division of the root is termed *furcation* (**Fig. 9.36**). It is called bifurcation if the root is divided into two parts and trifurcation if the root is divided into three parts.

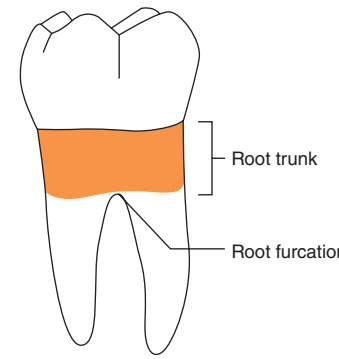


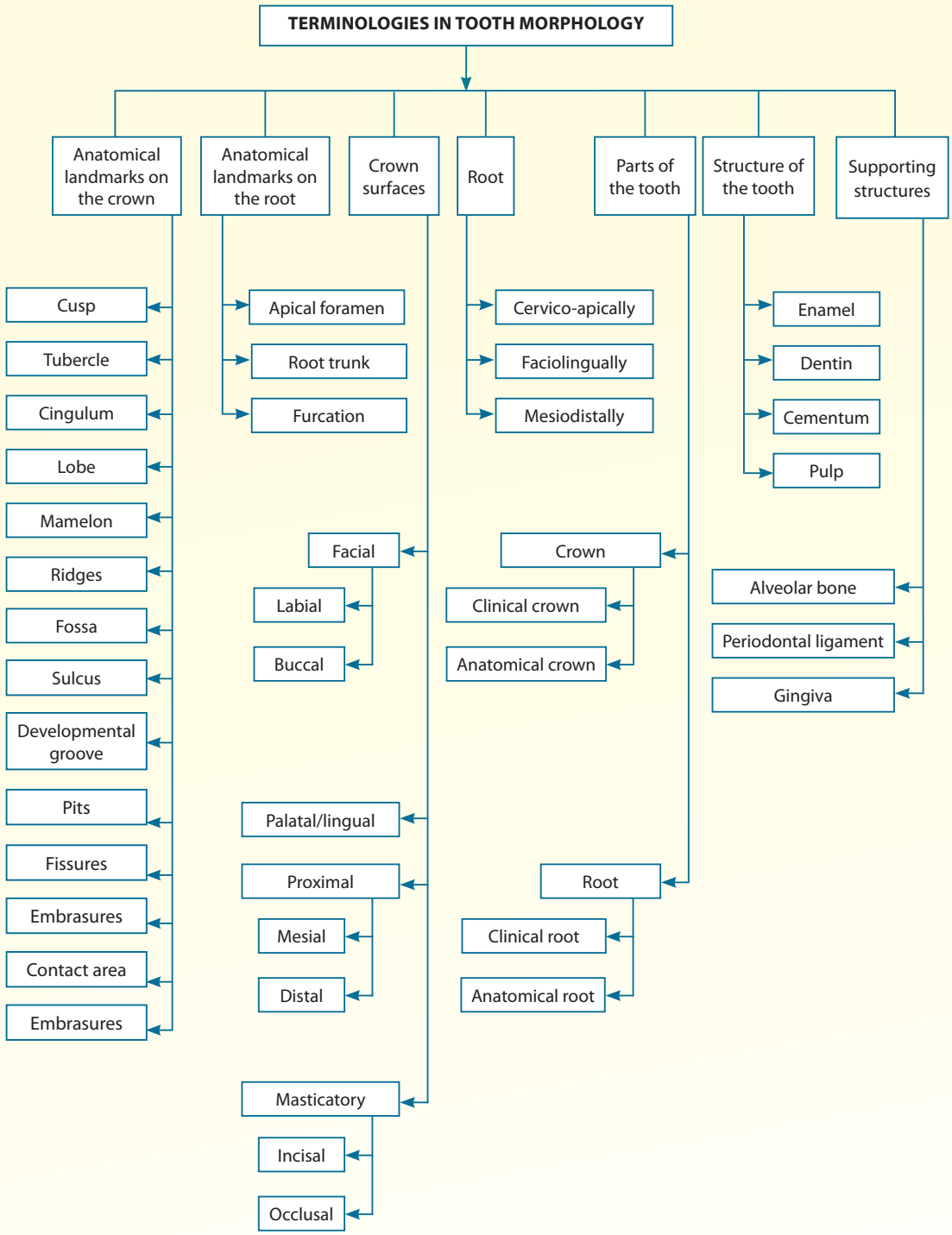
Figure 9.36 Root trunk and furcation of the mandibular first molar.

SECTION II

Key Points

1. The size of the anatomical crown and root remains constant throughout the lifetime of the tooth, except in cases of physiologic and pathologic conditions.
2. The cervical line is that which separates the anatomical crown from the anatomical root.
3. Each tooth is composed of three hard tissues—enamel, dentin and cementum—and one soft tissue—pulp tissue.
4. The periodontal ligament fibres are attached to the alveolar bone on one side and cementum of the tooth on the other side, thereby anchoring the tooth in the alveolus.
5. Anterior teeth have four surfaces—labial, palatal/lingual, mesial and distal—and one ridge—incisal ridge—whereas posterior teeth have five surfaces—buccal, palatal/lingual, mesial, distal and occlusal.
6. The elevations seen on the tooth surface are cusps, tubercles, cingula, lobes, mamelons and ridges.
7. Depressions seen on the tooth surface are fossae, sulci, grooves, pits and fissures.
8. The V-shaped spillway spaces or the triangular spaces adjacent to the contact area are called embrasures.

Mind Map


TERMINOLOGIES IN TOOTH MORPHOLOGY
Anatomical landmarks on the crown
Anatomical landmarks on the root
Crown surfaces
Root
Parts of the tooth
Structure of the tooth
Supporting structures
Cusp
Tubercle
Cingulum
Lobe
Mamelon
Ridges
Fossa
Sulcus
Developmental groove
Pits
Fissures
Embrasures
Contact area
Embrasures
Apical foramen
Root trunk
Furcation
Facial
Labial
Buccal
Palatal/lingual
Proximal
Mesial
Distal
Masticatory
Incisal
Occlusal
Cervico-apically
Faciolingually
Mesiodistally
Crown
Clinical crown
Anatomical crown
Root
Clinical root
Anatomical root
Enamel
Dentin
Cementum
Pulp
Alveolar bone
Periodontal ligament
Gingiva

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Multiple Choice Questions

1. The crown and root are separated by the
   (a) Cervical line
   (b) Dentinoenamel junction
   (c) Cementoenamel junction
   (d) Both a and c
2. The anatomical crown is covered by the
   (a) Dentin
   (b) Cementum
   (c) Enamel
   (d) Both b and c
3. What is the term used for the division of the root into three segments?
   (a) Furcation
   (b) Bifurcation
   (c) Trifurcation
   (d) All of the above
4. The height of the clinical root is determined by the position of the
   (a) Cementoenamel junction
   (b) Gingival margin
   (c) Alveolar bone
   (d) Both a and b
5. All are hard tissues of the tooth, except the
   (a) Pulp
   (b) Cementum
   (c) Dentin
   (d) Enamel
6. Which is the hardest substance in the body?
   (a) Bone
   (b) Cementum
   (c) Enamel
   (d) Dentin
7. The tissues of the tooth which develop from the mesodermal structure are
   (a) Enamel
   (b) Dentin
   (c) Cementum
   (d) Both b and c
8. The fibres which attach or anchor the teeth to the alveolus are known as the
   (a) Periodontal ligament fibres
   (b) Gingival fibres
   (c) Both a and b
   (d) None of the above
9. The opening present at the apex of the tooth is termed
   (a) Apical foramen
   (b) Accessory foramen
   (c) Both a and b
   (d) None of the above
10. The teeth which are closer to the midline are
    (a) Central incisors
    (b) Lateral incisors
    (c) Canine
    (d) All of the above

11. Occlusal and incisal surfaces are collectively known as
    (a) Masticatory surface
    (b) Facial surface
    (c) Proximal surface
    (d) Both a and b
12. Which is the angle formed by the junction or union of three surfaces?
    (a) Point
    (b) Line
    (c) Both a and b
    (d) None of the above
13. Permanent mandibular second premolars and mandibular molars develop from _____ lobes?
    (a) Four
    (b) Five
    (c) Three
    (d) None of the above
14. The oblique ridge is present on the occlusal surface of the maxillary
    (a) Permanent first molar
    (b) Deciduous second molar
    (c) Permanent third molar
    (d) Both a and c
    (e) All of the above
15. The V-shaped spillway space or the triangular space adjacent to the contact area is known as the
    (a) Embrasure
    (b) Interproximal space
    (c) Both a and b
    (d) None of the above



CHAPTER 10

Nomenclature of Human Teeth

Overview

Human dentition is classified into primary and permanent dentition on the basis of eruption sequence and time. Since human dentition includes 20 primary teeth and 32 permanent teeth it is mandatory to have a specific nomenclature for each tooth which is based on the type of dentition (primary/permanent), arch (maxillary/mandibular), class (incisor/canine/premolar/molar), side (right/left) and position (central/lateral/first/second/third). But for routine usage and easy communication, a simplified numbering system came into force. There are three universally recognized tooth numbering systems, namely Zsigmondy/Palmer system (1861), Universal system (1882) and FDI system (1971). The Zsigmondy/Palmer system denotesthe tooth of each quadrant with a specific alphabet for the primary tooth and specific number for the permanent tooth and horizontal/vertical lines to represent the quadrant. The Universal system assigns a specific alphabet (primary tooth) or number (permanent tooth) for each tooth in all four quadrants. The FDI system is a two-digit system wherein the first digit denotes the quadrant (5, 6, 7, 8 for primary dentition and 1, 2, 3, 4 for permanent dentition) and the second digit denotes the tooth number (1–5 for primary dentition and 1–8 for permanent dentition). The FDI system is the universally accepted and routinely followed tooth numbering system.

INTRODUCTION

Tooth (*pl.* teeth), *dentes* in Latin, is present in the oral cavity, and it is the hardest calcified tissue in the human body. The teeth are arranged in the upper and lower jaws in the form of a 'horseshoe' or 'U' shape. The upper jaw is otherwise called the maxillary jaw, and the teeth present in the maxillary jaw or arch are called maxillary teeth. The lower jaw is otherwise called the mandibular jaw, and the teeth present in the mandibular jaw or arch are called mandibular teeth.

The teeth are essential for the following functions of the body:

1. For acquiring and chewing food and helping in mastication and digestion
2. For protecting the oral cavity by acting as a hard physical barrier
3. For phonation and speech
4. For aesthetic purposes
5. For self-protection

CLASSES OF HUMAN TEETH

There are two classes of human teeth:

1. **Anterior teeth:** These are teeth present in the front of the mouth and comprise incisors (central and lateral incisors) and canines, which are present in both primary and permanent dentition.
2. **Posterior teeth:** These are teeth present in the back of the mouth and comprise premolars, which are present in permanent dentition, and molars, which are present in both primary and permanent dentition.

TYPES OF HUMAN DENTITION AND DENTAL FORMULAE

Dentition is the term used to describe all the teeth present in the upper and lower jaw bones. In their lifetime, humans develop two sets of dentition: primary and permanent.

Primary Dentition

Primary dentition is the first set of teeth to be seen in the mouth of a child from the age of 8 months to

6 years. It is also referred to as deciduous dentition because all these teeth eventually shed by the age of 12–13 years and are replaced by permanent dentition. Milk teeth, baby teeth, predecessor teeth or lacteal dentition are some of the other names for these teeth.

Primary dentition comprises 20 teeth, of which 10 are present in the upper jaw or the maxillary arch and 10 are present in the lower jaw or the mandibular arch. These two sets of 16 teeth in either jaw are subdivided into the right and left quadrants by the midsagittal plane or the midline or median line of the face, with five teeth in each quadrant.

Deciduous dentition consists of two classes of teeth—anterior and posterior teeth—starting on either side of the midline of the face (**Fig. 10.1**). The deciduous tooth next to the midline is the central incisor, followed by the lateral incisor, canine, first molar and second molar in each quadrant (five teeth).

So, on the basis of the number and type of teeth present, the dental formula for primary dentition is

$$I\ \tfrac{2}{2}\ C\ \tfrac{1}{1}\ M\ \tfrac{2}{2} = \tfrac{5}{5} = 10$$

In this formula, **I** represents *incisors*, **C** represents *canine* and **M** represents *molars,* and the formula is read as incisors, 2 in maxillary and 2 in mandibular; canine, 1 in maxillary and 1 in mandibular; and molars, 2 in maxillary and 2 in mandibular; so a total of 10 teeth are present on one side whether right or left.

Permanent Dentition

Permanent dentition is the second set of teeth to develop in the humans and is seen from the age of 6 years till death. It is also referred to as secondary dentition. Permanent dentition is also referred to as adult teeth.

Permanent dentition is subdivided into two types: succedaneous and non-succedaneous teeth. The succedaneous teeth replace deciduous dentition. These include the permanent anterior teeth, which replace the primary anterior teeth, and permanent premolars, which replace the primary molars. The non-succedaneous teeth are the permanent molars since these teeth do not replace primary dentition and erupt in the space distal to deciduous dentition.

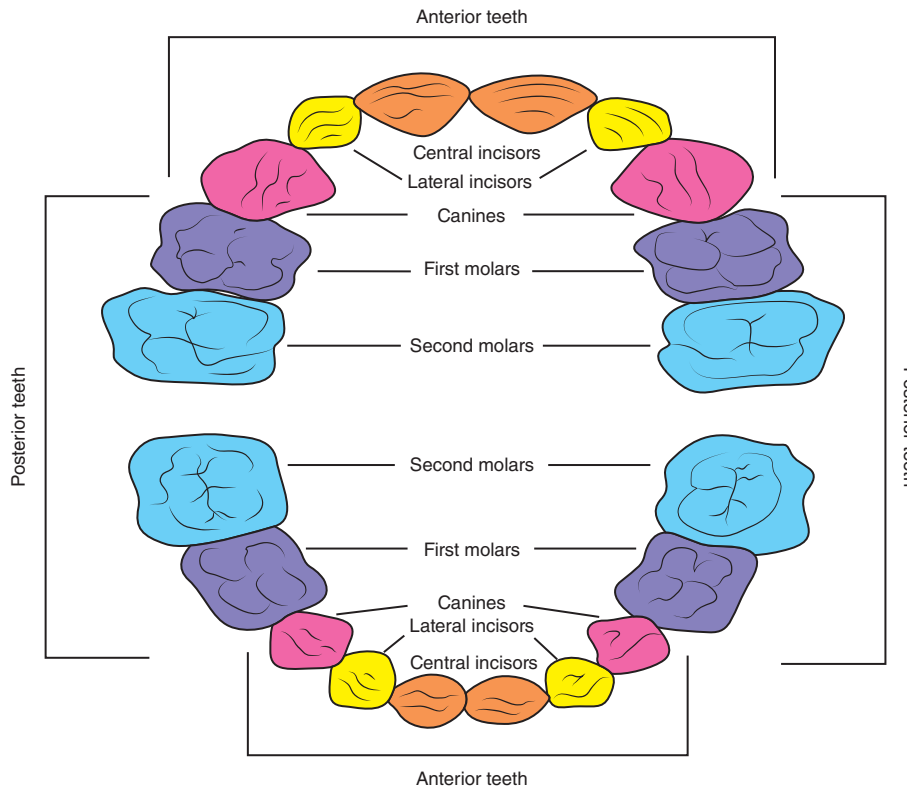


Figure 10.1 Deciduous dentition.

Permanent dentition comprises 32 teeth, of which 16 are present in the upper jaw or the maxillary arch and 16 in the lower jaw or the mandibular arch. These two sets of 16 teeth in either jaw are subdivided into the right and left quadrants by the midsagittal plane or the midline or median line of the face, with eight teeth in each quadrant (**Fig. 10.2**).

Permanent dentition consists of two classes of teeth—anterior and posterior teeth—starting on either side of the midline of the face. The permanent tooth next to the midline is the central incisor, followed by the lateral incisor, canine, first premolar, second premolar, first molar, second molar and third molar in each quadrant (eight teeth).

So, on the basis of the number and type of teeth present, the dental formula for permanent dentition is:

$$I\ \frac{2}{2}\ C\ \frac{1}{1}\ PM\ \frac{2}{2}\ M\ \frac{3}{3} = \frac{8}{8} = 16$$

In this formula, **I** represents *incisors,* **C** represents *canine*, **PM** represents *premolars* and **M** represents *molars* and the formula is read as incisors, 2 in maxillary and 2 in mandibular; canine, 1 in maxillary and 1 in mandibular; premolars, 2 in maxillary and 2 in mandibular; and molars, 3 in maxillary and 3 in mandibular; so a total of 16 teeth are present on one side whether right or left.

TOOTH IDENTIFICATION SYSTEMS/ TOOTH NUMBERING SYSTEMS

In humans, both the deciduous and permanent teeth combined together consist of 52 teeth in the entire lifetime, i.e. 20 primary teeth and 32 permanent teeth; so it becomes necessary for the identification of a particular tooth.

For the proper identification of a particular tooth, the dentition, arch, quadrant and tooth name has to be written in a particular order, such as *permanent maxillary right central incisor.*

In dental practice, it is necessary to maintain clinical records. The full anatomical name such as

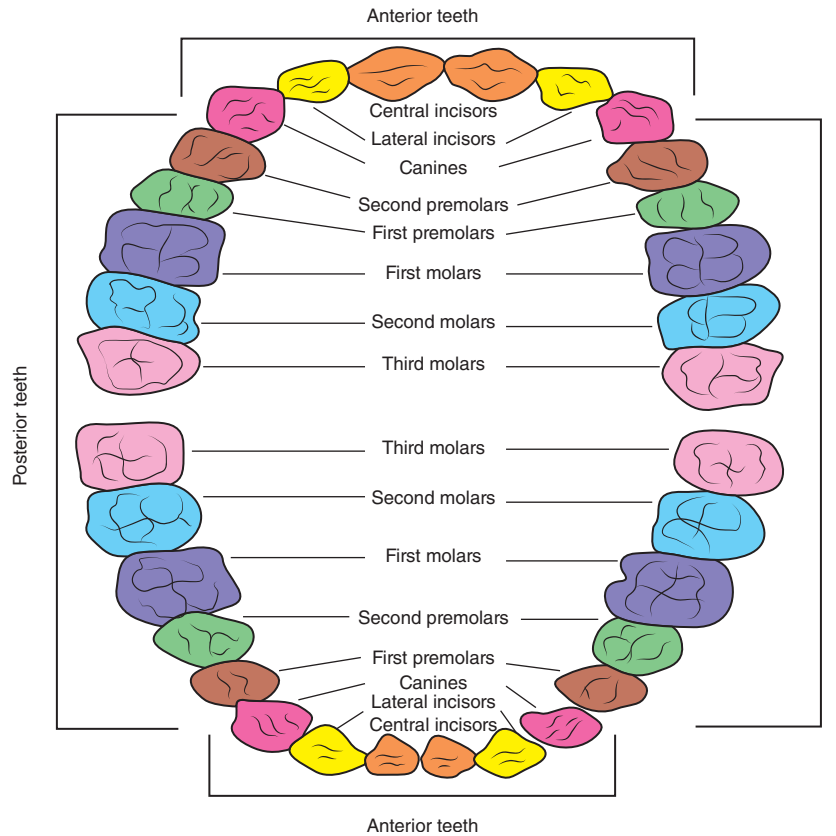


Figure 10.2 Permanent dentition.

permanent maxillary right central incisor is, however, inconvenient in a clinical situation and may have problems in terms of international understanding. To overcome these problems, various 'shorthand' systems have been devised for tooth numbering. Several systems of dental notation have been used over the years, and the three most common tooth numbering systems are as follows:

1. Universal system
2. Zsigmondy/Palmer system
3. FDI system

Universal System

The Universal system was first suggested by Parreidt in the year 1882 and was later officially accepted by the American Dental Association (ADA) in 1975. It is also endorsed by the American Society of Forensic Odontology.

Primary Teeth

In this system, primary teeth are denoted by letters of the alphabet, starting from **A** to **T**, written in capital letters. The numbering starts from the maxillary right second molar, which is denoted by **A**, goes sequentially around the arch up to **J**, which represents the maxillary left second molar, then drops down on the same side to **K**, which represents the mandibular left second molar and then moves clockwise towards the right up to **T**, which represents the mandibular right second molar (**Fig. 10.3**).

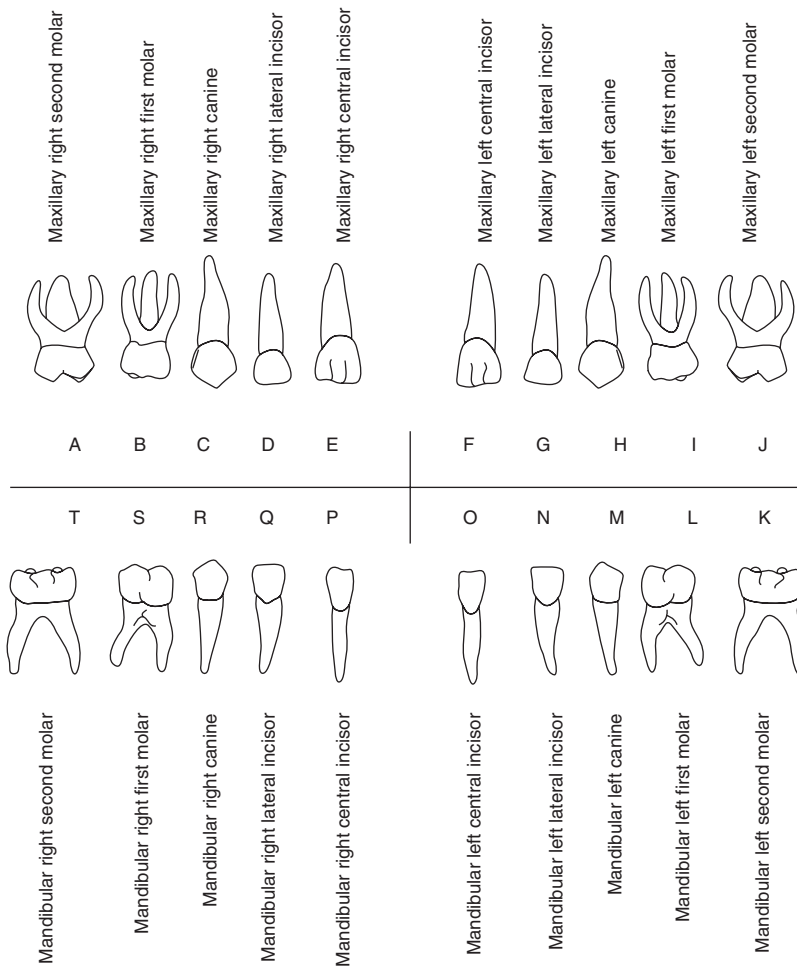


Figure 10.3 Universal numbering system for primary dentition.

Permanent Teeth

In this system, permanent teeth are denoted by numbers starting from **1** to **32**. The numbering starts from the maxillary right third molar, which is denoted by **1**, goes sequentially around the arch up to **16**, which represents the maxillary left third molar, then drops down on the same side to **17**, which represents the mandibular left third molar and then moves clockwise towards the right up to **32**, which represents the mandibular right third molar (**Fig. 10.4**).

Advantages of the System

1. Each tooth is assigned a specific alphabet or number.
2. It is easy to use with computing data on computers.
3. It can be used in word processing software.

Zsigmondy/Palmer System

The Zsigmondy/Palmer system was developed by Adolf Zsigmondy in the year 1861. He termed it the *Zsigmondy system*, where he used a Zsigmondy cross to record quadrants of tooth positions. This system was later modified by Palmer and he termed it the *Zsigmondy/Palmer notation*. This system is also known as the quadrant system or grid system because the dentition is divided into quadrants by a horizontal and a vertical line. The

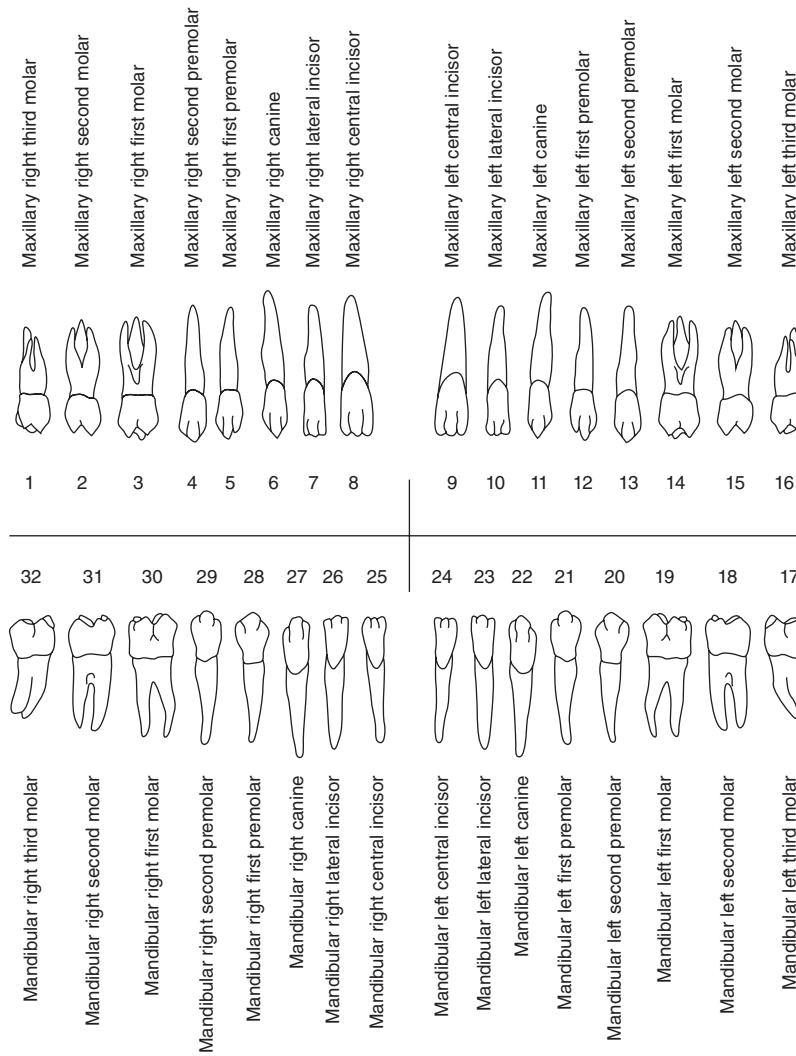


Figure 10.4 Universal numbering system for permanent dentition.

horizontal line represents the maxillary–mandibular dividing line and the vertical line represents the midsagittal plane. Each quadrant is assigned a specific symbol or quadrant bracket which surrounds a number or letter of the alphabet denoting the tooth (**Fig. 10.5**).

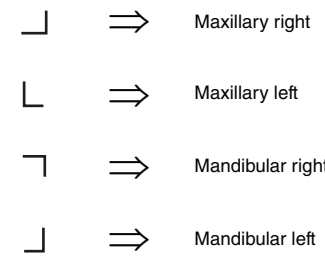


Figure 10.5 Specific symbols for the Zsigmondy/Palmer system.

Primary Teeth

In this system, primary teeth are denoted by letters of the alphabet in capital letters from **A** to **E** in all the four quadrants. The starting letter **A** is assigned to the teeth adjacent to the midline, i.e. the central incisor, and **E** represents the tooth at the end of the quadrant, i.e. the second molar. For example, the same letter **A** represents the four central incisors; so to represent a single tooth, such as the maxillary right central incisor, the notation is as **A** ⌟, where **A** represents the tooth and the symbol ⌟ represents the quadrant in which the tooth is present (**Fig. 10.6**).

Permanent Teeth

In this system, permanent teeth are denoted by numbers **1**–**8** in all the four quadrants. The starting

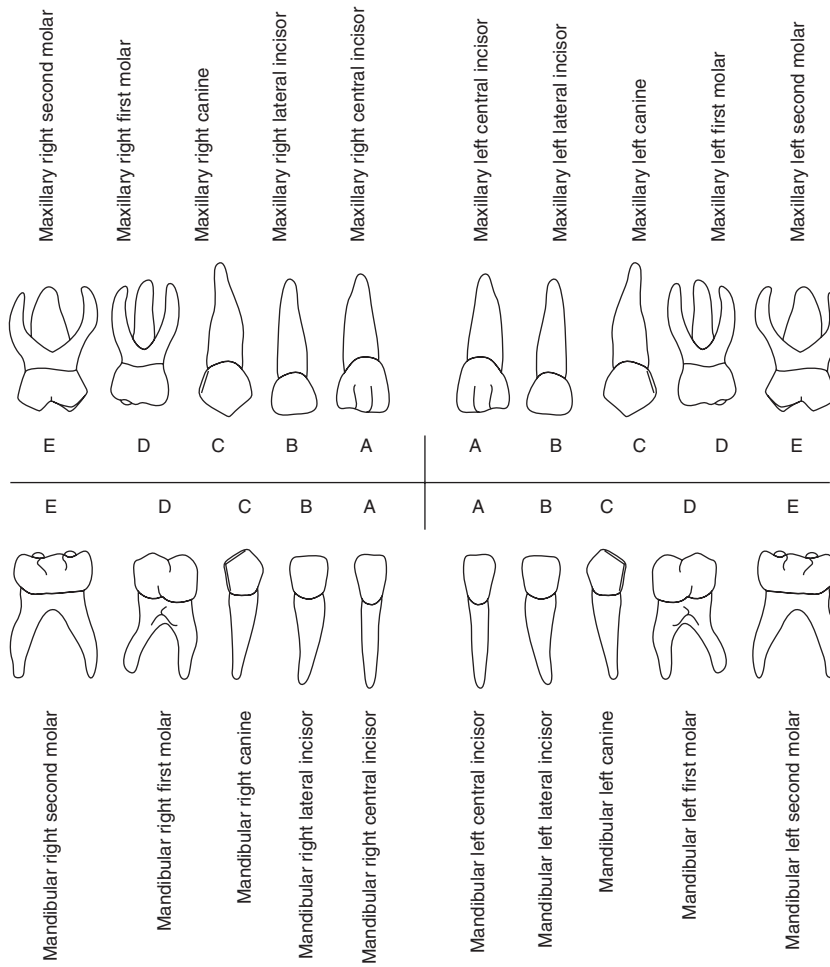


Figure 10.6 Zsigmondy/Palmer numbering system for primary dentition.

number **1** is assigned to the teeth just adjacent to the midline, i.e. the central incisor, and **8** represents the tooth at the end of the quadrant, i.e. the third molar. For example, the four first premolars are represented by the same number **4**. To represent a single tooth such as the mandibular left first premolar, the notation is **4** ⌝, where **4** represents the tooth and the symbol ⌝ represents the quadrant in which the tooth is present (**Fig. 10.7**).

Advantages of the System

1. Orthodontists use this system because it allows discussion of the particular tooth that requires treatment.
2. The quadrants are easily identified by the symbol.

Disadvantages of the System

This method of denoting the tooth is not compatible with computers and word processing software.

FDI System

The FDI World Dental Federation notation is widely used by dentists internationally to associate information to a specific tooth. It was developed by the Federation Dentaire Internationale (FDI) in the year 1971 to identify teeth, with a

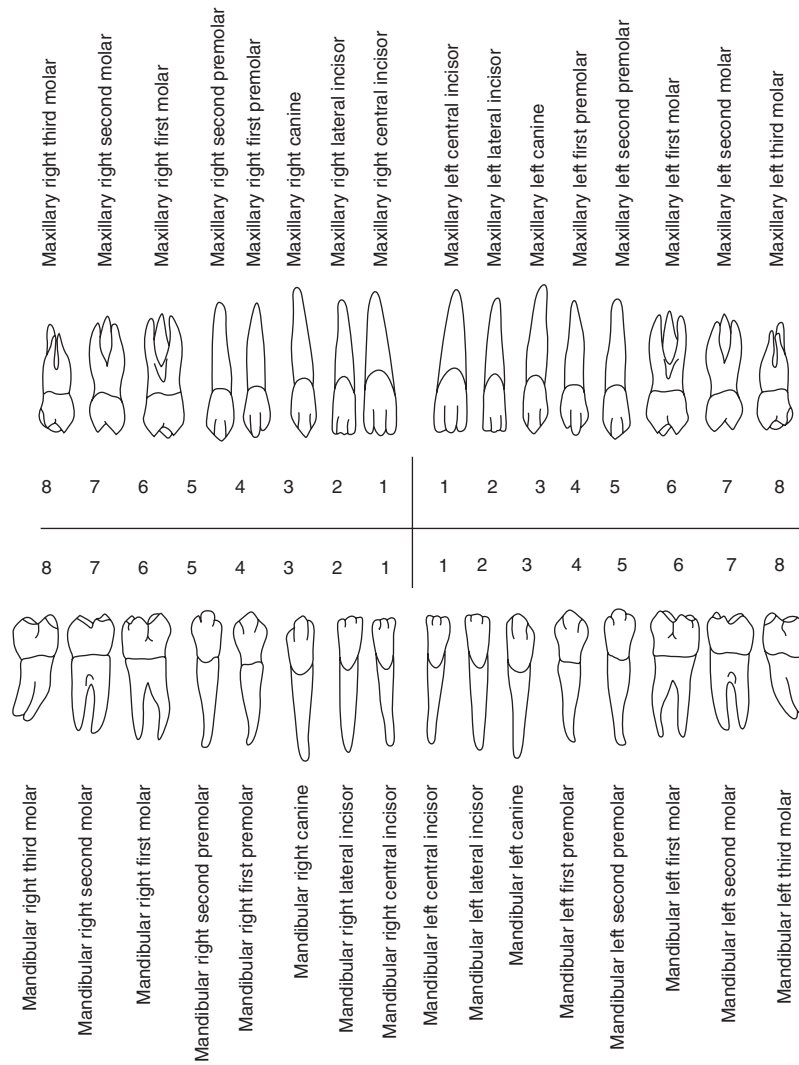


Figure 10.7 Zsigmondy/Palmer numbering system for permanent dentition.

particular number for both primary and permanent teeth and no use of any letters of the alphabet. This system is also known as the two-digit system and the International Organization for Standardization (ISO) designation system, ISO-3950 notation. This system is adopted by the WHO and is accepted by the International Association for Dental Research.

In this system, the teeth are represented by a two-digit code, where the first digit indicates the quadrant (right or left) and arch (maxillary or mandibular) and the second digit indicates the tooth within that particular quadrant.

Primary Teeth

In this system, deciduous dentition is divided into four quadrants and is numbered from **5** to **8**, in a clockwise manner, starting from the maxillary right quadrant and ending in the mandibular right quadrant. This number represents the first digit in the two-digit coding system, where **5** is for the maxillary right quadrant, **6** is for maxillary left quadrant, **7** is for the mandibular left quadrant and **8** is for the mandibular right quadrant.

The second digit or the tooth within that particular quadrant is numbered from **1** to **5,** starting from the midline (central incisor) and moving backwards up to the second molar. For example, the primary mandibular left canine is denoted as **73**, where **7** represents the primary left mandibular quadrant and **3** represents the third tooth within that quadrant, that is the canine (**Fig. 10.8**).

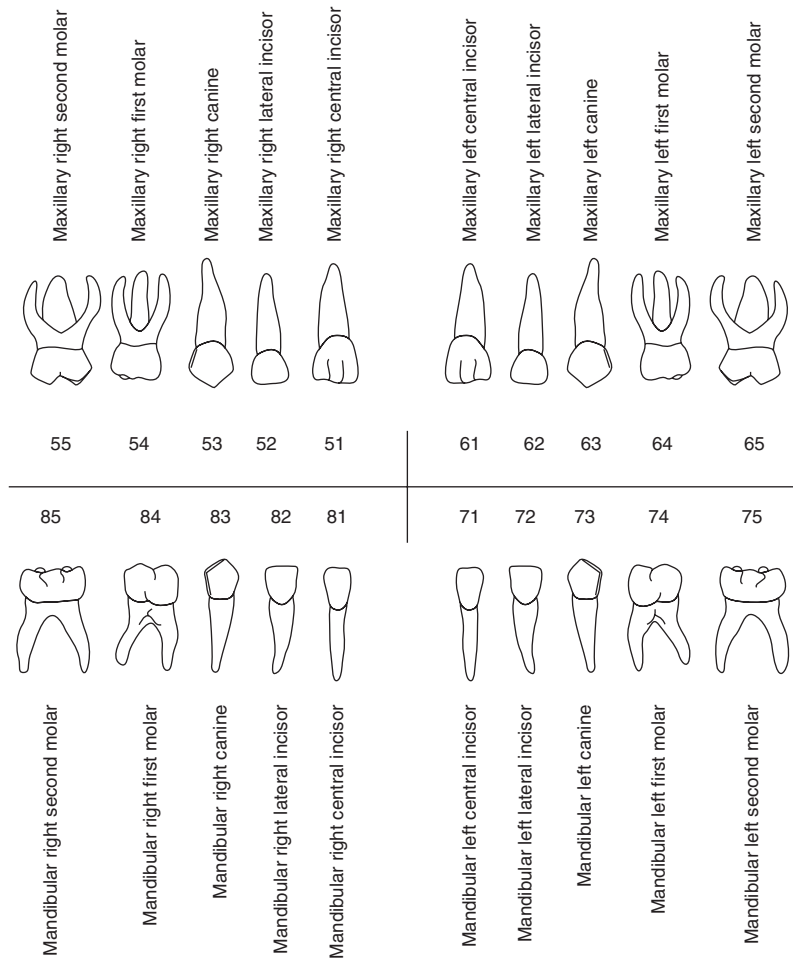


Figure 10.8 FDI system for deciduous dentition.

Permanent Teeth

In this system, the permanent dentition is divided into four quadrants and is numbered from **1** to **4** in a clockwise manner, starting from the maxillary right quadrant and ending in the mandibular right quadrant. This number represents the first digit in the two-digit coding system, where **1** is for the maxillary right quadrant, **2** is for the maxillary left quadrant, **3** is for the mandibular left quadrant and **4** is for the mandibular right quadrant. The second digit or the tooth within that particular quadrant is numbered from **1** to **8** starting from the midline (central incisor) and moving backwards up to the third molar. For example, the permanent maxillary right first molar is denoted as **16**, where **1** represents the permanent right maxillary quadrant and **6** represents the sixth tooth within that quadrant, the first molar **(Fig. 10.9)**.

Advantages of the System

1. Dentists use this system because numbers given to a particular tooth are unique.
2. This method of denoting the tooth is compatible with all computers and word processing software.

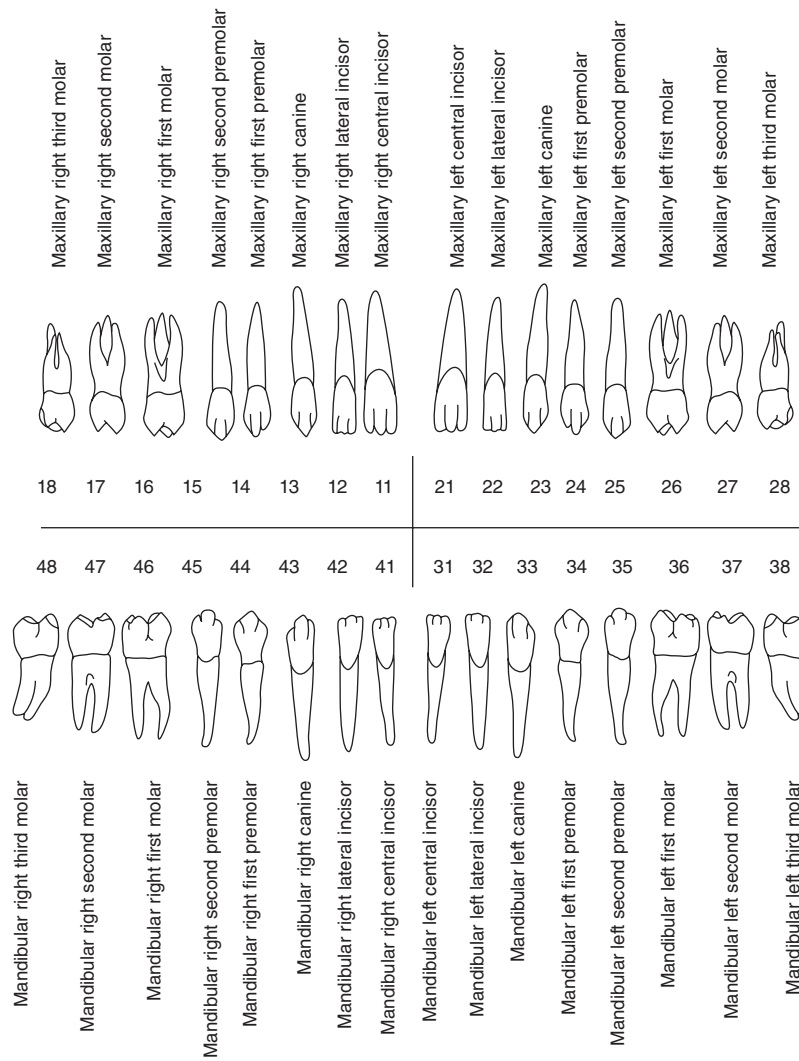
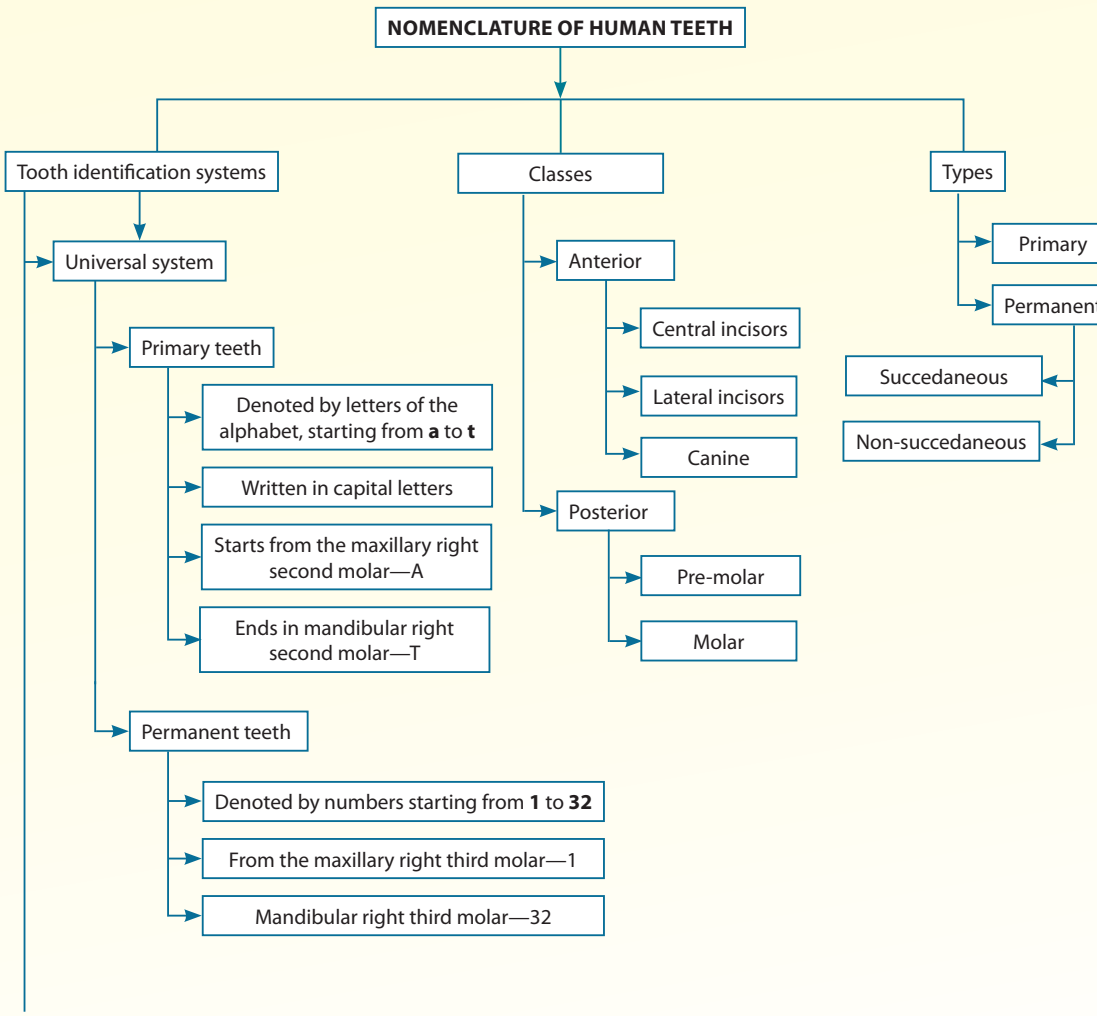


Figure 10.9 FDI system for permanent dentition.

Key Points

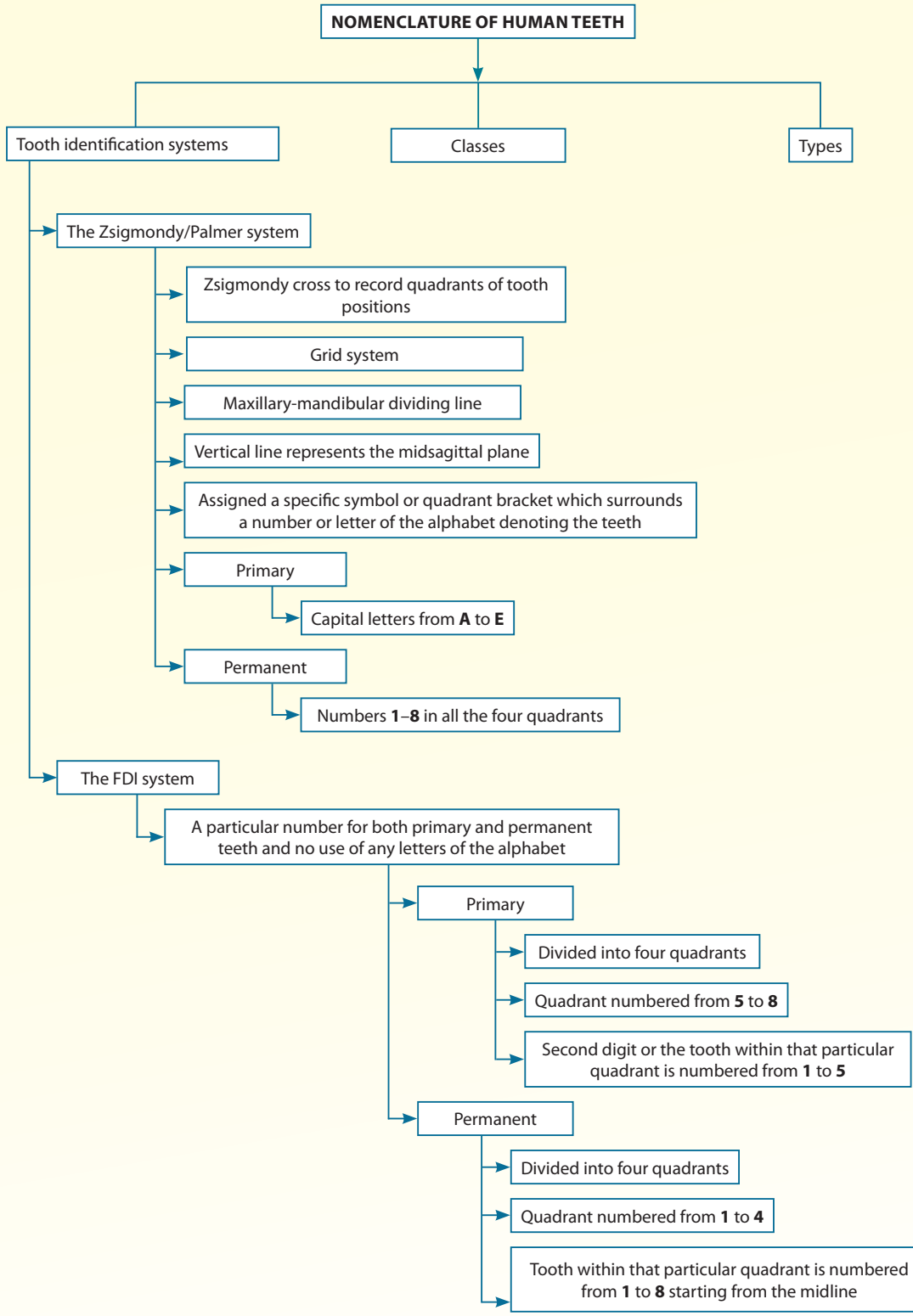
1. Humans have two types of dentition in their entire lifetime: primary and permanent.
2. Twenty teeth are present in primary dentition and 32 teeth in permanent dentition.
3. There are two classes of teeth in humans: anterior and posterior.
4. The teeth are classified on the basis of the type of dentition, arch, quadrant and tooth name.
5. Tooth numbering systems are essential for proper identification of particular tooth and for recording data in the dental office.
6. The Zsigmondy/Palmer system of tooth numbering is not compatible with computers and word processors; still, it is used by orthodontists for referring to a particular tooth.
7. The FDI system is the universally accepted system of tooth numbering and it is also accepted by the WHO.

Mind Map



(*Continued*)

(*Continued*)


NOMENCLATURE OF HUMAN TEETH
Tooth identification systems
Classes
Types
The Zsigmondy/Palmer system
Zsigmondy cross to record quadrants of tooth positions
Grid system
Maxillary-mandibular dividing line
Vertical line represents the midsagittal plane
Assigned a specific symbol or quadrant bracket which surrounds a number or letter of the alphabet denoting the teeth
Primary
Capital letters from **A** to **E**
Permanent
Numbers **1**–**8** in all the four quadrants
The FDI system
A particular number for both primary and permanent teeth and no use of any letters of the alphabet
Primary
Divided into four quadrants
Quadrant numbered from **5** to **8**
Second digit or the tooth within that particular quadrant is numbered from **1** to **5**
Permanent
Divided into four quadrants
Quadrant numbered from **1** to **4**
Tooth within that particular quadrant is numbered from **1** to **8** starting from the midline

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Multiple Choice Questions

1. The shape of the maxillary and mandibular arch is
   (a) Horseshoe
   (b) U
   (c) V
   (d) Both a and b
2. What are the two classes of teeth seen in humans?
   (a) Anterior
   (b) Superior
   (c) Posterior
   (d) Both a and c
3. Which is the first set of dentition seen in the oral cavity?
   (a) Primary
   (b) Deciduous
   (c) Lacteal
   (d) All of the above
4. Why are primary teeth called milk teeth?
   (a) Because of their colour
   (b) The refractive index is same as that of milk
   (c) Both a and b
   (d) None of the above
5. Non-succedaneous teeth include _____
   (a) Permanent molars
   (b) Deciduous molars
   (c) Permanent premolars
   (d) All of the above
6. Premolars are seen in _____ dentition.
   (a) Primary
   (b) Deciduous
   (c) Permanent
   (d) All of the above
7. Humans have _____ teeth in their entire lifetime.
   (a) 32
   (b) 20
   (c) 52
   (d) 50
8. What are the factors used in the identification of a tooth?
   (a) Quadrant
   (b) Arch
   (c) Dentition
   (d) Tooth name
   (e) All of the above
9. Which tooth system is accepted by the American Dental Association and endorsed by the American Society of Forensic Odontology?
   (a) Quadrant
   (b) ISO
   (c) Universal
   (d) Modified Palmer

10. In which system are letters of the alphabet used for denoting primary teeth?
    (a) FDI
    (b) Universal
    (c) Zsigmondy
    (d) Both b and c
11. In the Universal system, the primary maxillary left canine is denoted as _____
    (a) H
    (b) J
    (c) 11
    (d) O
12. Which system is easy for computing data into the computers?
    (a) ISO
    (b) FDI
    (c) Universal
    (d) All of the above
13. Which is the quadrant system of tooth notation?
    (a) Universal
    (b) FDI
    (c) Zsigmondy/Palmer
    (d) ISO
14. The FDI system is otherwise called the _____
    (a) ISO notation
    (b) Quadrant system
    (c) Two-digit system
    (d) Both a and c
15. Which is the tooth numbering system adopted by the WHO?
    (a) The FDI
    (b) The grid system
    (c) The Palmer system
    (d) All of the above

CHAPTER 11



Chronology of Dentition

Overview

The chronological events in the dentition include initiation, calcification and completion of crown (which occur at different time intervals in deciduous and permanent teeth) followed by root formation that begins immediately after completion of enamel formation. The tooth moves occlusally into the oral cavity gradually. The sequence of eruption of deciduous teeth is mandibular central incisor, maxillary central incisor, maxillary lateral incisor, mandibular lateral incisor, maxillary and mandibular first molar, maxillary canine, mandibular canine, mandibular second molar and maxillary second molar. The sequence of eruption of permanent teeth is maxillary and mandibular first molar, mandibular central incisor, maxillary central incisor, mandibular lateral incisor, maxillary lateral incisor, mandibular canine, maxillary first premolar, mandibular first premolar, maxillary second premolar, mandibular second premolar, maxillary canine, mandibular second molar, maxillary second molar, maxillary and mandibular third molar. Any discrepancy in the chronology or sequence of eruption can lead to malalignment of teeth.

INTRODUCTION

Basic knowledge of the development and emergence of normal dentition in the oral cavity allows clinicians to accurately identify normal and abnormal dental conditions and make recommendations for appropriate therapeutic interventions and patient counselling. The time of calcification and eruption of tooth plays an important role in the estimation of dental age in forensic odontology.

The term *chronology* refers to the record of events in the order of their occurrence. The chronology of human dentition refers to the developmental time-line of teeth at which various events related to the milestones of tooth development such as initiation, first evidence of calcification, crown completion, eruption and root completion occur. The dentition begins to form at approximately 6 weeks in utero and continues through late adolescence, when the development of the permanent third molars is completed.

The initiation, calcification and completion of crown in deciduous and permanent teeth occur at different time intervals. The root formation begins immediately after the completion of enamel formation, and the tooth gradually starts to move occlusally into the oral cavity. The completion of the root occurs 2 years after the eruption of the tooth. The sequence of eruption is the order in which the teeth appear in the oral cavity.

CHRONOLOGY OF PRIMARY TEETH (Table 11.1)

The initiation of the primary teeth formation occurs approximately at 6 weeks in utero; the crown begins to calcify between 3 and 4 months in utero and completes calcification by the 11th month after birth. The tooth starts to erupt into the oral cavity from 8 months and completes by the 30th month after birth. The root completion occurs 18–24 months after the eruption of the tooth into the oral cavity. The eruption of primary teeth occurs earlier in boys than in girls.

Table 11.1 Chronology of the Deciduous Teeth

Deciduous Teeth	First Evidence of Calcification (weeks in utero)	Crown Completion (months)	Eruption (months)	Root Completion (years)	Shedding (years)
Maxillary teeth					
Central incisor	14 (13–16)	1½	10 (8–12)	1½	7
Lateral incisor	16 (14–17)	2½	11 (9–13)	2	8
Canine	17 (15–18)	9	19 (16–22)	3¼	11
First molar	15 (14–17)	6	16 (13–19)	2½	10
Second molar	19 (16–24)	11	29 (25–33)	3	10
Mandibular teeth					
Central incisor	14 (13–16)	2½	8 (6–10)	1½	7
Lateral incisor	16 (14–17)	2½	13 (10–16)	1½	8
Canine	17 (16–18)	9	20 (17–23)	3¼	9
First molar	15 (14–17)	5½	16 (14–18)	2¼	9
Second molar	18 (17–19)	10	27 (23–31)	3	10

Sequence of Eruption

The sequence of eruption of the deciduous teeth is as follows (**Fig. 11.1**):

1. Mandibular central incisor
2. Maxillary central incisor
3. Maxillary lateral incisor
4. Mandibular lateral incisor
5. Maxillary and mandibular first molar
6. Maxillary canine
7. Mandibular canine
8. Mandibular second molar
9. Maxillary second molar

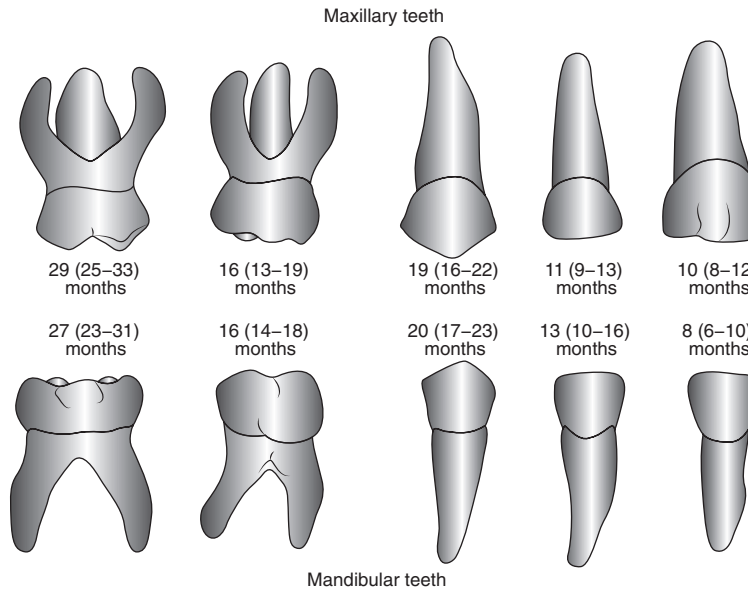


Figure 11.1 Eruption sequence of deciduous teeth.

According to the Zsigmondy/Palmer notation of teeth, the order of eruption of primary teeth in one quadrant is denoted as

A B D C E

A. Central incisor
B. Lateral incisor
C. Canine
D. First molar
E. Second molar

CHRONOLOGY OF PERMANENT TEETH (Table 11.2)

As the primary teeth erupt into the oral cavity and establish their function, the initiation of the permanent teeth development occurs, approximately during the first year of life, or at the time of birth in case of the first molar. The eruption of the permanent teeth begins at 6 years and is completed by 22 years. The root completion occurs 2½–3 years after the eruption of the tooth into the oral cavity. The eruption of permanent teeth occurs earlier in girls than in boys.

Sequence of Eruption

The sequence of eruption of the permanent teeth is as follows (**Fig. 11.2**):

1. Maxillary and mandibular first molar
2. Mandibular central incisor
3. Maxillary central incisor
4. Mandibular lateral incisor
5. Maxillary lateral incisor
6. Mandibular canine
7. Maxillary first premolar
8. Mandibular first premolar
9. Maxillary second premolar
10. Mandibular second premolar

Table 11.2 Chronology of the Permanent Teeth

Permanent Teeth	First Evidence of Calcification	Crown Completion (years)	Eruption (years)	Root Completion (years)
		Maxillary teeth		
Central incisor	3–4 months	4–5	7–8	10
Lateral incisor	10–12 months	4–5	8–9	11
Canine	4–5 months	6–7	11–12	13–15
First premolar	1½–1¾ years	5–6	10–11	12–13
Second premolar	2–2¼ years	6–7	10–12	12–14
First molar	At birth	2½–3	6–7	9–10
Second molar	2½–3 years	7–8	12–13	14–16
Third molar	7–9 years	12–16	17–21	18–25
		Mandibular teeth		
Central incisor	3–4 months	4–5	6–7	9
Lateral incisor	3–4 months	4–5	7–8	10
Canine	4–5 months	6–7	9–10	12–14
First premolar	1¾–2 years	5–6	10–12	12–13
Second premolar	2¼–2½ years	6–7	11–12	13–14
First molar	At birth	2½–3	6–7	9–10
Second molar	2½–3 years	7–8	11–13	14–15
Third molar	8–10 years	12–16	17–21	18–25

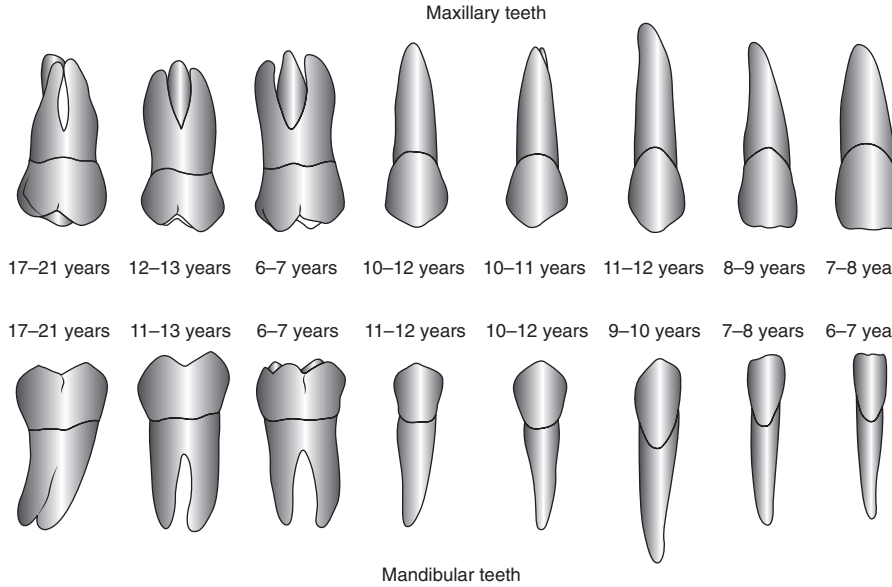


Figure 11.2 Eruption sequence of permanent teeth.

11. Maxillary canine
12. Mandibular second molar
13. Maxillary second molar
14. Maxillary and mandibular third molar

According to the Zsigmondy/Palmer notation of teeth, the order of eruption of permanent teeth in one quadrant is denoted as

61245378

1. Central incisor
2. Lateral incisor
3. Canine
4. First premolar
5. Second premolar
6. First molar
7. Second molar
8. Third molar

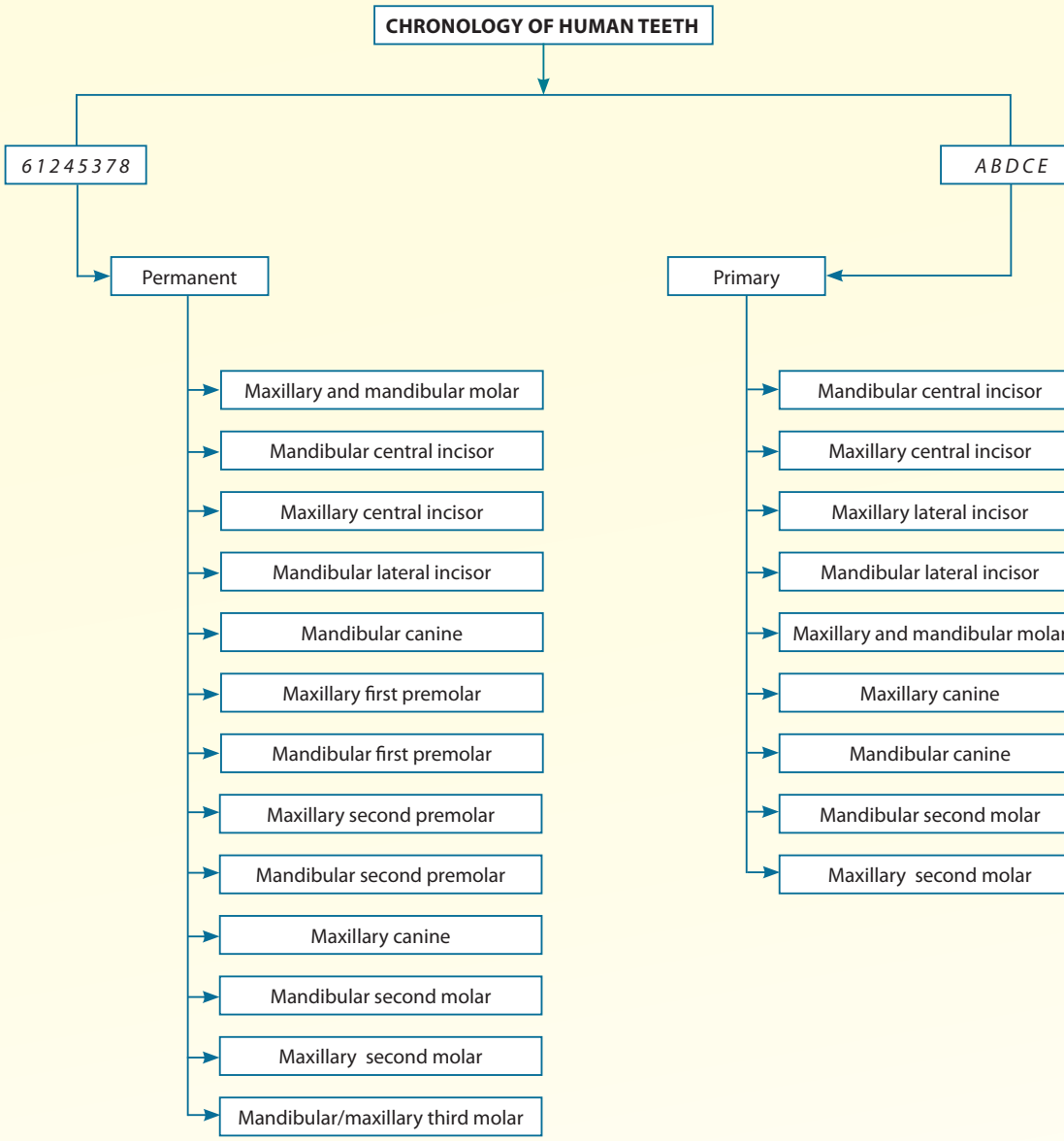
CLINICAL CONSIDERATIONS

1. Anodontia is the congenital absence of teeth. In case of permanent teeth, third molars, maxillary lateral incisors and maxillary or mandibular second premolars are the most commonly missing teeth. In case of primary teeth, maxillary lateral incisor, mandibular lateral incisor and mandibular cuspids are the most commonly missing teeth.
2. Natal teeth are teeth that are seen in the oral cavity at birth.
3. Neonatal teeth are those teeth erupting prematurely during the first 30 days of life.

Key Points

1. The chronology of human dentition refers to the developmental timeline of teeth.
2. The time of calcification and eruption of tooth plays an important role in the estimation of dental age in forensic odontology.
3. The sequence of eruption is the order in which the teeth appear in the oral cavity.
4. The order of eruption of primary teeth in one quadrant is denoted as *ABDCE*.
5. The order of eruption of permanent teeth in one quadrant is denoted as *61245378*.

Mind Map


CHRONOLOGY OF HUMAN TEETH
61245378
ABDCE
Permanent
Primary
Maxillary and mandibular molar
Mandibular central incisor
Maxillary central incisor
Mandibular lateral incisor
Mandibular canine
Maxillary first premolar
Mandibular first premolar
Maxillary second premolar
Mandibular second premolar
Maxillary canine
Mandibular second molar
Maxillary second molar
Mandibular/maxillary third molar
Mandibular central incisor
Maxillary central incisor
Maxillary lateral incisor
Mandibular lateral incisor
Maxillary and mandibular molar
Maxillary canine
Mandibular canine
Mandibular second molar
Maxillary second molar

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Multiple Choice Questions

1. The development of dentition begins at _____ weeks in utero.
   (a) 4
   (b) 5
   (c) 6
   (d) None of the above
2. The root formation starts after the completion of _____.
   (a) Dentin
   (b) Cementum
   (c) Enamel
   (d) None of the above
3. The sequence of eruption of the primary teeth is
   (a) *acdeb*
   (b) *abcde*
   (c) *acdbe*
   (d) *abdce*
4. The first permanent tooth to erupt in the oral cavity is
   (a) First molar
   (b) Central incisor
   (c) Both a and b
   (d) None of the above
5. The first evidence of calcification for the permanent maxillary and mandibular first molar occurs at _____.
   (a) Fourth month in utero
   (b) Birth
   (c) 6 years
   (d) None of the above

CHAPTER 12



Differences Between Deciduous and Permanent Teeth

Overview

The deciduous and permanent dentitions have some differentiating features between them on the basis of general features, crown morphology, root morphology, pulp anatomy and histology which aid in differentiating the individual characters of each tooth of the dentitions. With respect to general features, the deciduous dentition differs from permanent dentition in various aspects such as number of teeth, dental formulae, sequence of eruption, size, colour, shedding and root formation. With respect to crown morphology, the deciduous dentition differs from permanent dentition in various aspects such as shape, dimensions, surface, mamelons, cingulum, cusps, occlusal surface, occlusal area, contact area, cervical line, cervical ridge and cervical constriction. With respect to root morphology, the deciduous dentition differs from permanent dentition in various aspects such as root length, crown:root ratio, inclination of root, level of furcation, root trunk, root flare and morphology of apical foramen. With respect to pulp anatomy, the deciduous dentition differs from permanent dentition in various structures such as pulp chamber, pulp horn, pulp canal and presence or absence of the accessory pulp canal. Histologically enamel, dentin, dentinoenamel junction and cementum demonstrate differences in deciduous and permanent teeth.

INTRODUCTION

The deciduous and permanent dentitions have some differentiating features between them which make them unique. These differentiating features can be listed under the following headings:

1. General features
2. Morphological differences present in the crown, root and pulp anatomy
3. Histologic differences

GENERAL FEATURES

1. **Number** (*see* Fig. 10.1)
   (a) *Deciduous teeth:* There are *20* deciduous teeth with 5 teeth in each quadrant.
   (b) *Permanent teeth:* There are *32* permanent teeth with 8 teeth in each quadrant.
2. **Types of teeth** (*see* Fig. 10.1)
   (a) *Deciduous teeth:* They consist of central incisor, lateral incisor, canine and first and second molars.
   (b) *Permanent teeth:* They consist of central incisor, lateral incisor, canine, first and second premolars and first, second and third molars.
3. **Dental formula**
   (a) *Deciduous teeth*

$$I\ \tfrac{2}{2}\ C\ \tfrac{1}{1}\ M\ \tfrac{2}{2} = \tfrac{5}{5} = 10$$

   (b) *Permanent teeth*

$$I\ \tfrac{2}{2}\ C\ \tfrac{1}{1}\ PM\ \tfrac{2}{2}\ M\ \tfrac{3}{3} = \tfrac{8}{8} = 16$$

4. **Size** (**Fig. 12.1**)
   (a) *Deciduous teeth:* The deciduous teeth are generally *small* when compared with their permanent counterpart, except in the case of deciduous molars, which are larger when compared with their permanent counterpart, i.e. the premolars.
   (b) *Permanent teeth:* The permanent teeth are generally *large* when compared with their deciduous counterpart, except the premolars which are small when compared with their deciduous counterpart, i.e. the molars.
5. **Colour**
   (a) *Deciduous teeth:* They are *white* because the enamel is *less mineralized* and *opaque*,

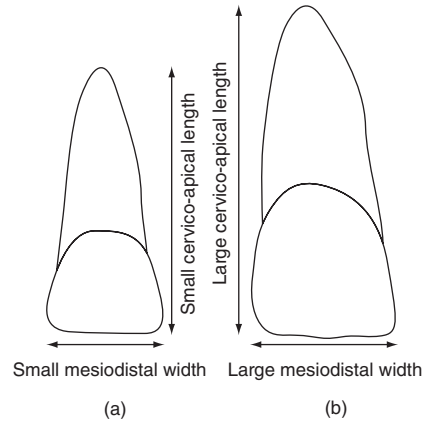


Figure 12.1 Labial aspect of (a) deciduous and (b) permanent maxillary central incisors.

so it does not reflect the colour of the underlying dentin.

(b) *Permanent teeth:* They are *yellowish white* or *grey* or *brown* because the enamel is *more mineralized* and *translucent*, so it reflects the colour of the underlying dentin.

6. **Placement in the jaws**
   (a) *Deciduous teeth:* They are placed *perpendicular* in relation to the jaws.
   (b) *Permanent teeth:* They are placed *oblique* in relation to the jaws.
7. **Eruption**
   (a) *Deciduous teeth:* Eruption begins at *8 months* after birth and is completed by *30 months* of age.
   (b) *Permanent teeth:* Eruption of permanent teeth starts at 6 years after birth and is completed by 25 years of age.
8. **Root formation**
   (a) *Deciduous teeth:* The roots of deciduous teeth are fully formed *after 1 year of eruption* of the particular tooth.
   (b) *Permanent teeth:* It takes about *3 years* for the root to be completed in the permanent teeth.
9. **Shedding**
   (a) *Deciduous teeth:* They start exfoliating from the oral cavity by around *76 years* of age and continue up to *10 years* of age as a result of physiologic resorption of the root.
   (b) *Permanent teeth:* They do not undergo shedding but can be lost due to any pathologic resorption.

MORPHOLOGICAL DIFFERENCES

Differences in Crown Morphology

1. **Shape**
   (a) *Deciduous teeth:* They are *more bulbous*.
   (b) *Permanent teeth:* They are *less bulbous*.
2. **Dimensions** (**Fig. 12.2**)
   (a) *Deciduous teeth:* The crowns of primary teeth are *wider mesiodistally* in comparison with their crown length.
   (b) *Permanent teeth:* The *length of the crown* of permanent teeth is *more* when compared with their mesiodistal width.
3. **Surface** (**Fig. 12.3**)
   (a) *Deciduous teeth:* In deciduous anterior teeth, the facial (labial and buccal) surface is *flat* above the cervical ridge up to the incisal surface. In the deciduous molars, the lingual/palatal surfaces are also flat above the cervical ridge up to the occlusal surface.
   (b) *Permanent teeth:* In case of permanent teeth, the facial and lingual/palatal surfaces are *convex*.

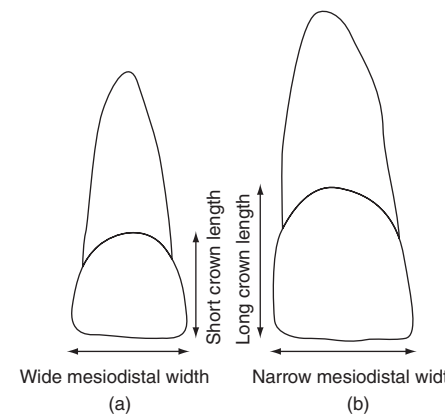


Figure 12.2 Mesiodistal dimension of (a) deciduous and (b) permanent maxillary central incisors.

SECTION II

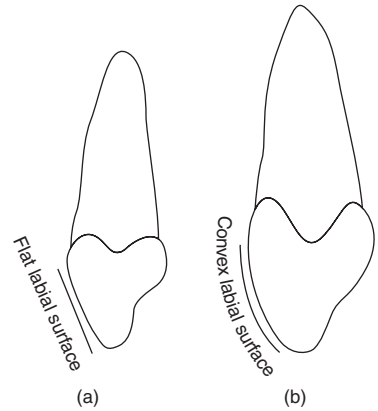


Figure 12.3 Labial outline of (a) deciduous and (b) permanent maxillary central incisors.

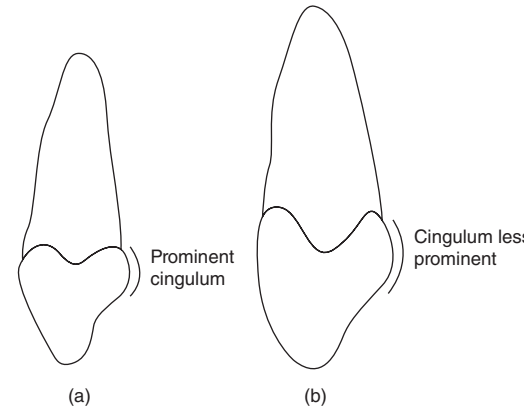


Figure 12.5 Mesial aspect of (a) deciduous and (b) permanent maxillary central incisors showing the cingulum.

4. **Mamelons** (**Fig. 12.4**)
   (a) *Deciduous teeth:* Mamelons are *absent* in the incisal surface of the deciduous incisors.
   (b) *Permanent teeth:* The permanent incisors have *mamelons* in their incisal surfaces.
5. **Cingulum** (**Fig. 12.5**)
   (a) *Deciduous teeth:* In the lingual/palatal surface, the cingulum is *more prominent* and occupies one-third of the crown length.
   (b) *Permanent teeth:* The cingulum is *not as prominent* as in the deciduous teeth.
6. **Cusps** (**Fig. 12.6**)
   (a) *Deciduous teeth:* The cusps are *short, sharp* and *pointed* in deciduous molars but become flat due to wear and tear.
   (b) *Permanent teeth:* The cusps in permanent premolars and molars are *less sharp* when compared with the deciduous molars.
7. **Occlusal surface**
   (a) *Deciduous teeth:* Since the cusps are short and the fossae and ridges are less prominent, the deciduous molars have a *shallow* occlusal surface.

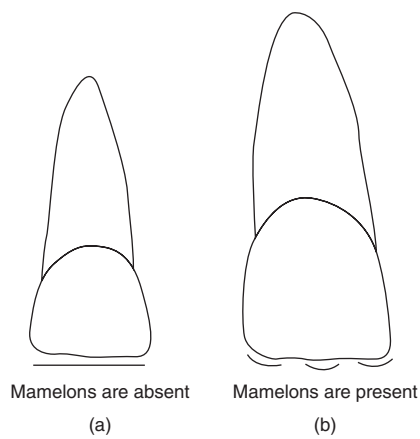


Figure 12.4 Labial aspect of (a) deciduous and (b) permanent maxillary central incisors showing the mamelons.

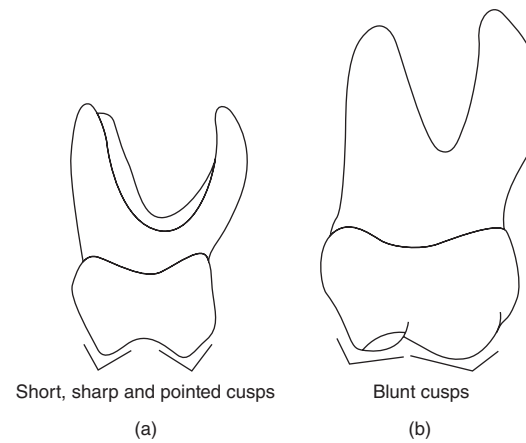


Figure 12.6 Proximal aspect of (a) deciduous and (b) permanent maxillary first molars showing the buccal and palatal cusps.

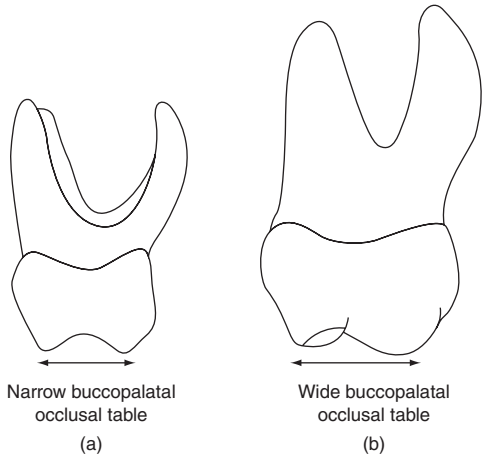


Figure 12.7 Mesial aspect of (a) deciduous and (b) permanent maxillary first molars showing the occlusal table.

(b) *Permanent teeth:* The permanent molars and premolars have a *deeper* occlusal surface because the cusps are long and the fossae and ridges are prominent.

8. **Occlusal area** (**Fig. 12.7**)
   (a) *Deciduous teeth:* The buccal and lingual/palatal surfaces of the deciduous molars converge more occlusally. As a result, the occlusal area/table appears *narrow* buccolingually.
   (b) *Permanent teeth:* The buccal and lingual/palatal surfaces of the permanent premolars and molars also converge occlusally but not as much as seen in the deciduous molars. As a result, the occlusal area/table appears *wider* buccolingually.
9. **Contact area** (**Fig. 12.8**)
   (a) *Deciduous teeth:* The crowns of primary teeth have a *small* contact area placed more *gingivally*.
   (b) *Permanent teeth:* The crowns of permanent teeth have a *large* contact area, and they are placed either in the *middle third* or at the *junction of the middle* and *incisal third*.
10. **Cervical line** (**Fig. 12.9**)
    (a) *Deciduous teeth:* The cervical line is *less curved*.
    (b) *Permanent teeth:* The cervical line is *more curved*.
11. **Cervical ridge** (**Fig. 12.10**)
    (a) *Deciduous teeth:* The cervical ridges at the cervical third of the crown are *prominent* in all deciduous teeth, especially on the labial surface of anterior teeth and the buccal and mesial surfaces of the molars.

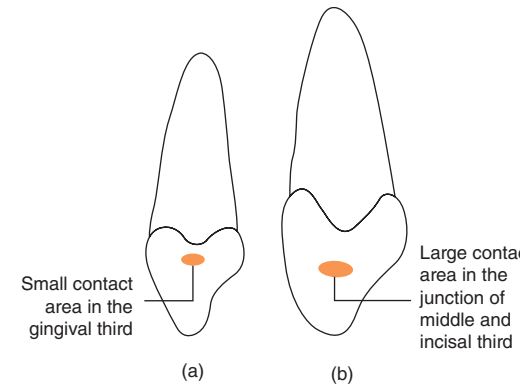


Figure 12.8 Proximal aspect of (a) deciduous and (b) permanent maxillary central incisors showing the contact area.

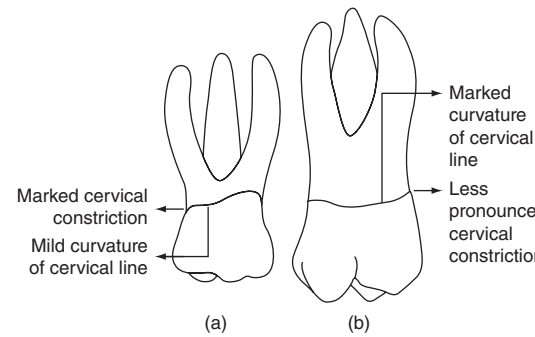


Figure 12.9 Buccal aspect of (a) deciduous and (b) permanent maxillary first molars.

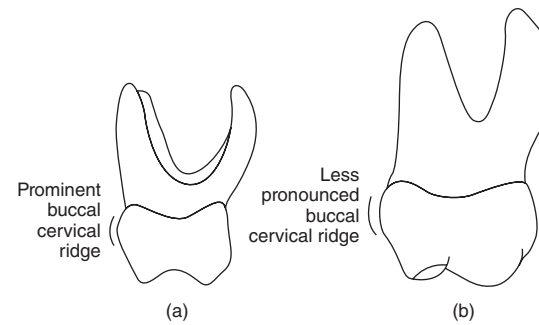


Figure 12.10 Proximal aspect of (a) deciduous and (b) permanent maxillary central incisors showing the buccal cervical ridge.

(b) *Permanent teeth:* The cervical ridges are *less pronounced* in the crown of permanent teeth.

12. **Cervical constriction** (Fig. 12.9)
    (a) *Deciduous teeth:* The cervix of the tooth shows *marked constriction* between the crown and the root, making the crown appear more bulbous.
    (b) *Permanent teeth:* The cervical constriction is *less pronounced* in permanent teeth when compared with the deciduous teeth.

Differences in Root Morphology

1. **Length of the root** (Fig. 12.11)
    (a) *Deciduous teeth:* The roots of the deciduous teeth are *shorter* and *slender* when compared with the permanent teeth.
    (b) *Permanent teeth:* The roots of the permanent teeth are *long* and *strong* when compared with the deciduous teeth.
2. **Crown: root ratio** (Fig. 12.11)
    (a) *Deciduous teeth:* The roots of the deciduous teeth are *proportionally longer* when compared with the crown size.
    (b) *Permanent teeth:* The roots of the permanent teeth are *not as long* as the crown size.
3. **Inclination of the root** (Fig. 12.12)
    (a) *Deciduous teeth:* There is a *slight labial inclination* of as much as 10° seen in the apical third of the roots of the deciduous anterior teeth.

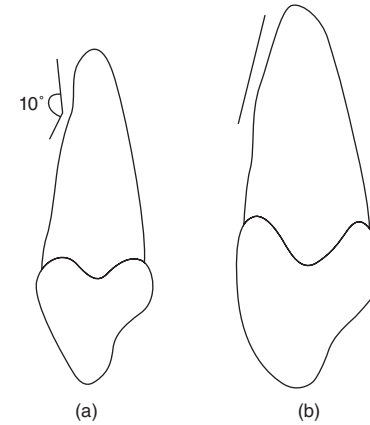


Figure 12.12 Labial inclination of the root in (a) deciduous and (b) permanent maxillary central incisors.

    (b) *Permanent teeth:* The roots of the permanent teeth do not show any labial inclination.
4. **Furcation** (Fig. 12.13)
    (a) *Deciduous teeth:* The level of furcation of the root is near the *cervix* in deciduous molars.
    (b) *Permanent teeth:* The level of furcation of the root is about 3 *or* 4 *mm from the cervix* or is more apically placed.
5. **Root trunk** (Fig. 12.13)
    (a) *Deciduous teeth:* Since the level of furcation is very close to the cervix, the root trunk is *not distinct*.
    (b) *Permanent teeth:* The root trunk is *long* and *distinct* as the level of furcation is not close to the cervix.

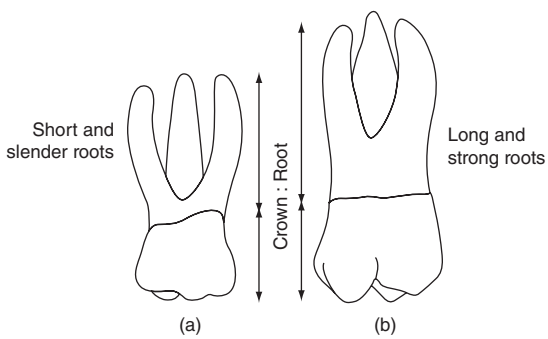


Figure 12.11 Crown: root ratio of (a) deciduous to (b) permanent maxillary first molars.

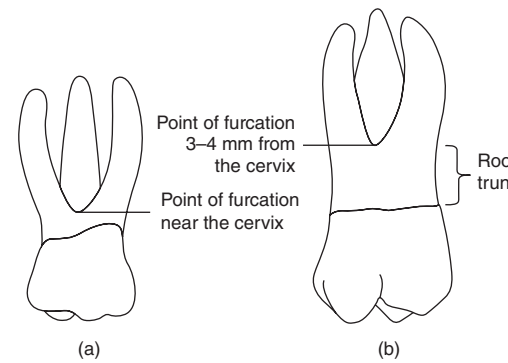


Figure 12.13 Level of furcation and length of the root trunk in (a) deciduous and (b) permanent maxillary first molars.

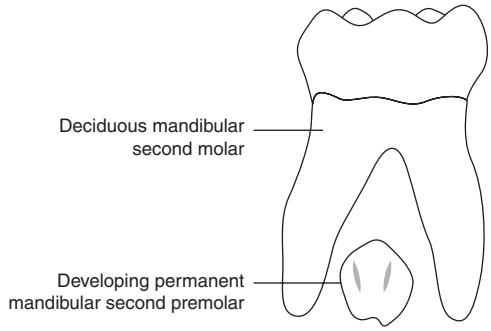


Figure 12.14 Root flare in deciduous molar.

6. **Root flare** (Fig. 12.14)
   (a) *Deciduous teeth:* The roots of the deciduous molars *flare beyond the mesiodistal* and *buccolingual outline* of the crown to allow room/space for development of the permanent tooth crown.
   (b) *Permanent teeth:* In case of permanent teeth, the roots *do not flare* and are well within the boundaries of the crown.

Applied Morphology

As the roots of the deciduous teeth are divergent to accommodate the developing permanent premolar, the removal or extraction of the deciduous molars before the resorption of the roots can result in the accidental removal of the developing portion of the premolar.

7. **Apical foramen** (Fig. 12.15)
   a. *Deciduous teeth:* The apical foramen is *wide* in deciduous teeth.
   b. *Permanent teeth:* In case of permanent teeth, the apical foramen is *narrow* and *constricted*.

Differences in Pulp Morphology (Fig. 12.15)

1. **Pulp chamber**
   (a) *Deciduous teeth:* The pulp chambers are *large* when compared with the size of the crown.
   (b) *Permanent teeth:* The pulp chambers are relatively small when compared with the size of the crown.
2. **Pulp horn**
   (a) *Deciduous teeth:* The pulp horns *extend more incisally* or *occlusally,* and they are placed close to the enamel.
   (b) *Permanent teeth:* The pulp horns are not placed at a high level as in deciduous teeth.

Applied Morphology

In case of deciduous teeth, care should be taken during cavity preparation, as the pulp horns are placed at a high level and there are chances of accidental exposure of the pulp.

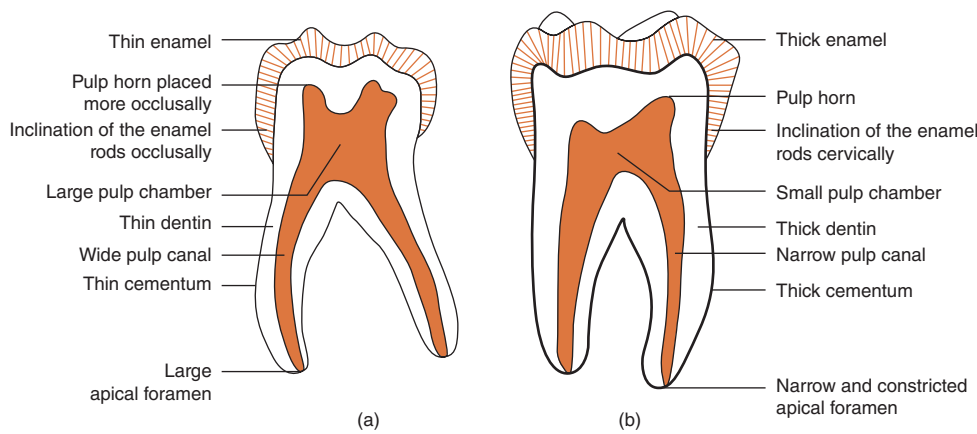


Figure 12.15 Cross-section of (a) deciduous and (b) permanent mandibular first molars.

SECTION II

3. **Pulp canal**
   (a) *Deciduous teeth:* The pulp canal is *wider* in comparison to the root width and is more *tortuous*.
   (b) *Permanent teeth:* The pulp canal is *narrow* in comparison to the root width.

Applied Morphology

Pulpal calcifications are commonly seen in permanent teeth as a result of regressive alteration of the teeth.

4. **Accessory pulp canals**
   (a) *Deciduous teeth:* In deciduous teeth, the accessory pulp canals are *more in number* and are situated mostly in the *furcation* area.
   (b) *Permanent teeth:* In case of permanent teeth, the accessory pulp canals are seen mostly in the *apical region*.

HISTOLOGIC DIFFERENCES (Fig. 12.15)

1. **Enamel**
   (a) *Deciduous teeth*
   - The enamel is *thin* and is of *uniform thickness* covering the crown of the deciduous teeth.
   - The enamel is *less calcified* and *more permeable*.
   - In the cervical region, the enamel rods incline either *incisally/occlusally/horizontally* towards the enamel surface.

   (b) *Permanent teeth*
   - The enamel is *thick* and is of *varying thickness,* covering the crown of the permanent teeth.
   - The enamel is *more calcified* and *less permeable.*
   - In the cervical region, the enamel rods incline *apically* or *cervically* towards the enamel surface.

Applied Morphology

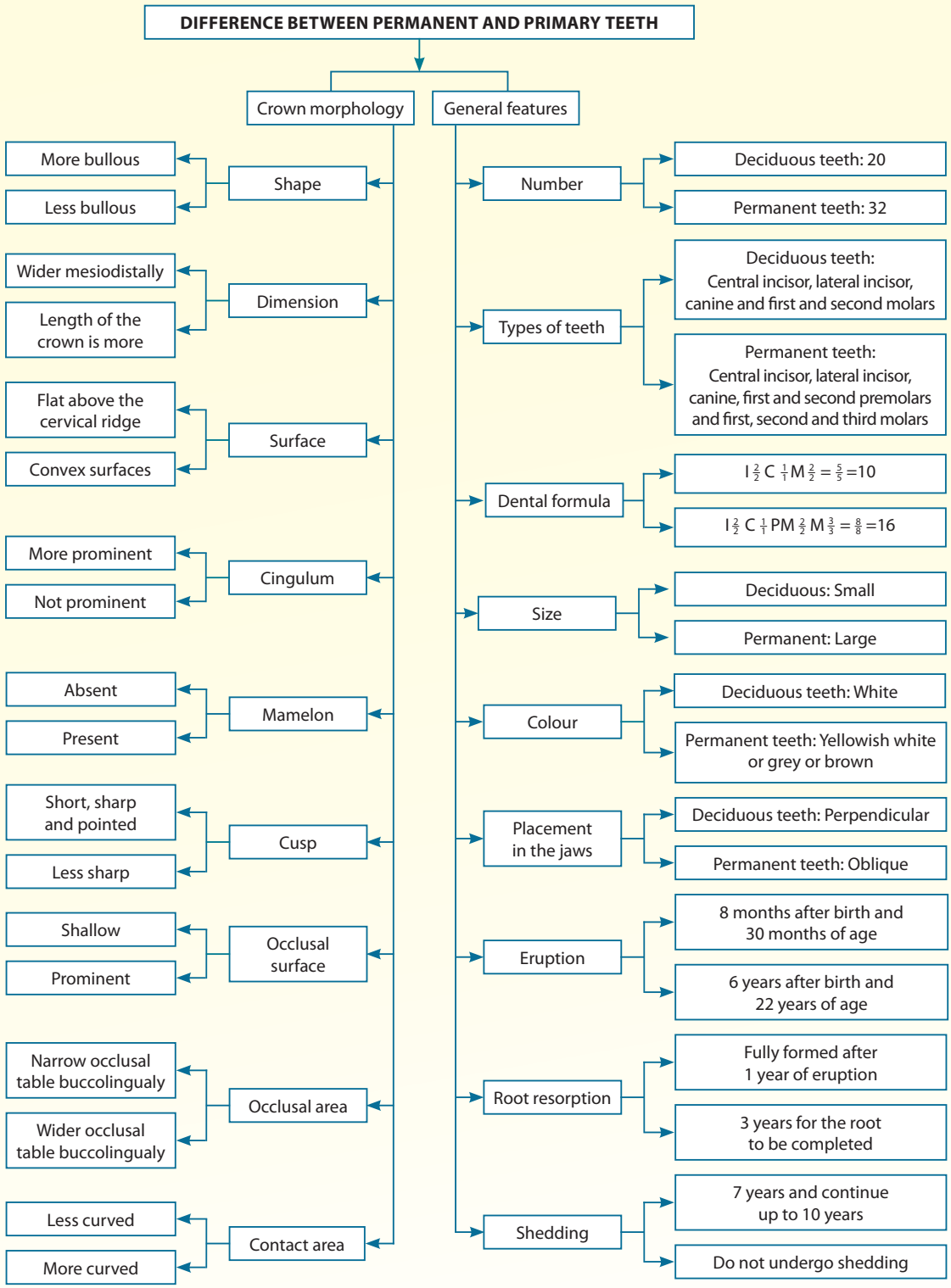
Attrition is the physiologic wearing of the tooth as a result of tooth-to-tooth contact. Because the deciduous teeth are less mineralized than the permanent teeth, the incisal and occlusal surfaces of the deciduous teeth undergo attrition to a greater extent than in the permanent teeth. This occurs due to the growth of the jaws and the various positions of occlusion of the deciduous teeth before their shedding.

2. **Dentin**
   (a) *Deciduous teeth:* The dentin is *thin* and is of *variable thickness,* with increased thickness near the occlusal fossae area.
   (b) *Permanent teeth:* The dentin is *thick* and is of *uniform thickness,* covering the crown of the permanent teeth.
3. **Neonatal line**
   (a) *Deciduous teeth:* The neonatal line is seen in *all* deciduous teeth.
   (b) *Permanent teeth:* The neonatal line is seen only in the *permanent first molars* because the first evidence of calcification of this tooth starts at birth.
4. **Dentinoenamel junction**
   (a) *Deciduous teeth:* The dentinoenamel junction is usually *scalloped* in deciduous teeth.
   (b) *Permanent teeth:* The dentinoenamel junction is *smooth* in permanent teeth.
5. **Cementum**
   (a) *Deciduous teeth:* The acellular and cellular cementum is relatively *thin* in deciduous teeth.
   (b) *Permanent teeth:* In permanent teeth, the cementum is relatively *thick* with the cellular cementum being thicker in the apical region of the root.

Key Points

1. The differentiating features between the deciduous and permanent teeth are based on their general features; their morphology of the crown, root, and pulp; and their histology.
2. Usually the deciduous teeth are smaller than the permanent teeth, except in the case of the deciduous molar, which is larger in size when compared with the permanent premolar.
3. The deciduous teeth are white when compared with the permanent teeth, which have a yellow tone.
4. The deciduous teeth undergo physiologic resorption of the root whereas the permanent teeth undergo pathologic resorption.
5. The occlusal surface of the deciduous molars is shallow when compared with that of the permanent teeth, which is deep.
6. There is marked cervical constriction of the deciduous molars and a prominent cervical ridge, making the crown appear more bulbous.
7. The roots of the deciduous teeth are slender and long when compared with their crown length, and the area of furcation of the root is very near the cervix of the crown.
8. In deciduous teeth, the apical foramen is large, whereas in permanent teeth, the apical foramen is narrow and constricted.
9. The pulp chambers are large and the pulp horns are placed at a higher level in the deciduous teeth.
10. In the cervical region of the deciduous teeth, the enamel rods incline either incisally/occlusally or horizontally towards the enamel surface, whereas in the permanent teeth, they incline apically or cervically.

Mind Map


DIFFERENCE BETWEEN PERMANENT AND PRIMARY TEETH
Crown morphology
General features
Shape
More bullous
Less bullous
Dimension
Wider mesiodistally
Length of the crown is more
Surface
Flat above the cervical ridge
Convex surfaces
Cingulum
More prominent
Not prominent
Mamelon
Absent
Present
Cusp
Short, sharp and pointed
Less sharp
Occlusal surface
Shallow
Prominent
Occlusal area
Narrow occlusal table buccolingualy
Wider occlusal table buccolingualy
Contact area
Less curved
More curved
Number
Deciduous teeth: 20
Permanent teeth: 32
Types of teeth
Deciduous teeth: Central incisor, lateral incisor, canine and first and second molars
Permanent teeth: Central incisor, lateral incisor, canine, first and second premolars and first, second and third molars
Dental formula
I 2/2 C 1/1 M 2/2 = 5/5 =10
I 2/2 C 1/1 PM 2/2 M 3/3 = 8/8 =16
Size
Deciduous: Small
Permanent: Large
Colour
Deciduous teeth: White
Permanent teeth: Yellowish white or grey or brown
Placement in the jaws
Deciduous teeth: Perpendicular
Permanent teeth: Oblique
Eruption
8 months after birth and 30 months of age
6 years after birth and 22 years of age
Root resorption
Fully formed after 1 year of eruption
3 years for the root to be completed
Shedding
7 years and continue up to 10 years
Do not undergo shedding

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Multiple Choice Questions

1. The number of deciduous and permanent teeth are
   (a) 32 and 20
   (b) 20 and 32
   (c) 52 and 20
   (d) 20 and 52
2. The deciduous teeth are white in colour because the
   (a) Enamel is less mineralized
   (b) Enamel does not reflect the colour of the underlying dentin
   (c) Enamel is opaque
   (d) All of the above
3. The eruption of the deciduous teeth begins at _____ months after birth.
   (a) 8
   (b) 30
   (c) 6
   (d) 22
4. Mamelons are seen in the
   (a) Deciduous central incisor
   (b) Deciduous canine
   (c) Permanent incisors
   (d) Permanent canine
5. The contact area in the permanent teeth are placed at the
   (a) Middle third
   (b) Gingival third
   (c) Junction of incisal and middle third
   (d) Both a and c
6. The degree of labial inclination of the apical third of the root of the deciduous teeth is
   (a) 20°
   (b) 12°
   (c) 10°
   (d) 8°
7. The level of furcation of the roots of the deciduous teeth is
   (a) 4 mm from the cervix
   (b) 3 mm from the cervix
   (c) Near the cervix
   (d) Both a and c
8. In deciduous teeth, the accessory pulp canals are situated at the
   (a) Apical region
   (b) Furcation area
   (c) Middle third
   (d) All of the above
9. The enamel rods at the cervical region of the deciduous teeth are inclined _____ towards the enamel surface.
   (a) Incisally
   (b) Apically
   (c) Gingivally
   (d) Vertically
10. The cellular cementum is thick in the
    (a) Apical region of the deciduous teeth
    (b) Apical region of the permanent teeth
    (c) Cervical region of the deciduous teeth
    (d) Cervical region of the permanent teeth

CHAPTER 13



Deciduous Dentition

Overview

The first set of dentition in the lifetime of a human being is primary or deciduous dentition. Deciduous teeth or primary teeth are the teeth present in the deciduous dentition. In the deciduous dentition, there are 20 teeth with 5 teeth in each quadrant and 10 teeth per arch. Beginning with the median line, the teeth are named in each quadrant as central incisor, followed by lateral incisor, canine, first molar and second molar. The development of deciduous teeth starts at 6 weeks in utero; the calcification begins between 3 and 4 months in utero and completes by 11 months after birth. At birth, these deciduous teeth are not visible in the oral cavity. The deciduous mandibular central incisor is the first tooth to erupt in the oral cavity at 8 months after birth. Eruption of deciduous teeth is completed by 30 months. The roots of the deciduous teeth are completed by 1½–2 years after the eruption of the tooth into the oral cavity. Each tooth possesses a distinct morphology which aids in identification of the tooth and the respective quadrant.

INTRODUCTION

Primary or deciduous dentition is the first set of dentition in the lifetime of a human being. The teeth present in the deciduous dentition are called *deciduous teeth* or *primary teeth*. The term *deciduous* comes from a Latin word which means 'fall off', since these teeth usually exfoliate and are replaced by permanent teeth. The other names by which they are referred to are milk teeth, baby teeth, predecessor teeth or lacteal dentition. They are called milk teeth as the colour of the primary teeth is as white as milk and the refractive index of the teeth is similar to that of milk. The term *lacteal* refers to milk and hence the name *lacteal dentition*. They are known as *predecessor teeth* as they precede the eruption of the permanent teeth.

In the deciduous dentition, there are 20 teeth with 5 teeth in each quadrant and 10 teeth per arch. Beginning with the median line, the teeth are named in each quadrant as central incisor, followed by lateral incisor, canine, first molar and second molar (*see* Fig. 10.1). All of these are gradually replaced with a permanent counterpart, except for the first and second molars which are replaced by premolars.

IMPORTANCE OF DECIDUOUS DENTITION

1. The deciduous dentition plays an important part in mastication during the growth and development of the child.
2. The normal facial appearance and smile of the child are maintained as the teeth provide support to the cheeks and lips.
3. They contribute to the growth of the maxillary and mandibular arches.
4. They aid in the formulation of clear speech.
5. Deciduous teeth are essential for location, alignment and occlusion of permanent teeth and thereby for the prevention of malocclusion.
6. Developmental spaces are seen in the anterior teeth of deciduous dentition as they erupt into the oral cavity; the spaces also occur as a result of the growth of the maxillary and mandibular bones. These spaces are called *primate spaces* and are seen between the maxillary lateral incisor and canine and between the mandibular canine and first molar. The primate spaces provide space for the permanent teeth, which are wider mesiodistally than the deciduous teeth.

LIFE CYCLE OF DECIDUOUS DENTITION

The development of deciduous teeth starts at 6 weeks in utero; the calcification begins between 3 and 4 months in utero and completes by 11 months after birth. At birth, these deciduous teeth are not visible in the oral cavity. The deciduous mandibular central incisor is the first tooth to erupt in the oral cavity at 8 months after birth. Eruption of deciduous teeth is completed by 30 months. The roots of the deciduous teeth are completed by 1½–2 years of age after the eruption of the tooth into the oral cavity.

The deciduous dentition is seen in children from the age of 2 years to about 6 years in the oral cavity, after which the roots of the deciduous teeth begin to resorb. Three years after root completion, this resorption starts near the apical end and continues towards the crown because of which the crown lacks support and gets exfoliated or falls off and gives way for the eruption of the permanent teeth. The process of exfoliation of the deciduous teeth is known as *shedding* and occurs between 7 and 11 years of age.

DECIDUOUS INCISORS

The deciduous incisors are the first tooth to erupt in the oral cavity and they are eight in number, four in each arch. Each quadrant has two incisors, a central incisor and a lateral incisor. The sequence of eruption of the deciduous incisors is as follows: mandibular central incisor → mandibular lateral incisor → maxillary central incisor → maxillary lateral incisor. The main function of deciduous incisors is shearing or cutting the food during the process of mastication (chewing), articulation of speech and supporting the lips. The surface area of the tooth used in eating is known as *incisal ridge* or *incisal edge*.

Deciduous Maxillary Central Incisor

The maxillary central incisors are the most visible of all teeth in the mouth and they are two in number: right and left. These are located on either side of the midline of the face. The maxillary central incisors are the only teeth in the maxillary arch where two mesial surfaces of the adjacent teeth contact each other. Only in the anterior teeth is the mesiodistal width of the crown more than the cervicoincisal length of the crown.

Table 13.1a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	E	F
Zsigmondy/ Palmer system	A|	|A
FDI system	51	61

Table 13.1b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
14 (13–16) weeks in utero	1½ months	10 (8–12) months	1½ years	7 years

Table 13.1c Dimensions (Fig. 13.1a)

Total length	16.0 mm
Cervicoincisal length of crown	6.0 mm
Cervicoapical length of root	10.0 mm
Mesiodistal diameter of crown	6.5 mm
Mesiodistal diameter of crown at the cervix	4.5 mm
Labiopalatal diameter of crown	5.0 mm
Labiopalatal diameter of crown at cervix	4.0 mm

The nomenclature, chronology and dimensions of deciduous maxillary central incisors are given in **Table 13.1(a–c)**.

Labial Aspect (Fig. 13.1b)

1. **Shape of the crown:** The crown is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. Because of this divergence, the mesiodistal width of the crown at the incisal third is more than the cervical third.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line up to the incisal edge ending in a sharp

SECTION II

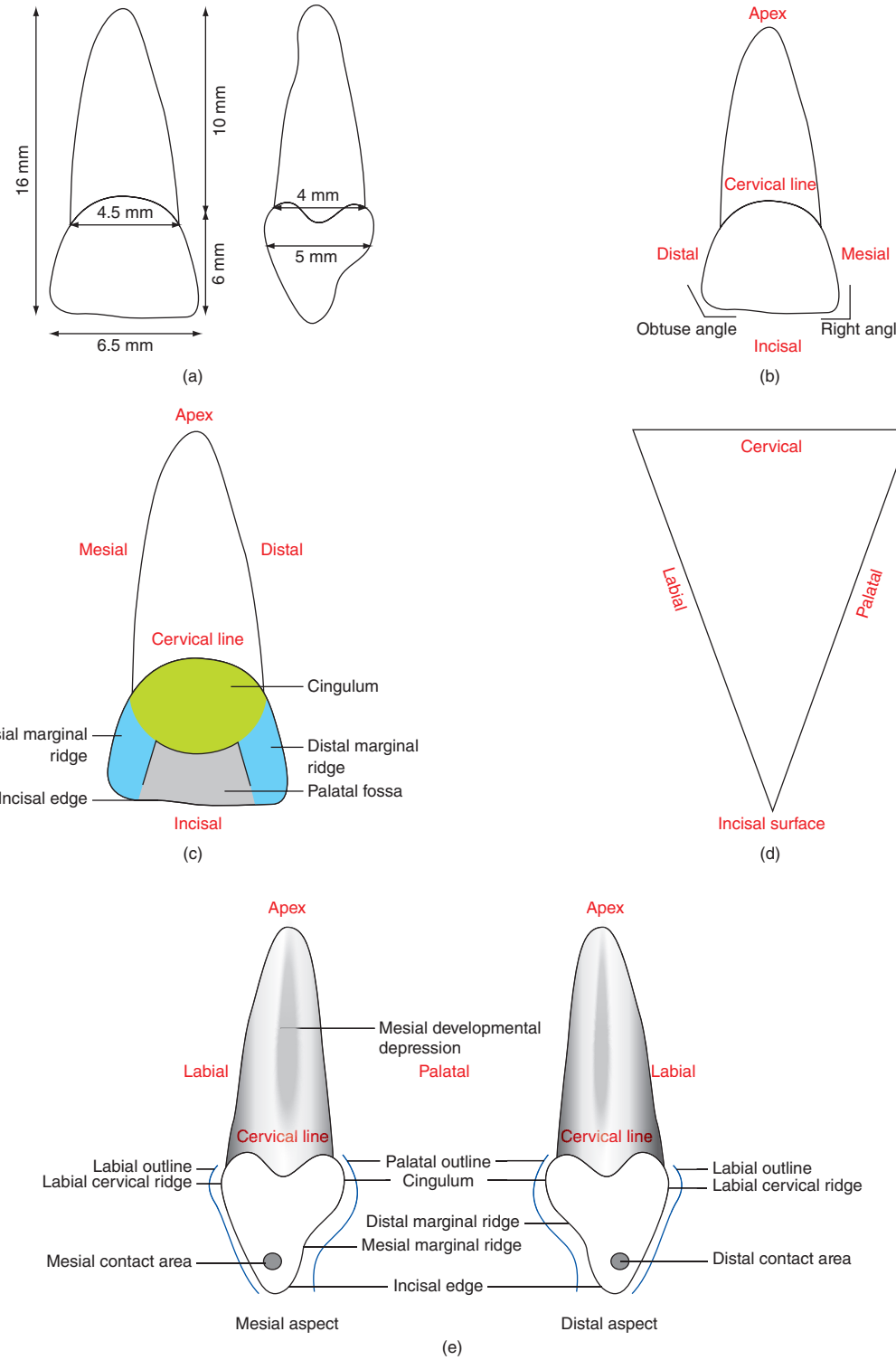


Figure 13.1 Deciduous maxillary right central incisor: (a) dimensions, (b) labial aspect, (c) palatal aspect, (d) proximal outline of the crown, and (e) mesial and distal aspects. (*Continued*)

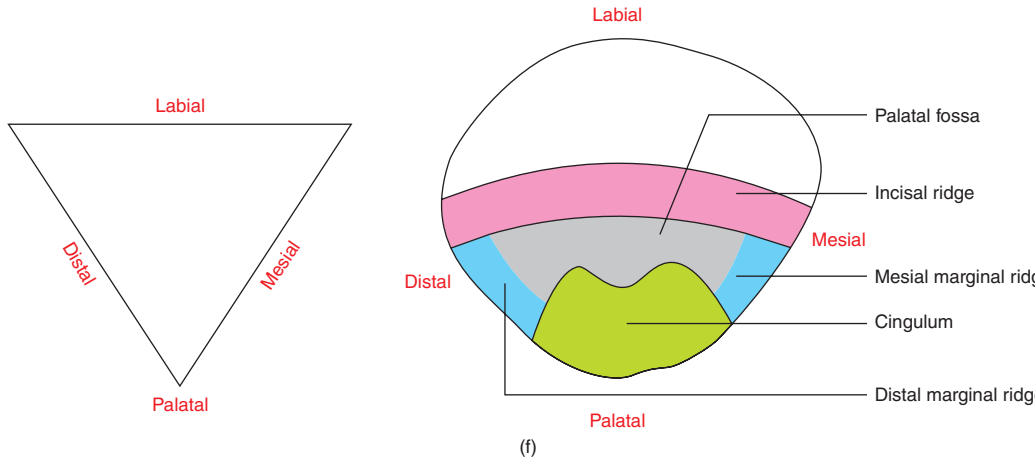


Figure 13.1 (*Continued*) (f) Incisal aspect.

mesioincisal angle. The mesioincisal angle is a right angle.

(b) *Distal outline:* The distal outline of the crown is convex from the cervical line up to the incisal edge ending in a round distoincisal angle. The distoincisal angle forms an obtuse angle.

(c) *Cervical outline:* The curvature of the cervical outline is semicircular with the convexity facing towards the root apex.

(d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge. Mamelons are not present.

3. **Labial surface of the crown:** The labial surface is smooth without any developmental depressions or imbrication lines. In the cervical third of the labial surface, a prominent cervical ridge is present running in a mesiodistal direction. This cervical ridge is known as the *labial cingulum*.
4. **Shape of the root:** A single, cone-shaped root is present with a blunt apex. The length of the root is longer relative to the crown length.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex.
6. **Labial surface of the root:** The labial surface is flat and smooth without any developmental depressions or grooves.

Palatal Aspect (Fig. 13.1c)

1. **Shape of the crown:** The crown in the palatal aspect is also roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. The mesiodistal width of the crown in this aspect is comparatively less than in the labial aspect because of the palatal convergence of the mesial and distal sides of the crown.
2. **Outlines of the crown**

(a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line up to the incisal edge ending in a sharp mesioincisal angle. The mesioincisal angle is a right angle.

(b) *Distal outline:* The distal outline of the crown is convex from the cervical line up to the incisal edge ending in a round distoincisal angle. The distoincisal angle forms an obtuse angle.

(c) *Cervical outline:* The curvature of the cervical outline is semicircular with the convexity facing towards the root apex.

(d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge. Mamelons are not present.

3. **Palatal surface of the crown:** The palatal surface is irregular with a depression in the centre of the crown known as the *palatal fossa*. The palatal fossa is bordered mesially and distally by

well-developed mesial and distal marginal ridges and cervically by a prominent cingulum. The cingulum is well developed and extends beyond the cervical one-third of the crown and thereby divides the palatal fossa into mesial and distal palatal fossae. The palatal fossa bordered by the prominent cingulum and marginal ridges give a shovel-shaped appearance to the palatal surface.

4. **Shape of the root:** A single, cone-shaped root is present with a blunt apex.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex. Similar to the crown, the root also tapers towards the palatal surface making it narrow mesiodistally.
6. **Palatal surface of the root:** The palatal surface is smooth with a ridge extending from the cervical line up to the apex. This ridge is formed due to the palatal tapering of the mesial and distal surface of the root. The cross-section of the root is triangular, with the base formed by the labial surface, the apex formed by the palatal surface and the other two sides of the triangle formed by the mesial and distal sides.

Mesial Aspect (Fig. 13.1e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and palatal surfaces (**Fig. 13.1d**). The labiopalatal width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated labial to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the incisal ridge.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the mesial marginal ridge/fossa and again convex at the incisal ridge. The mesial marginal ridge is prominent and extends from the middle third up to the incisal third.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.
3. **Mesial surface of the crown:** The mesial surface is smooth, without any developmental depressions or grooves.
4. **Mesial contact area:** The mesial contact area is situated in the incisal third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present, with a blunt apex; it is wider labiopalatally.
6. **Outlines of the root:** The labial and palatal outlines of the root taper evenly from the cervical line up to the apex. There is a slight lingual inclination, as much as 10°, in the apical third of the root.
7. **Mesial surface of the root:** The mesial surface is more or less smooth and a developmental depression is present in the cervical and middle third of the root.

Distal Aspect (Fig. 13.1e)

1. **Shape of the crown:** The crown in the distal aspect is also wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and palatal surfaces (**Fig. 13.1d**). The labiopalatal width of the crown at the cervical third is comparatively more than the labiopalatal width at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated labial to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the incisal ridge.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the distal marginal ridge/fossa and again convex at the incisal ridge. The

distal marginal ridge is prominent and extends from the middle third up to the incisal third.

(c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge, but the depth of curvature is less than the mesial aspect.

(d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.

3. **Distal surface of the crown:** The distal surface is smooth without any developmental depressions or grooves.
4. **Distal contact area:** The distal contact area is situated in the incisal third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex; it is wider labiopalatally.
6. **Outlines of the root:** The labial and palatal outlines of the root taper evenly from the cervical line up to the apex. There is a slight lingual inclination of as much as 10° in the apical third of the root.
7. **Distal surface of the root:** The distal surface is smoothly convex without any developmental grooves.

Incisal Aspect (Fig. 13.1f)

1. **Shape of the crown:** The crown in the incisal aspect is triangular, with the base formed by the labial outline, the apex formed by the cingulum/palatal surface and the other two sides formed by the mesial and distal surfaces. The mesiodistal width of the crown is comparatively more than the labiopalatal width. The incisal ridge appears nearly straight or slightly curved mesiodistally, and it is 1 mm thick labiopalatally.
2. **Outlines of the crown**

(a) *Labial outline:* The labial outline is broad and smoothly convex mesiodistally.

(b) *Palatal outline:* The palatal outline is narrower than the labial outline because of the tapering of the palatal surface towards the cingulum.

(c) *Mesial and distal outlines:* The mesial and distal outlines of the crown are relatively broad to have a good contact area with the adjacent teeth.

Deciduous Maxillary Lateral Incisor

The maxillary lateral incisors are two in number: right and left. These are situated distal to the maxillary central incisors with one tooth each in the right and left maxillary arches. These are mostly similar to the maxillary central incisors but their dimensions are smaller. The cervicoincisal length of the crown is more than the mesiodistal width of the crown which is exactly the opposite of the maxillary central incisor.

The nomenclature, chronology and dimensions of deciduous maxillary lateral incisors are given in **Table 13.2(a–c)**.

Table 13.2a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	D	G
Zsigmondy/ Palmer system	B|	|B
FDI system	52	62

Table 13.2b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
16 (14–17) weeks in utero	2½ months	11 (9–13) months	2 years	8 years

Table 13.2c Dimensions (Fig. 13.2a)

Total length	17 mm
Cervicoincisal length of crown	5.6 mm
Cervicoapical length of root	11.14 mm
Mesiodistal diameter of crown	5.1 mm
Mesiodistal diameter of crown at the cervix	3.7 mm
Labiopalatal diameter of crown	4.0 mm
Labiopalatal diameter of crown at cervix	3.7 mm

Labial Aspect (Fig. 13.2b)

1. **Shape of the crown:** The crown is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. Because of this divergence, the mesiodistal width of the crown at the incisal third is more than the cervical third. The crown is less symmetrical than in the maxillary central incisor.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line up to the incisal edge ending in a sharp mesioincisal angle. The mesioincisal angle is a right angle.
   (b) *Distal outline:* The distal outline of the crown is convex from the cervical line up to the incisal edge ending in a round distoincisal angle. The distoincisal angle is more rounded than the maxillary central incisor and forms an obtuse angle.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge with a slight distal inclination. Mamelons are not present.
3. **Labial surface of the crown:** The labial surface is smooth without any developmental depressions or imbrication lines. A prominent cervical ridge is present running in a mesiodistal direction in the cervical third. This cervical ridge, known as the *labial cingulum*, is not that prominent as in the maxillary central incisor.
4. **Shape of the root:** A single, cone-shaped root is present with a sharp, pointed apex. The length of the root is twice as long as the crown length.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the pointed apex.
6. **Labial surface of the root:** The labial surface is flat and smooth without any developmental depressions or grooves.

Palatal Aspect (Fig. 13.2c)

1. **Shape of the crown:** The crown in the palatal aspect is also roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. The mesiodistal width of the crown in this aspect is comparatively less than that of the labial aspect because of the palatal convergence of the mesial and distal sides of the crown.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line up to the incisal edge ending in a sharp mesioincisal angle. The mesioincisal angle is a right angle.
   (b) *Distal outline:* The distal outline of the crown is convex from the cervical line up to the incisal edge ending in a round distoincisal angle. The distoincisal angle is more rounded than the maxillary central incisor and forms an obtuse angle.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge and slight distal inclination. Mamelons are not present.
3. **Palatal surface of the crown:** The palatal surface is irregular with a depression in the centre of the crown called *palatal fossa*. The palatal fossa is bordered mesially and distally by the mesial and distal marginal ridges and cervically by a prominent cingulum. The cingulum and the marginal ridges are not as well developed as in the maxillary central incisor. The palatal fossa is shallow and not as deep as in the maxillary central incisor.
4. **Shape of the root:** A single, cone-shaped root is present with a sharp, pointed apex.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the pointed apex. Similar to the crown, the root also tapers towards the palatal surface making it narrow mesiodistally.
6. **Palatal surface of the root:** The palatal surface is smooth with a ridge extending from the

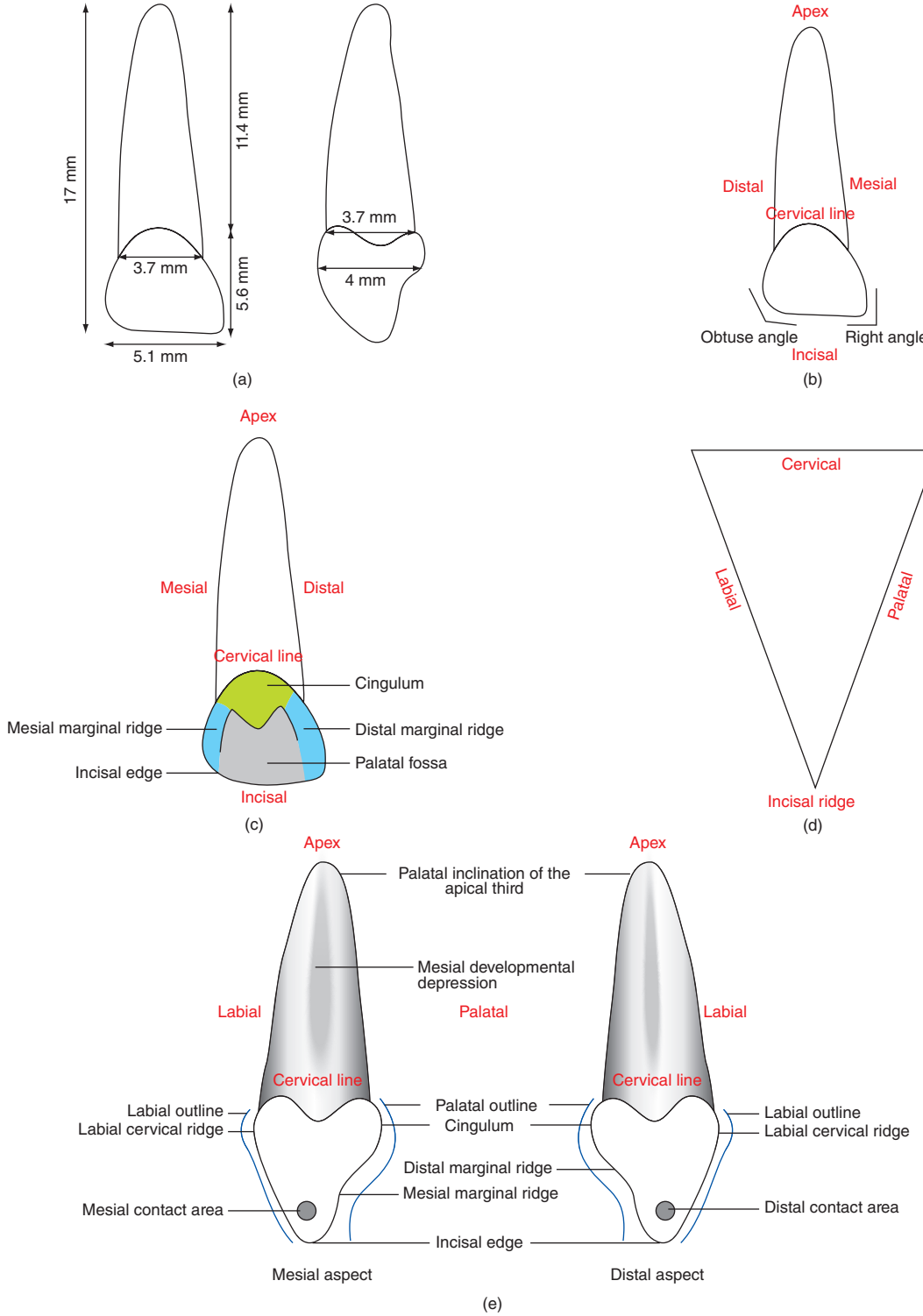


Figure 13.2 Deciduous maxillary right lateral incisor: (a) dimensions, (b) labial aspect, (c) palatal aspect, (d) proximal outline of the crown, (e) mesial and distal aspects. (*Continued*)

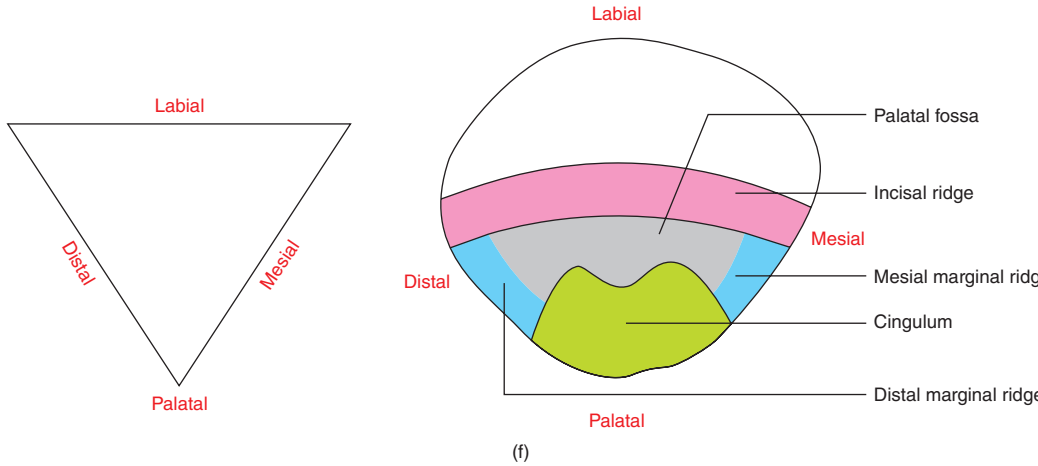


Figure 13.2 (*Continued*) (f) Incisal aspect.

cervical line up to the apex. This ridge is formed as a result of the palatal tapering of the mesial and distal surface of the root. The cross-section of the root is triangular, with the base formed by the labial surface, apex formed by the palatal surface and the other two sides of the triangle formed by the mesial and distal sides.

Mesial Aspect (Fig. 13.2e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and palatal surfaces (**Fig. 13.2d**). The labiopalatal width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated labial to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the incisal ridge.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the mesial marginal ridge/fossa and again convex at the incisal ridge. The mesial marginal ridge is prominent and extends from the middle third up to the incisal third.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.
3. **Mesial surface of the crown:** The mesial surface is smooth without any developmental depressions or grooves.
4. **Mesial contact area:** The mesial contact area is situated in the incisal third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a sharp, pointed apex. The root is wider labiopalatally.
6. **Outlines of the root:** The labial and palatal outlines of the root taper evenly from the cervical line up to the apex. There is a slight palatal inclination of as much as 10° in the apical third of the root.
7. **Mesial surface of the root:** The mesial surface is more or less smooth, and a developmental depression is present in the cervical and middle third of the root.

Distal Aspect (Fig. 13.2e)

1. **Shape of the crown:** The crown in the distal aspect is also wedge shaped or triangular,

with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and palatal surfaces (**Fig. 13.2d**). The labiopalatal width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the incisal third. The incisal ridge is situated labial to the root axis line.

2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the incisal ridge.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the distal marginal ridge/fossa and again convex at the incisal ridge. The distal marginal ridge is prominent and extends from the middle third up to the incisal third.
   (c) *Cervical outline:* The cervical outline is semicircular with the convexity facing towards the incisal ridge, but the depth of curvature is less than that of the mesial aspect.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.
3. **Distal surface of the crown:** The distal surface is smooth without any developmental depressions or grooves.
4. **Distal contact area:** The distal contact area is situated in the incisal third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a sharp, pointed apex, and it is wider labiopalatally.
6. **Outlines of the root:** The labial and palatal outlines of the root taper evenly from the cervical line up to the apex. There is a slight palatal inclination of as much as 10° in the apical third of the root.
7. **Distal surface of the root:** The distal surface is smoothly convex without any developmental groove.

Incisal Aspect (Fig. 13.2f)

1. **Shape of the crown:** The crown in the incisal aspect is triangular, with the base formed by the labial outline, the apex formed by the cingulum/palatal surface and the other two sides formed by the mesial and distal surfaces. The mesiodistal width of the crown is comparatively more than the labiopalatal width. The incisal ridge appears nearly straight or curved mesiodistally and is 1 mm thick labiopalatally.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is broad and smoothly convex mesiodistally.
   (b) *Palatal outline:* The palatal outline is narrower than the labial outline because of the tapering of the palatal surface towards the cingulum.
   (c) *Mesial and distal outlines:* The mesial and distal outlines of the crown are relatively broad to have a good contact area with the adjacent teeth.

Deciduous Mandibular Central Incisor

The mandibular central incisor is the first tooth to erupt in the oral cavity in the lifetime of a human being. They are two in number—right and left—and are situated on either side of the midline of the face. The mandibular central incisors are the only teeth in the mandibular arch in which the mesial surface contacts with the adjacent mesial surface. They are the smallest teeth in the entire human dentition.

The nomenclature, chronology and dimensions of deciduous mandibular central incisors are given in **Table 13.3(a–c)**.

Table 13.3a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	P	O
Zsigmondy/ Palmer system	$\overline{A}\rfloor$	$\lfloor\overline{A}$
FDI system	81	71

SECTION II

Table 13.3b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
14 (13–16) weeks in utero	2½ months	8 (6–10) months	1½ years	7 years

Table 13.3c Dimensions (Fig. 13.3a)

Total length	14.0 mm
Cervicoincisal length of crown	5.0 mm
Cervicoapical length of root	9.0 mm
Mesiodistal diameter of crown	4.2 mm
Mesiodistal diameter of crown at the cervix	3.0 mm
Labiopalatal diameter of crown	4.0 mm
Labiopalatal diameter of crown at cervix	3.5 mm

Labial Aspect (Fig. 13.3b)

1. **Shape of the crown:** The crown is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. Because of this divergence, the mesiodistal width of the crown at the incisal third is more than the cervical third. This tooth is narrower mesiodistally than the deciduous mandibular lateral incisor and is symmetrical in outline.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown tapers evenly from the mesial contact area up to the narrow cervix. The mesioincisal angle is a right angle.
   (b) *Distal outline:* The distal outline of the crown also tapers evenly from the distal contact area up to the narrow cervix. The distoincisal angle is rounded.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular in shape with the convexity facing towards the root apex.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge which is perpendicular to the long axis of the tooth. Mamelons are not present.
3. **Labial surface of the crown:** The labial surface is smooth and convex without any developmental depressions or imbrication lines. The highest point of convexity is in the cervical third due to the prominent cervical ridge which is seen in a mesiodistal direction. This cervical ridge is called the *labial cingulum*.
4. **Shape of the root:** A single, cone-shaped root is present with a pointed apex. The length of the root is twice the length of the crown.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex.
6. **Labial surface of the root:** The labial surface is flat and smooth without any developmental depressions or grooves.

Lingual Aspect (Fig. 13.3c)

1. **Shape of the crown:** The crown in the lingual aspect is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. The mesiodistal width of the crown in this aspect is comparatively less than the labial aspect because of the lingual convergence or tapering of the mesial and distal sides of the crown.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown tapers evenly from the mesial contact area up to the cingulum. The mesioincisal angle is sharp.
   (b) *Distal outline:* The distal outline of the crown also tapers evenly from the distal contact area up to the cingulum. The distoincisal angle is sharp.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge which is perpendicular to the long axis of the tooth. Mamelons are not present.
3. **Lingual surface of the crown:** The lingual surface is smooth with a slight concavity called lingual fossa in the middle and incisal third. The lingual fossa is bordered

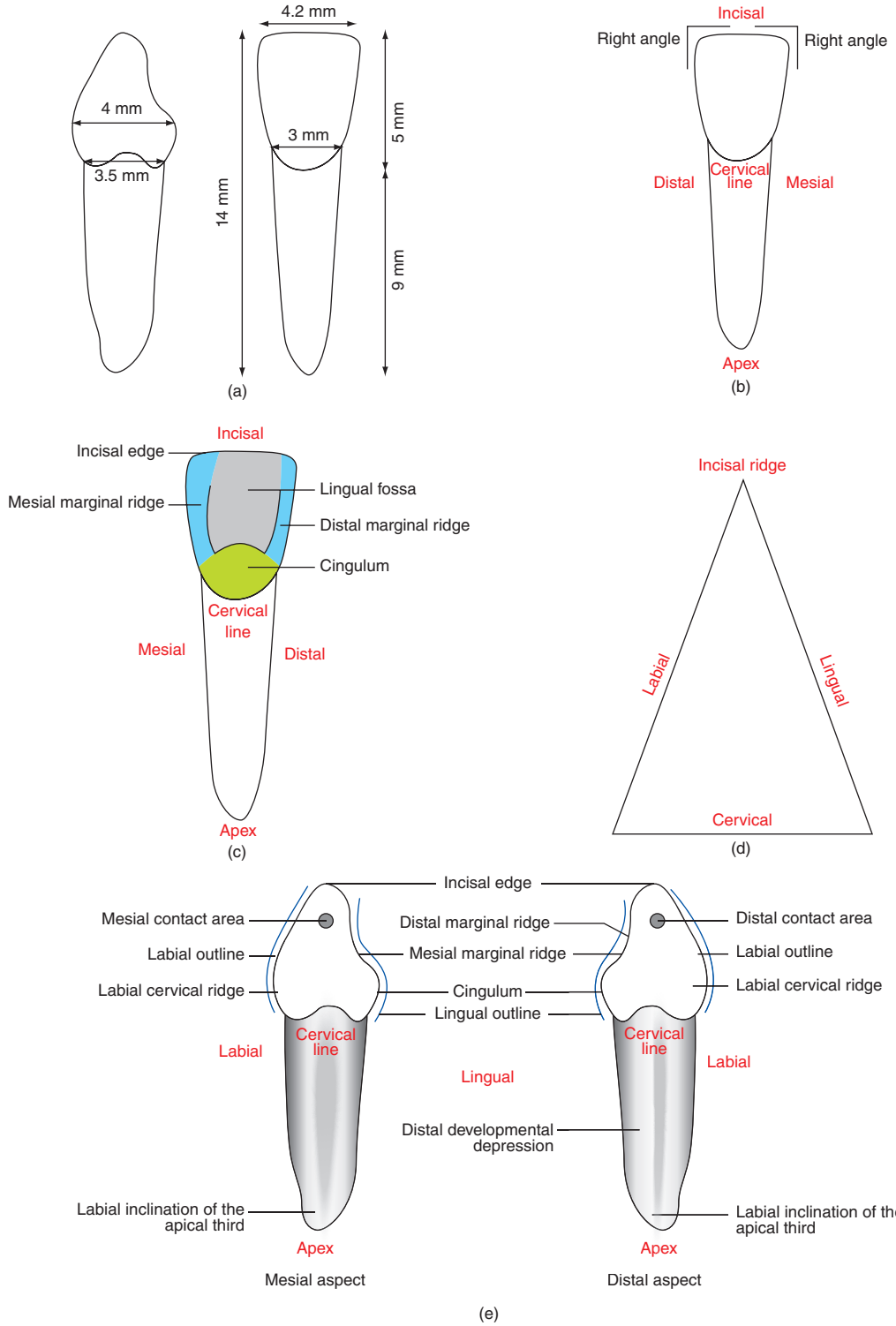


Figure 13.3 Deciduous mandibular right central incisor: (a) dimensions, (b) labial aspect, (c) lingual aspect, (d) proximal outline of the crown, (e) mesial and distal aspects. (*Continued*)

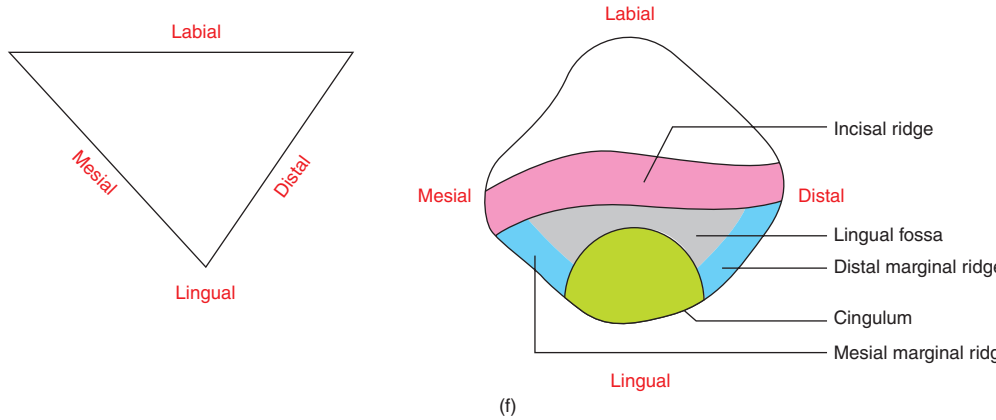


Figure 13.3 (*Continued*) (f) Incisal aspect.

mesially and distally by the mesial and distal marginal ridges and cervically by the cingulum. The cingulum is prominent and occupies the major part of the lingual surface and the marginal ridges are not that well developed as they are in the deciduous maxillary incisors.

4. **Shape of the root:** A single, cone-shaped root is present with a pointed apex.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex. Similar to the crown, the root is narrow in the lingual aspect due to the lingual convergence of the mesial and distal surfaces of the root.
6. **Lingual surface of the root:** The lingual surface is smooth with a ridge extending from the cervical line up to the apex. This ridge is the result of the lingual tapering of the mesial and distal surfaces of the root. Like the maxillary incisors, the cross-section of the root is triangular, with the base formed by the labial surface, the apex formed by the lingual surface and the other two sides of the triangle formed by the mesial and distal sides.

Mesial Aspect (Fig. 13.3e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and lingual surfaces (**Fig. 13.3d**). The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated on the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is smoothly convex from the cervical line up to the incisal ridge.
   (b) *Lingual outline:* The lingual outline is S shaped. It is convex at the cingulum and concave at the mesial marginal ridge/fossa and again convex at the incisal ridge. The mesial marginal ridge is prominent and extends from the middle third up to the incisal third.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.
3. **Mesial surface of the crown:** The mesial surface is smooth without any developmental depressions or grooves.
4. **Mesial contact area:** The mesial contact area is situated in the incisal third of the crown.

5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex; it is wider labiolingually.
6. **Outlines of the root:** The labial and lingual outlines of the root taper evenly from the cervical line up to the apex. There is a slight labial inclination of as much as 10° in the apical third of the root.
7. **Mesial surface of the root:** The mesial surface is smooth without any developmental groove or depression.

Distal Aspect (Fig. 13.3e)

1. **Shape of the crown:** The crown in the distal aspect is also wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and lingual surfaces (**Fig. 13.3d**). The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated on the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is smoothly convex from the cervical line up to the incisal ridge.
   (b) *Lingual outline:* The lingual outline is S shaped. It is convex at the cingulum and concave at the distal marginal ridge/fossa and again convex at the incisal ridge. The distal marginal ridge is prominent and extends from the middle third up to the incisal third.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge, but the depth of curvature is less than the mesial aspect.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.
3. **Distal surface of the crown:** The distal surface is smooth without any developmental depressions or grooves.
4. **Distal contact area:** The distal contact area is situated in the incisal third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex; it is wider labiolingually.
6. **Outlines of the root:** The labial and lingual outlines of the root taper evenly from the cervical line up to the apex. There is a slight labial inclination of as much as 10° in the apical third of the root.
7. **Distal surface of the root:** The distal surface is smoothly convex with a prominent developmental depression in the middle and cervical third of the root.

Incisal Aspect (Fig. 13.3f)

1. **Shape of the crown:** The crown in the incisal aspect is triangular, with the base formed by the labial outline, the apex formed by the cingulum/lingual surface and the other two sides formed by the mesial and distal surfaces. The mesiodistal width of the crown is the same as the labiolingual width. The incisal ridge appears nearly straight and is 1 mm thick labiolingually.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is flat and slightly convex mesiodistally.
   (b) *Lingual outline:* The lingual outline is narrower than the labial outline because of the tapering of the lingual surface towards the cingulum.
   (c) *Mesial and distal outlines:* The mesial and distal outlines of the crown are relatively broad to have a good contact area with the adjacent teeth.

Deciduous Mandibular Lateral Incisor

The mandibular central incisor is the second tooth to erupt in the oral cavity in the lifetime of a human being. These are two in number—right and left—and are situated distal to the mandibular central incisor with one tooth each in the right and left mandibular arches. The cervicoincisal length of the crown is more than the mesiodistal width of the crown.

The nomenclature, chronology and dimensions of deciduous mandibular lateral incisors are given in **Table 13.4(a–c)**.

Table 13.4a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	Q	N
Zsigmondy/ Palmer system	$\overline{\text{B}}\rfloor$	$\lfloor\overline{\text{B}}$
FDI system	82	72

Table 13.4b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
16 (14–17) weeks in utero	2½ months	13 (10–16) months	1½ years	8 years

Table 13.4c Dimensions (Fig. 13.4a)

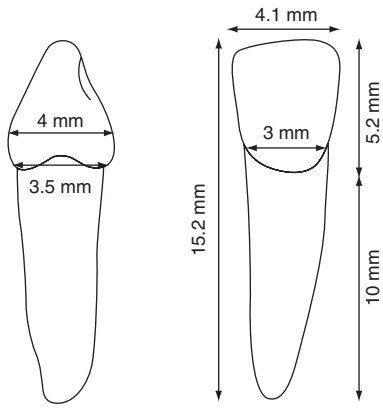
Total length	15.2 mm
Cervicoincisal length of crown	5.2 mm
Cervicoapical length of root	10.0 mm
Mesiodistal diameter of crown	4.1 mm
Mesiodistal diameter of crown at the cervix	3.0 mm
Labiopalatal diameter of crown	4.0 mm
Labiopalatal diameter of crown at cervix	3.5 mm

Labial Aspect (Fig. 13.4b)

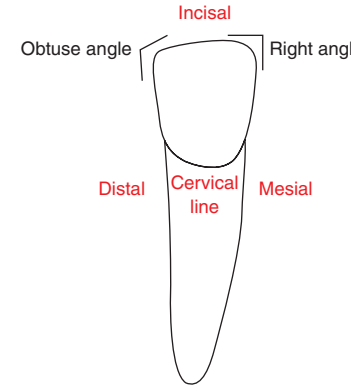
1. **Shape of the crown:** The crown is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. As a result of this divergence, the mesiodistal width of the crown at the incisal third is more than that of the cervical third. The mesiodistal width of the crown is larger than in the deciduous mandibular central incisor and is not bilaterally symmetrical.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown tapers evenly from the mesial contact area up to the narrow cervix. The mesioincisal angle is a right angle.
   (b) *Distal outline:* The distal outline of the crown is convex from the distal contact area up to the narrow cervix. The distoincisal angle is more rounded than in the mandibular central incisor.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge without any mamelons. The incisal ridge is not perpendicular to the long axis of the tooth, but it slopes towards the distal surface making the distoincisal angle more rounded.
3. **Labial surface of the crown:** The labial surface is smooth and convex without any developmental depressions or imbrication lines. The highest point of convexity is in the cervical third due to the prominent cervical ridge which is seen in a mesiodistal direction. This cervical ridge is called the *labial cingulum*.
4. **Shape of the root:** A single, cone-shaped root is present with a blunt apex. The length of the root is twice the length of the crown and is longer and narrower than in the deciduous mandibular central incisor.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex.
6. **Labial surface of the root:** The labial surface is flat and smooth without any developmental depressions or grooves.

Lingual Aspect (Fig. 13.4c)

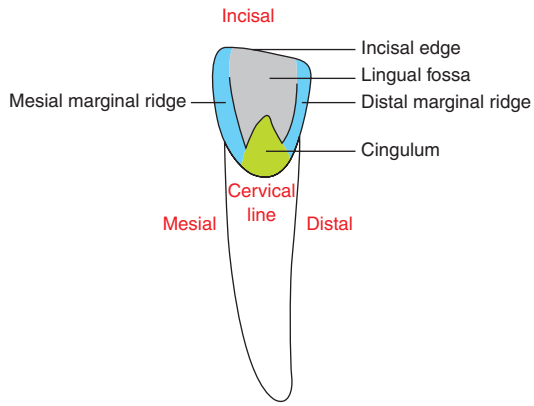
1. **Shape of the crown:** The crown in the lingual aspect is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect. The mesiodistal width of the crown in this aspect is comparatively less than in the labial aspect because of the lingual convergence or tapering of the mesial and distal sides of the crown.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown tapers evenly from the mesial contact area up to the cingulum. The mesioincisal angle is sharp.



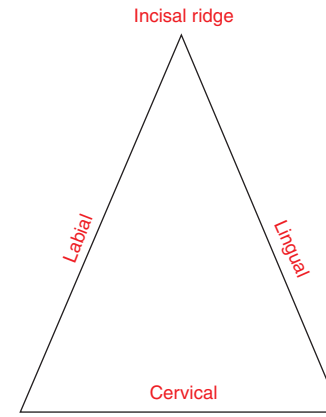
(a)



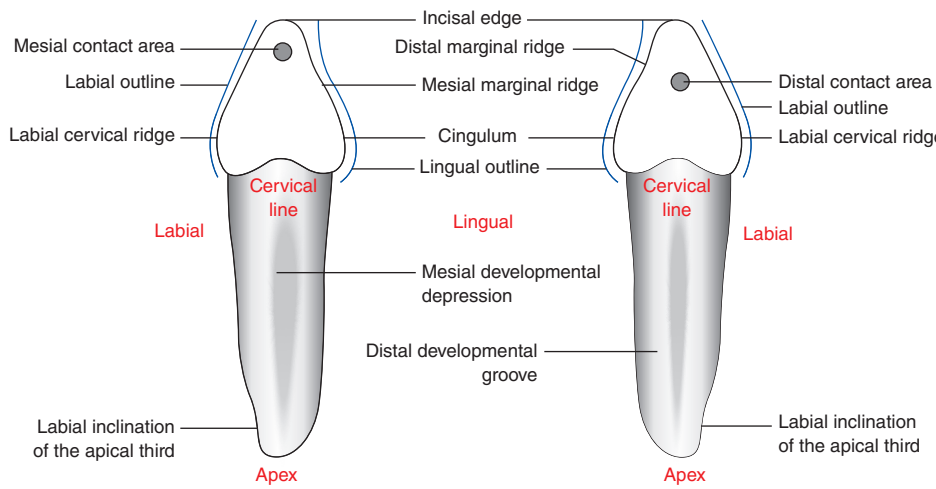
(b)



(c)



(d)



(e)

Figure 13.4 Deciduous mandibular right lateral incisor: (a) dimensions, (b) labial aspect, (c) lingual aspect, (d) proximal outline of the crown, (e) mesial and distal aspects. (*Continued*)

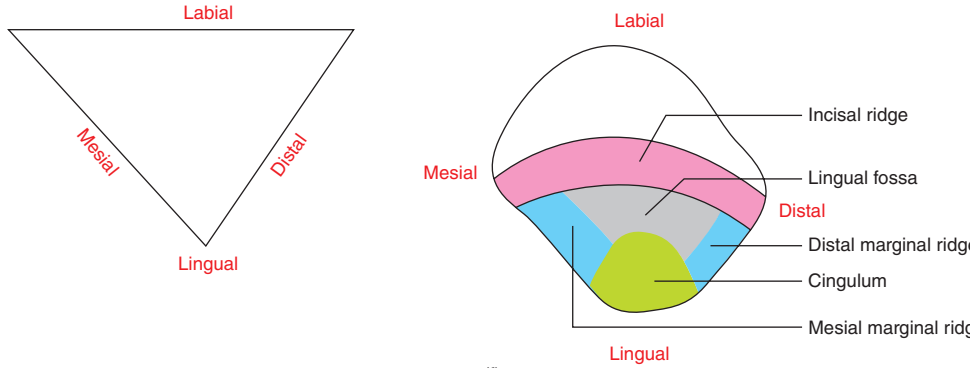


Figure 13.4 (*Continued*) (f) Incisal aspect.

(b) *Distal outline:* The distal outline of the crown also tapers evenly from the distal contact area up to the cingulum. The distoincisal angle is more rounded.

(c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.

(d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge without any mamelons. The incisal ridge is not perpendicular to the long axis of the tooth, but it slopes towards the distal surface making the distoincisal angle more rounded.

3. **Lingual surface of the crown:** The lingual surface is smooth with a slight concavity in the middle and incisal third called the *lingual fossa*. The lingual fossa is bordered mesially and distally by the mesial and distal marginal ridges and cervically by the cingulum. The cingulum is prominent and occupies the major part of the lingual surface and the marginal ridges are more prominent than the deciduous mandibular central incisor.
4. **Shape of the root:** A single, cone-shaped root is present with a blunt apex.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex. Similar to the crown, the root is narrow in the lingual aspect due to the lingual convergence of the mesial and distal surfaces of the root.
6. **Lingual surface of the root:** The lingual surface is smooth with a ridge extending from the cervical line up to the apex. This ridge is the result of the lingual tapering of the mesial and distal surfaces of the root. The cross-section of the root is triangular, with the base formed by the labial surface, the apex formed by the lingual surface and the other two sides of the triangle formed by the mesial and distal sides.

Mesial Aspect (Fig. 13.4e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and lingual surfaces (**Fig. 13.4d**). The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated on the root axis line.
2. **Outlines of the crown**

(a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is smoothly convex from the cervical line up to the incisal ridge.

(b) *Lingual outline:* The lingual outline is S shaped. It is convex at the cingulum and concave at the mesial marginal ridge/fossa and again convex at the incisal ridge. The mesial marginal ridge is prominent and extends from the middle third up to the incisal third.

(c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge.

(d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.

3. **Mesial surface of the crown:** The mesial surface is smooth without any developmental depressions or grooves.
4. **Mesial contact area:** The mesial contact area is situated in the incisal third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex; it is wider labiolingually.
6. **Outlines of the root:** The labial and lingual outlines of the root taper evenly from the cervical line up to the apex. There is a slight labial inclination of as much as 10° in the apical third of the root.
7. **Mesial surface of the root:** The mesial surface is smooth with mesial developmental depression in the middle and incisal third.

Distal Aspect (Fig. 13.4e)

1. **Shape of the crown:** The crown in the distal aspect is also wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal surface and the other two sides formed by the labial and lingual surfaces (**Fig. 13.4d**). The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third. The incisal ridge is situated on the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is smoothly convex from the cervical line up to the incisal ridge.
   (b) *Lingual outline:* The lingual outline is S shaped. It is convex at the cingulum and concave at the distal marginal ridge/fossa and again convex at the incisal ridge. The distal marginal ridge is prominent and extends from the middle third up to the incisal third.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the incisal ridge, but the depth of curvature is less than that in the mesial aspect.
   (d) *Incisal outline:* The incisal outline is straight with a prominent incisal ridge.
3. **Distal surface of the crown:** The distal surface is smooth without any developmental depressions or grooves.
4. **Distal contact area:** The distal contact area is situated in the middle third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex; it is wider labiolingually.
6. **Outlines of the root:** The labial and lingual outlines of the root taper evenly from the cervical line up to the apex. There is a slight labial inclination of as much as 10° in the apical third of the root.
7. **Distal surface of the root:** The distal surface is smoothly convex with a prominent developmental groove in the middle and cervical third of the root.

Incisal Aspect (Fig. 13.4f)

1. **Shape of the crown:** The crown in the incisal aspect is triangular, with the base formed by the labial outline, the apex formed by the cingulum/lingual surface and the other two sides formed by the mesial and distal surfaces. The incisal ridge is distally curved and is 1 mm thick labiolingually.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is flat and slightly convex mesiodistally.
   (b) *Lingual outline:* The lingual outline is narrower than the labial outline because of the tapering of the lingual surface towards the cingulum.
   (c) *Mesial and distal outlines:* The mesial and distal outlines of the crown are relatively broad to have a good contact area with the adjacent teeth.

DECIDUOUS CANINES

The deciduous canines are four in number with one tooth in each quadrant. The maxillary canine erupts first followed by the mandibular canine. The main function of deciduous canine is holding and tearing of food during the process of mastication

(chewing); it also contributes to facial appearance. The deciduous canines are larger than the deciduous incisors in all aspects. In the incisal aspect, instead of an incisal ridge, the deciduous canines have a well-developed cusp called the *canine cusp*. They are also called *cuspids* as only a single cusp is seen in the incisal aspect.

Deciduous Maxillary Canine

The maxillary canines are two in number: right and left. These are situated distal to the maxillary lateral incisors in the right and left quadrants of the maxillary arch. The mesiodistal width of the crown is equal to the cervicoincisal length of the crown and in the cervix, there is a marked cervical constriction present.

The nomenclature, chronology and dimensions of deciduous maxillary canines are given in **Table 13.5(a–c)**.

Table 13.5a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	C	H
Zsigmondy/ Palmer system	C|	|C
FDI system	53	63

Table 13.5b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
17 (15–18) weeks in utero	9 months	19 (16–22) months	3½ years	11 years

Table 13.5c Dimensions (Fig. 13.5a)

Total length	20.0 mm
Cervicoincisal length of crown	6.5 mm
Cervicoapical length of root	13.5 mm
Mesiodistal diameter of crown	7.0 mm
Mesiodistal diameter of crown at the cervix	5.1 mm
Labiopalatal diameter of crown	7.0 mm
Labiopalatal diameter of crown at cervix	5.5 mm

Labial Aspect (Fig. 13.5b)

1. **Shape of the crown:** The crown is roughly angular or diamond shaped, formed by the mesial outline, distal outline, mesial cusp ridge and distal cusp ridge.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is convex from the cervical line up to the mesial contact area and it is shorter than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is also convex but more rounded and longer than the mesial aspect and it extends from the cervical line up to the distal contact area.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* In the incisal aspect, a long, well-developed, sharp cusp is seen. It is formed by two cusp ridges—mesial cusp ridge and distal cusp ridge—which meet at an acute angle. The distal cusp ridge is short and convex, with a steep inclination from the cusp tip. The mesial cusp ridge is longer than the distal cusp ridge and is either flat or concave and not as steep as the distal cusp ridge. As a result of this variation in the length of the cusp ridges, the canine cusp is distally placed to the long axis of the tooth.
3. **Labial surface of the crown:** The labial surface exhibits a distinct labial ridge called the *canine ridge,* which extends from the cervical line up to the cusp tip and is distally placed. On either side of the canine ridge, developmental depressions are seen demarcating the facial developmental lobes. In the cervical third of the labial surface, a prominent cervical ridge is present running in a mesiodistal direction.
4. **Shape of the root:** A single, long and slender root is present with a blunt apex. The root length is twice the length of the crown. There is a slight distal inclination of the root at the apical third.

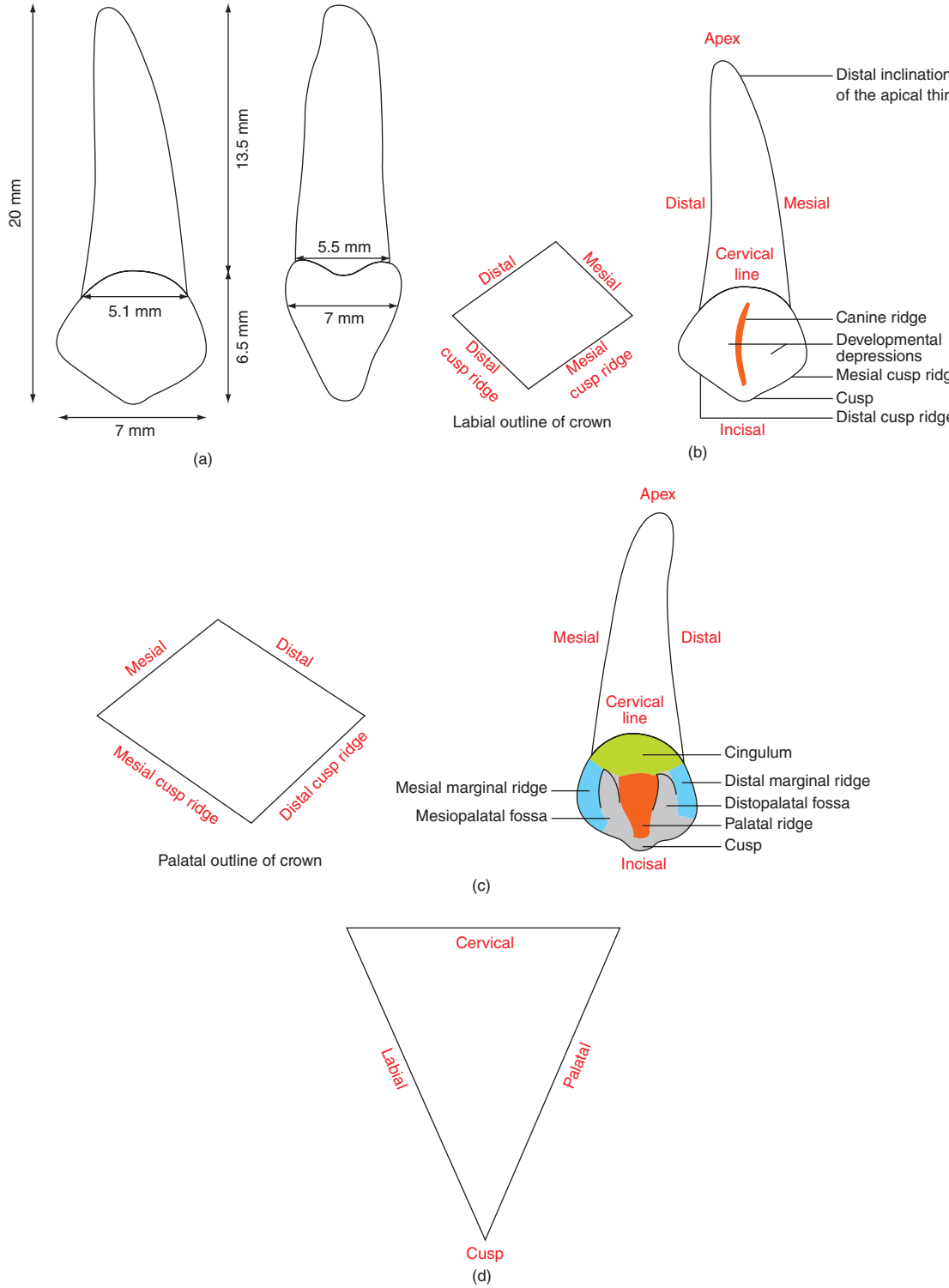
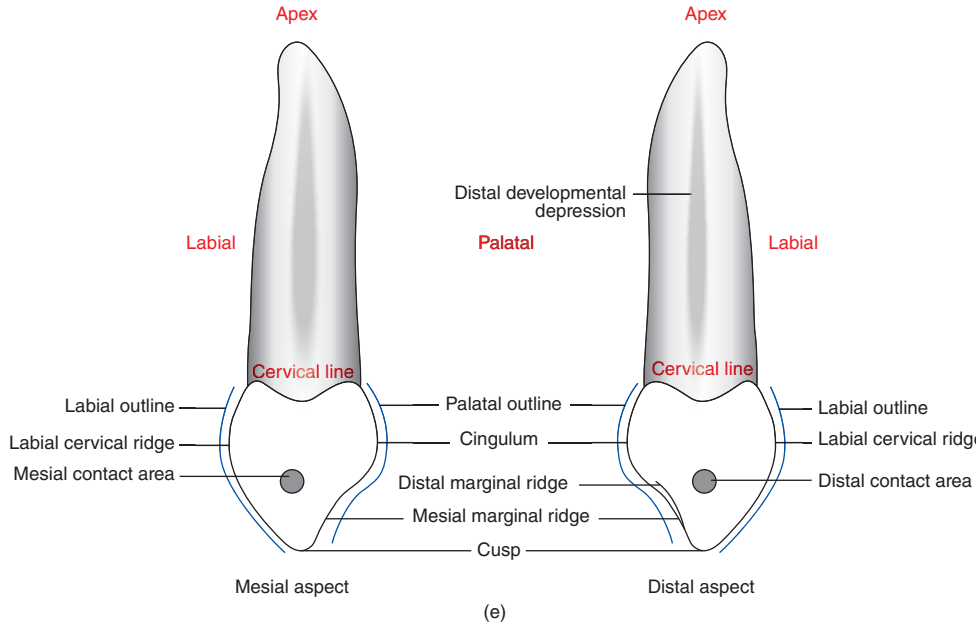


Figure 13.5 Deciduous maxillary right canine: (a) dimensions, (b) labial aspect, (c) palatal aspect, (d) proximal outline of the crown. (*Continued*)



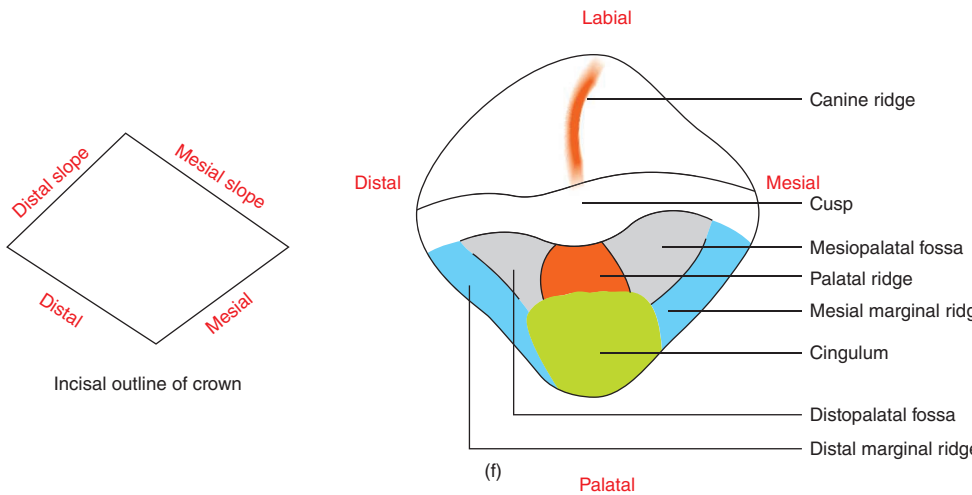


Figure 13.5 (*Continued*) (e) Mesial and distal aspects and (f) incisal aspect.

5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex.
6. **Labial surface of the root:** The labial surface is flat and smooth without any developmental depressions or grooves.

Palatal Aspect (Fig. 13.5c)

1. **Shape of the crown:** The crown in the palatal aspect is roughly angular or diamond shaped, formed by the mesial outline, distal outline, mesial cusp ridge and distal cusp

ridge. The mesiodistal width of the crown in this aspect is comparatively less than that of the labial aspect because of the palatal convergence of the mesial and distal sides of the crown.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is convex from the cervical line up to the mesial contact area and is shorter than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is also convex but more rounded and longer than the mesial aspect and it extends from the cervical line up to the distal contact area.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* In the incisal aspect, a long, well-developed, sharp cusp is seen. It is formed by the mesial cusp ridge and distal cusp ridge which meet at an acute angle.

   The distal cusp ridge is short and convex, with a steep inclination from the cusp tip. The mesial cusp ridge is longer than the distal cusp ridge and is either flat or concave and not as steep as the distal cusp ridge. As a result of this variation in the length of the cusp ridges, the canine cusp is distally placed to the long axis of the tooth.
3. **Palatal surface of the crown:** The palatal surface is irregular with palatal fossa and prominent enamel ridges—mesial marginal ridge, distal marginal ridge, cingulum, canine cusp ridge and palatal ridge. The cingulum is well developed and occupies the cervical third of the crown. The marginal ridges are well developed and the distal marginal ridge is longer than the mesial marginal ridge. The palatal ridge is distally placed and extends from the cusp tip to the cingulum and divides the palatal fossa into a mesial palatal fossa and distal palatal fossa. The mesial palatal fossa is broad and shallow and the distal palatal fossa is small and deep.
4. **Shape of the root:** A single, long and slender root is present with a blunt apex. The root length is twice the length of the crown. There is a slight distal inclination of the root at the apical third.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex. Similar to the crown, the root also tapers towards the palatal surface making it narrow mesiodistally.
6. **Palatal surface of the root:** The palatal surface is smooth with a ridge extending from the cervical line up to the apex. The palatal tapering of the mesial and distal surfaces of the root results in this ridge. The cross-section of the root is triangular, with the base formed by the labial surface and the apex formed by the palatal surface and the other two sides of the triangle formed by the mesial and distal sides.

Mesial Aspect (Fig. 13.5e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the cusp and the other two sides formed by the labial and palatal surfaces (**Fig. 13.5d**). The labiopalatal width of the crown at the cervical third is comparatively more than that of the deciduous incisors. The cusp tip is situated labial to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the cusp tip.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the mesial marginal ridge/fossa and again convex at the cusp region.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the cusp.
   (d) *Incisal outline:* A sharp cusp is seen in the incisal aspect.
3. **Mesial surface of the crown:** The mesial surface is smooth without any developmental depressions or grooves.

4. **Mesial contact area:** The mesial contact area is situated in the middle of the middle third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex.
6. **Outlines of the root:** The root is wider labiopalatally in the cervical and middle third and tapers in the incisal third ending in a blunt apex. There is a slight labial inclination of as much as 10° in the apical third of the root.
7. **Mesial surface of the root:** The mesial surface is smooth without any developmental depressions or grooves.

Distal Aspect (Fig. 13.5e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the cusp and the other two sides formed by the labial and palatal surfaces (**Fig. 13.5d**). The labiopalatal width of the crown at the cervical third is comparatively more than that of the deciduous incisors. The cusp tip is situated labial to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the cusp tip.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the distal marginal ridge/fossa and again convex at the cusp region.
   (c) *Cervical outline:* The cervical outline is semicircular in shape with the convexity facing towards the incisal ridge, but the depth of curvature is less than in the mesial aspect.
   (d) *Incisal outline:* A sharp cusp is seen in the incisal aspect.
3. **Distal surface of the crown:** The distal surface is smooth without any developmental depressions or grooves.
4. **Distal contact area:** The distal contact area is situated in the middle of the middle third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex.
6. **Outlines of the root:** The root is wider labiopalatally in the cervical and middle third and tapers in the incisal third ending in a blunt apex. There is a slight labial inclination, as much as 10°, in the apical third of the root.
7. **Distal surface of the root:** The distal surface is smoothly convex with a prominent developmental depression in the middle and cervical third of the root.

Incisal Aspect (Fig. 13.5f)

1. **Shape of the crown:** The crown in the incisal aspect is diamond shaped. The mesiodistal width of the crown is comparatively more than the labiopalatal width. The labiopalatal width of the mesial half of the crown is more than that of the distal half. The tip of the canine cusp is placed distal to the long axis of the tooth.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is broad and smoothly convex mesiodistally and shows a prominent canine ridge in the centre of the labial surface.
   (b) *Palatal outline:* The palatal outline is narrower than the labial outline because of the tapering of the palatal surface towards the cingulum. The cingulum is prominent and extends mesiodistally.
   (c) *Mesial and distal outlines:* The mesial and distal outlines of the crown are relatively broad to have a good contact area with the adjacent teeth.

Deciduous Mandibular Canine

The mandibular canines are two in number—right and left—and are situated distal to the mandibular lateral incisors in the right and left quadrants of the mandibular arch. In the mandibular canines, the cervicoincisal length of the crown is more than the mesiodistal width of the crown. There is a marked cervical constriction in the cervix of the tooth.

The nomenclature, chronology and dimensions of deciduous mandibular canines are given in **Table 13.6(a–c)**.

Table 13.6a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	R	M
Zsigmondy/ Palmer system	$\overline{C}\vert$	$\vert\overline{C}$
FDI system	83	73

Table 13.6b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
17 (16–18) weeks in utero	9 months	20 (17–23) months	3¼ years	9 years

Table 13.6c Dimensions (Fig. 13.6a)

Total length	17.5 mm
Cervicoincisal length of crown	6.0 mm
Cervicoapical length of root	11.5 mm
Mesiodistal diameter of crown	5.0 mm
Mesiodistal diameter of crown at the cervix	3.7 mm
Labiopalatal diameter of crown	4.8 mm
Labiopalatal diameter of crown at cervix	4.0 mm

Labial Aspect (Fig. 13.6b)

1. **Shape of the crown:** The crown is roughly angular or diamond shaped, formed by the mesial outline, distal outline, mesial cusp ridge and distal cusp ridge.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is convex from the cervical line up to the mesial contact area and it is longer than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is also convex but less rounded and shorter than the mesial aspect and it extends from the cervical line up to the distal contact area.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* There is a long, well-developed, sharp, pointed cusp in the incisal aspect. It forms the mesial cusp ridge and distal cusp ridge which meet at an acute angle. The mesial cusp ridge is shorter than the distal cusp ridge and is convex, with a steep inclination from the cusp tip. The distal cusp ridge is long and is either flat or concave and not as steep as the mesial cusp ridge. As a result of this variation in the length of the cusp ridges, the canine cusp is mesially placed to the long axis of the tooth.
3. **Labial surface of the crown:** The labial surface exhibits an indistinct labial ridge called the *canine ridge,* which extends from the cervical line up to the cusp tip and is mesially placed. On either side of the canine ridge, developmental depressions are seen demarcating the facial developmental lobes. In the cervical third of the labial surface, the labial cervical ridge is seen but it is not that prominent.
4. **Shape of the root:** A single, long and slender root is present with a pointed apex. The root length is twice the length of the crown. There is a slight distal inclination of the root at the apical third.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex.
6. **Labial surface of the root:** The labial surface is flat and smooth without any developmental depressions or grooves.

Lingual Aspect (Fig. 13.6c)

1. **Shape of the crown:** The crown in the lingual aspect is roughly angular or diamond shaped, formed by the mesial outline, distal outline, mesial cusp ridge and distal cusp ridge. The mesiodistal width of the crown in this aspect is comparatively less than that of the labial aspect because of the lingual convergence of the mesial and distal sides of the crown.

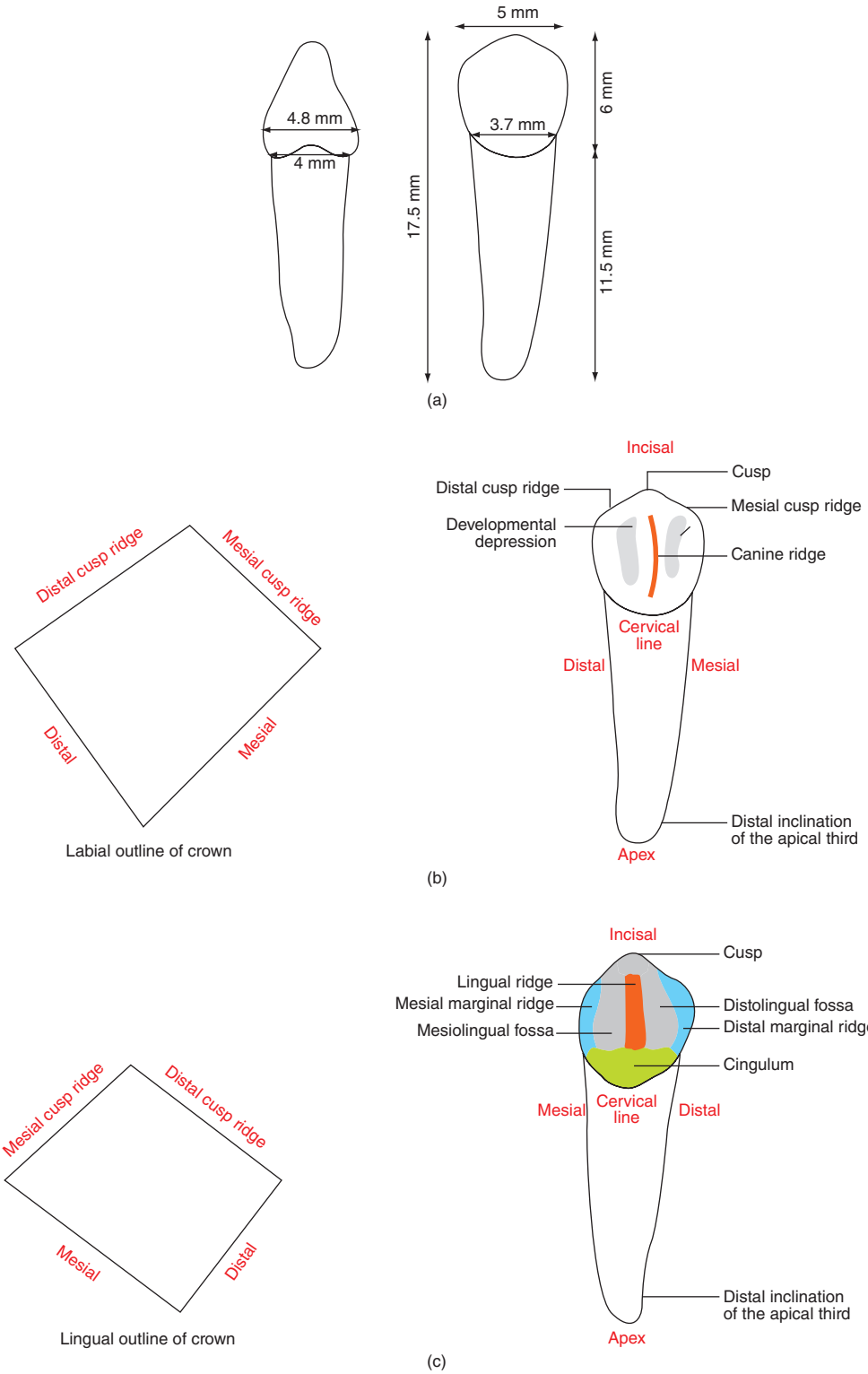
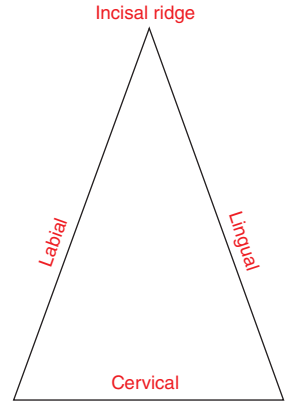
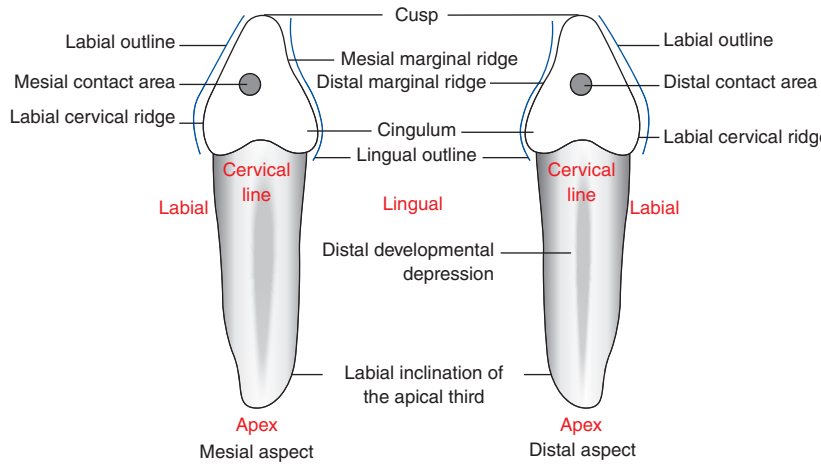


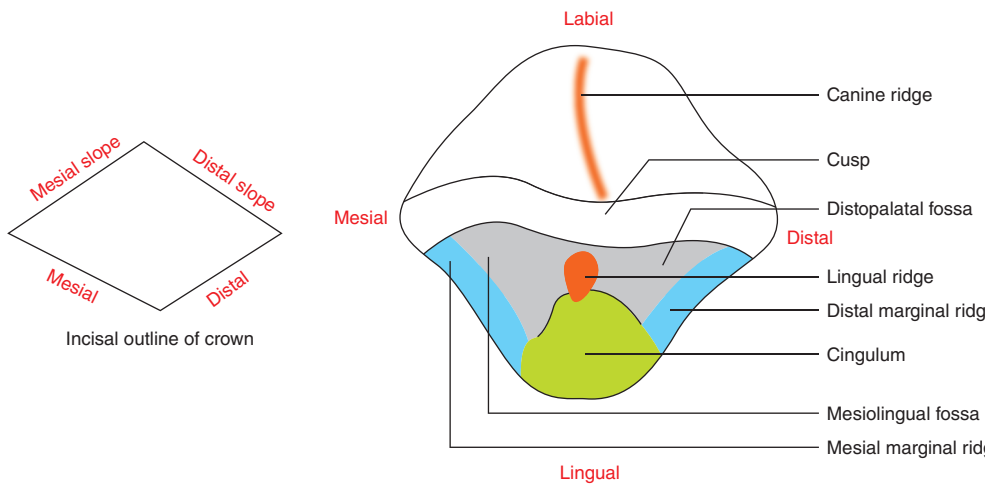
Figure 13.6 Deciduous mandibular right canine: (a) dimensions, (b) labial aspect, (c) lingual aspect. (*Continued*)



(d)



(e)



(f)

Figure 13.6 (*Continued*) (d) Proximal outline of the crown, (e) mesial and distal aspects and (f) incisal aspect.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is convex from the cervical line up to the mesial contact area and is longer than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is also convex but more rounded and shorter than the mesial aspect and extends from the cervical line up to the distal contact area.
   (c) *Cervical outline:* The curvature of the cervical outline is semicircular, with the convexity facing towards the root apex.
   (d) *Incisal outline:* A long, well-developed, sharp, pointed cusp is seen in the incisal aspect. It is formed by the mesial cusp ridge and the distal cusp ridge, which meet at an acute angle. The mesial cusp ridge is shorter than the distal cusp ridge and is convex with a steep inclination from the cusp tip. The distal cusp ridge is long and is either flat or concave and not as steep as the mesial cusp ridge. As a result of the variation in the length of the cusp ridges, the canine cusp is mesially placed to the long axis of the tooth.
3. **Lingual surface of the crown:** The lingual surface is irregular and indistinct. The cingulum is not that well developed as the maxillary canine and it occupies the cervical third of the crown. The marginal ridges are also not well developed and the distal marginal ridge is shorter than the mesial marginal ridge. The indistinct lingual ridge is mesially placed and extends from the cusp tip to the cingulum and divides the lingual fossa into shallow mesial and distal lingual fossae.
4. **Shape of the root:** A single, long and slender root is present with a blunt apex. The root length is twice the length of the crown. There is a slight distal inclination of the root at the apical third.
5. **Outlines of the root:** The mesial and distal outlines of the root taper evenly from the cervical line up to the apex. Similar to the crown, the root also tapers towards the palatal surface making it narrow mesiodistally.
6. **Lingual surface of the root:** The lingual surface is smooth with a ridge extending from the cervical line up to the apex. The lingual tapering of the mesial and distal surface of the root results in this ridge. The cross-section of the root is triangular, with the base formed by the labial surface, the apex formed by the lingual surface and the other two sides of the triangle formed by the mesial and distal sides.

Mesial Aspect (Fig. 13.6e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the incisal ridge and the other two sides formed by the labial and lingual surfaces (**Fig. 13.6d**). The labiolingual width of the crown at the cervical third is comparatively less than that of the deciduous maxillary canine. The cusp tip is situated lingual to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the cusp tip.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the mesial marginal ridge/fossa and again convex at the cusp region.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the cusp.
   (d) *Incisal outline:* A sharp pointed cusp is seen in the incisal aspect.
3. **Mesial surface of the crown:** The mesial surface is smooth without any developmental depressions or grooves.
4. **Mesial contact area:** The mesial contact area is situated in the middle of the middle third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex.
6. **Outlines of the root:** The root is wider labiolingually in the cervical and middle third and tapers in the incisal third, ending in a blunt apex. There is a slight lingual inclination of as much as 10° in the apical third of the root.

7. **Mesial surface of the root:** The mesial surface is smooth without any developmental depressions or grooves.

Distal Aspect (Fig. 13.6e)

1. **Shape of the crown:** The crown in the mesial aspect is wedge shaped or triangular, with the base formed by the cervical line, the apex formed by the cusp and the other two sides formed by the labial and lingual surfaces (**Fig. 13.6d**). The labiolingual width of the crown at the cervical third is comparatively less than that of the deciduous maxillary canine. The cusp tip is situated lingual to the root axis line.
2. **Outlines of the crown**
   (a) *Labial outline:* From the cementoenamel junction or the cervix, the labial outline is convex in the cervical third and flat in the middle and incisal third up to the cusp tip.
   (b) *Palatal outline:* The palatal outline is S shaped. It is convex at the cingulum and concave at the distal marginal ridge/fossa and again convex at the cusp region.
   (c) *Cervical outline:* The cervical outline is semicircular, with the convexity facing towards the cusp, but the depth of curvature is less than in the mesial aspect.
   (d) *Incisal outline:* A sharp, pointed cusp is seen in the incisal aspect.
3. **Distal surface of the crown:** The distal surface is smooth without any developmental depressions or grooves.
4. **Distal contact area:** The distal contact area is situated in the middle of the middle third of the crown.
5. **Shape of the root:** A single, cone-shaped root is present with a blunt apex.
6. **Outlines of the root:** The root is wider labiolingually in the cervical and middle third and tapers in the incisal third ending in a blunt apex. There is a slight lingual inclination of as much as 10° in the apical third of the root.
7. **Distal surface of the root:** The distal surface is smoothly convex with a prominent developmental depression in the middle and cervical third of the root.

Incisal Aspect (Fig. 13.6f)

1. **Shape of the crown:** The crown in the incisal aspect is diamond shaped. The mesiodistal width of the crown is comparatively more than the labiolingual width. The labiolingual width of the mesial half of the crown is more than that of the distal half. The tip of the canine cusp is placed mesially to the long axis of the tooth.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is broad and smoothly convex mesiodistally and shows an indistinct canine ridge in the centre of the labial surface.
   (b) *Lingual outline:* The lingual outline is narrower than the labial outline because of the tapering of the lingual surface towards the cingulum. The cingulum is prominent and it extends mesiodistally.
   (c) *Mesial and distal outlines:* The mesial and distal outlines of the crown are relatively broad to have a good contact area with the adjacent teeth.

DECIDUOUS MAXILLARY MOLARS

The deciduous maxillary molars constitute the posterior teeth in the maxillary arch. They are four in number with two teeth each—first molar and second molar—in the right and left maxillary quadrants. The maxillary first molar is the fourth tooth to erupt in the maxillary arch followed by the maxillary second molar. The main function of deciduous maxillary molars is to aid the process of mastication (chewing); it also contributes to facial appearance. The deciduous maxillary molars are larger than the deciduous maxillary incisors and canines in all aspects. The buccopalatal width of the crown is relatively broad and the buccal cervical ridge is very prominent in these teeth. There is a marked cervical constriction seen in the cervix of the tooth. The deciduous maxillary molars have three roots: mesiobuccal, distobuccal and palatal. The level of furcation of the roots is near the cervix in deciduous maxillary molars, and the roots are thin and flare beyond the mesiodistal and buccopalatal outlines of the crown to allow room/space for development of the permanent maxillary premolar crown.

Deciduous Maxillary First Molar

The deciduous maxillary first molar is situated distal to the maxillary canine in both the right and the left quadrants of the maxillary arch. It resembles an intermediate between the permanent maxillary premolar and molar. It is smaller than the deciduous maxillary second molar in all aspects. It has three roots: mesiobuccal, distobuccal and palatal. Two occlusal patterns are seen in this tooth: four-cusp type and three-cusp type.

The nomenclature, chronology and dimensions of deciduous maxillary first molars are given in **Table 13.7(a–c)**.

Table 13.7a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	B	I
Zsigmondy/ Palmer system	D|	|D
FDI system	54	64

Table 13.7b Chronology

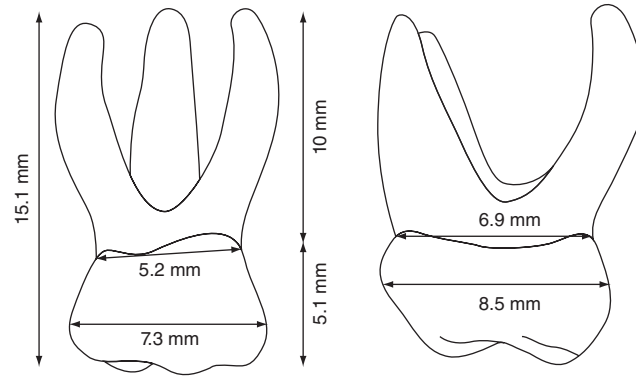
First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
15 (14–17) weeks in utero	6 months	16 (13–19) months	2½ years	10 years

Table 13.7c Dimensions (Fig. 13.7a)

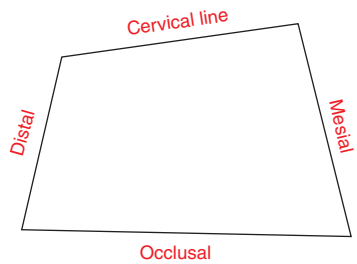
Total length	15.1 mm
Cervicoincisal length of crown	5.0 mm
Cervicoapical length of root	10.0 mm
Mesiodistal diameter of crown	7.3 mm
Mesiodistal diameter of crown at the cervix	5.2 mm
Labiopalatal diameter of crown	8.5 mm
Labiopalatal diameter of crown at cervix	6.9 mm

Buccal Aspect (Fig. 13.7b)

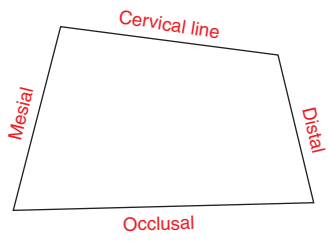
1. **Shape of the crown:** The crown is roughly trapezoidal in shape, formed by the mesial outline, distal outline, occlusal outline and cervical outline. The mesiodistal width of the crown is more than the cervico-occlusal width. The mesiodistal width is more in the level of contact areas and becomes narrower in the cervix of the tooth by about 2 mm, making the crown appear constricted at the cervix. The cervico-occlusal width in the mesial half of the crown is longer than in the distal half. The height of contour is present in the cervical third of the crown occupied by the buccal cervical ridge.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line up to the mesial contact area and is longer than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is convex from the cervical line up to the distal contact area and is shorter than the mesial outline.
   (c) *Cervical outline:* The curvature of the cervical outline is irregular with the convexity facing towards the root apex. The depth of curvature of the cervical line is less than in the anterior teeth.
   (d) *Occlusal outline:* The occlusal outline is not regular but appears scalloped, and two cusps are seen—large mesiobuccal cusp and indistinct distobuccal cusp—separated by a buccal developmental groove.
3. **Buccal surface of the crown:** The buccal surface of the crown is smooth, with a prominent cervical ridge in the cervical third which runs in a mesiodistal direction and extends to half of the mesial surface of the crown. This well-developed cervical ridge is called the *buccal cingulum*. Mesiobuccal cusp and distobuccal cusp are seen in this aspect. The mesiobuccal cusp is larger than the distobuccal cusp and the two cusps are separated by a poorly developed buccal developmental groove which extends up to the occlusal third of the crown and is slightly



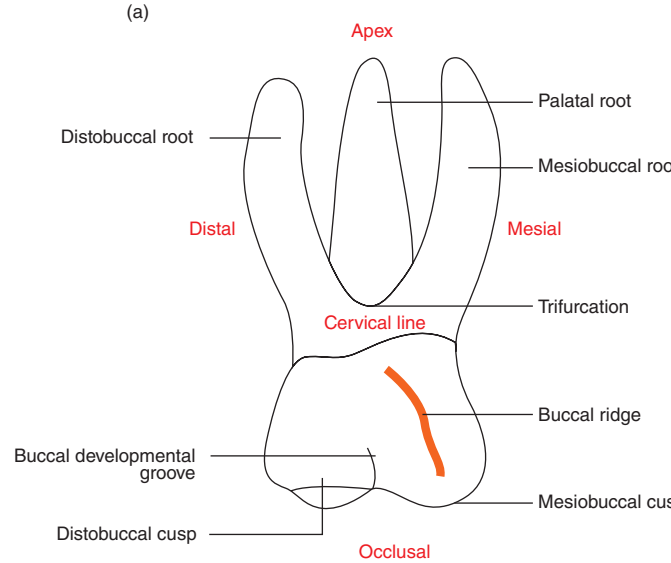
(a)



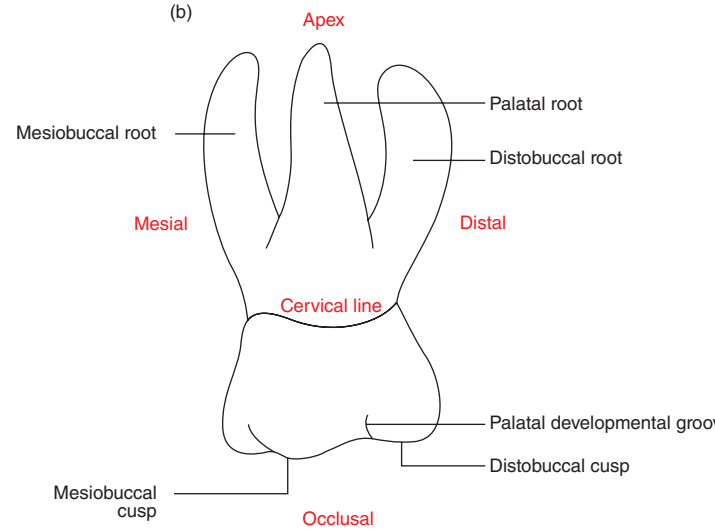
Buccal outline of crown



Palatal outline of crown



(b)



(c)

Figure 13.7 Deciduous maxillary right first molar: (a) dimensions, (b) buccal aspect, (c) palatal aspect. (*Continued*)

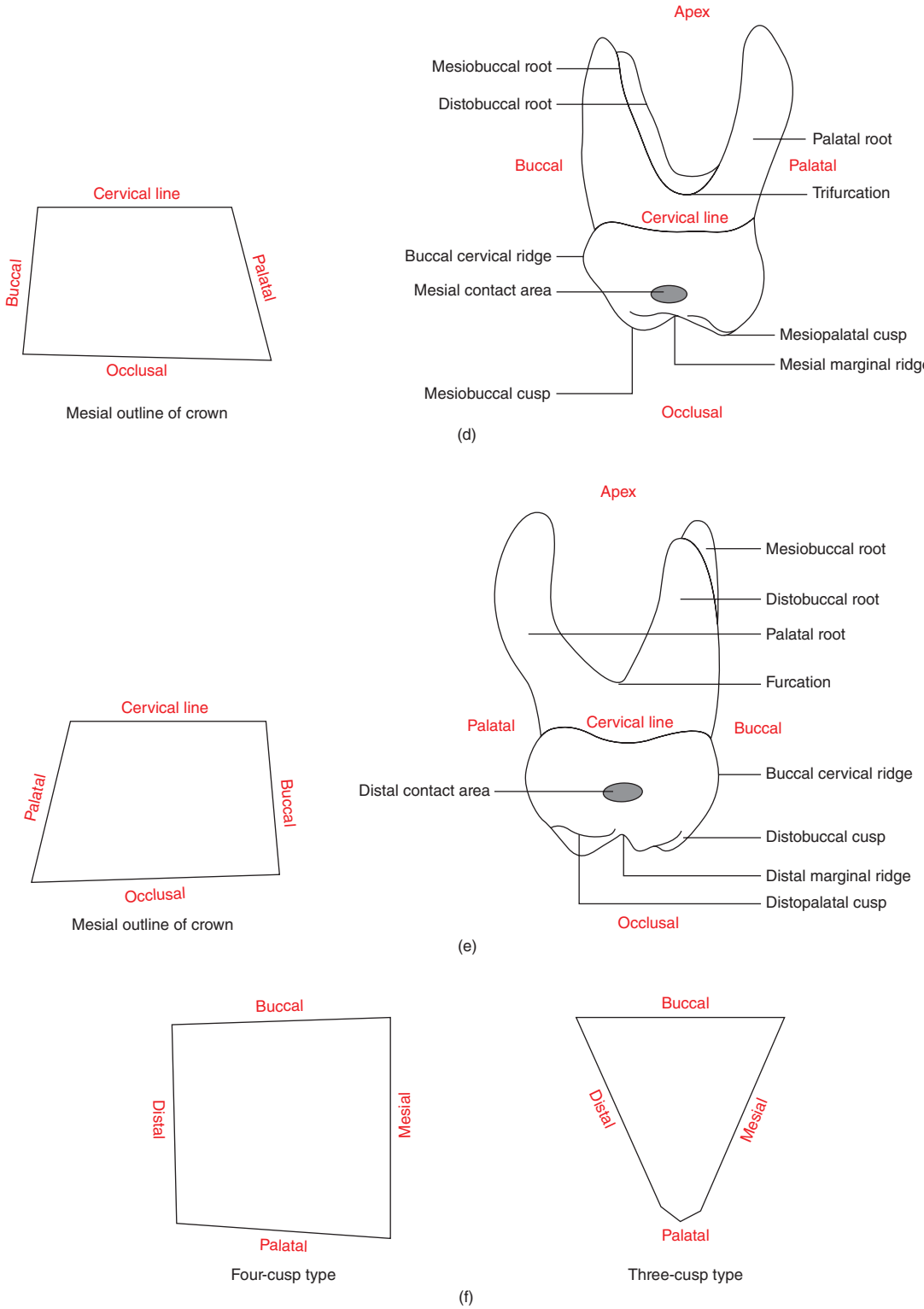
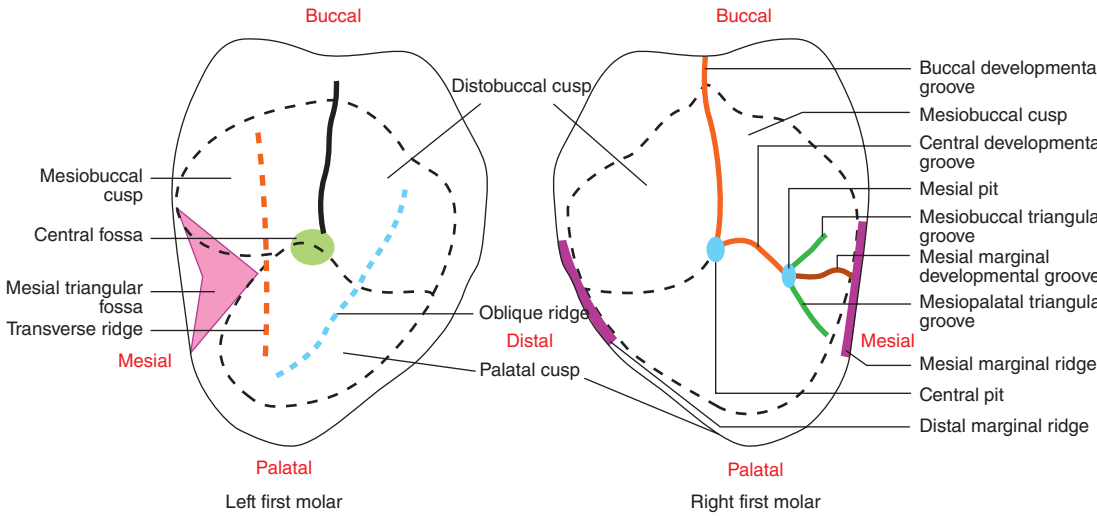


Figure 13.7 (*Continued*) (d) Mesial aspect, (e) distal aspect and (f) occlusal outline. (*Continued*)



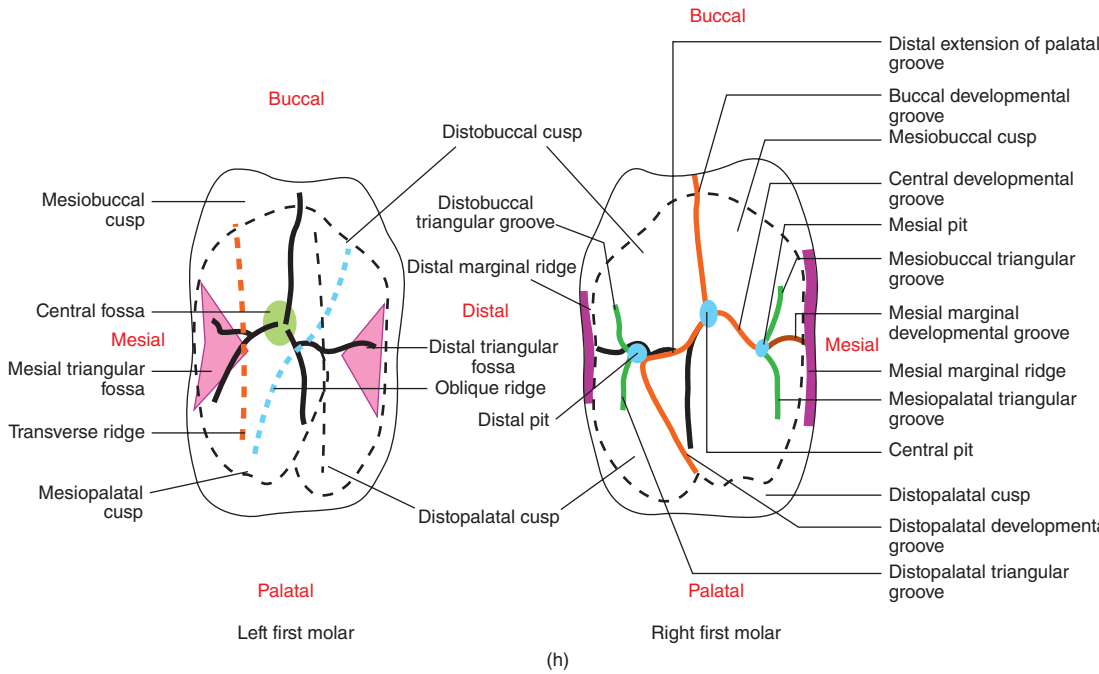


Figure 13.7 (*Continued*) Deciduous maxillary left and right first molars: (g) occlusal aspect—three-cusp type and (h) occlusal aspect—four-cusp type.

distally placed to the centre of the crown mesiodistally. An indistinct buccal ridge is seen extending from the centre of the cervical line up to the mesiobuccal cusp tip and this is mesially placed to the centre of the crown mesiodistally.

4. **Shape of the roots:** All the three roots, mesiobuccal, distobuccal and palatal, are seen in the buccal aspect. They are long and slender with a blunt apex. The mesiobuccal root is longer than the distobuccal root, but the palatal root is longer than the other two roots. The level

of trifurcation of the three roots is near the cervix and the root trunk is either small or indistinct.

5. **Outlines of the roots:** The mesial outline of the mesiobuccal root and the distal outline of the distobuccal root are convex from the cervical line up to the middle third and then taper evenly up to the apex. The distal outline of the mesiobuccal root and the mesial outline of the distobuccal root are concave from the point of furcation up to the apex. The mesial and distal outlines of the palatal root taper evenly from the point of furcation up to the apex. The thin roots are widely placed and flare beyond the mesiodistal outline of the crown to provide space for the development of the permanent maxillary first premolar.
6. **Buccal surface of the roots:** The buccal surface is flat and smooth without any developmental depressions or grooves in all the three roots.

Palatal Aspect (Fig. 13.7c)

1. **Shape of the crown:** The shape of the crown is similar to that in the buccal aspect. The mesiodistal width of the crown in this aspect is comparatively less than that of the buccal aspect because of the palatal convergence of the mesial and distal sides of the crown.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is similar to that of buccal aspect.
   (b) *Distal outline:* The distal outline is similar to that of the buccal aspect.
   (c) *Cervical outline:* The curvature of the cervical outline is irregular with the convexity facing towards the occlusal aspect.
   (d) *Occlusal outline:* The occlusal outline is not regular but appears scalloped, and two cusps are seen—large mesiopalatal cusp and indistinct distopalatal cusp—separated by a palatal developmental groove.
3. **Palatal surface of the crown:** The palatal surface of the crown is smoothly convex mesiodistally and cervico-occlusally. The cervical ridge is not as prominent as the buccal surface. Two palatal cusps are seen: mesiopalatal cusp and distopalatal cusp. The mesiopalatal cusp is longer and sharper than the distopalatal cusp and is the most prominent cusp of the deciduous maxillary first molar. The distopalatal cusp is small and rounded and may or may not be present. The mesiopalatal cusp and the distopalatal cusp are separated by the distopalatal developmental groove, which extends up to the occlusal third of the crown. If the distopalatal cusp is absent, then the entire occlusal part is occupied by a palatal cusp.
4. **Shape of the roots:** Three roots are present: mesiobuccal, distobuccal and palatal. All the three roots are seen in the palatal aspect, and they are long and slender with a blunt apex. The mesiobuccal root is longer than the distobuccal root, but the palatal root is longer than the other two roots.
5. **Outlines of the roots:** The mesial and distal outlines of the three roots are similar to those of the buccal aspect.
6. **Palatal surface of the roots:** The palatal surface is flat and smooth without any developmental depressions or grooves in all the three roots.

Mesial Aspect (Fig. 13.7d)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal formed by the buccal, palatal, occlusal and cervical outlines. The buccopalatal width of the crown is more than the cervico-occlusal width. The buccopalatal width of the crown at the cervical third is more than that at the occlusal third. The greater buccopalatal width at the cervical third is due to the prominent buccal cervical ridge which makes the crown appear bulbous.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is flat up to the mesiobuccal cusp tip. The height of contour is at the cervical third of the crown.
   (b) *Palatal outline:* From the cervix, the palatal outline is convex in the cervical and the middle third and then becomes flat up to the mesiopalatal cusp tip. The

height of contour is at the middle third of the crown.

(c) *Cervical outline:* The curvature of the cervical outline is irregular with the convexity facing towards the occlusal aspect.

(d) *Occlusal outline:* The occlusal outline is not regular and two cusps are seen—mesiobuccal and mesiopalatal cusps—with a prominent mesial marginal ridge. The mesiopalatal cusp is longer and sharper than the mesiobuccal cusp. The occlusal area is narrow buccopalatally because of the marked convergence of the buccal and palatal surfaces of the crown. The mesial marginal ridge is wide buccopalatally and sometimes may be crossed by a mesial marginal developmental groove.

3. **Mesial surface of the crown:** The mesial surface is flat except in the mesial contact area, where it is slightly convex.
4. **Mesial contact area:** The mesial contact area is situated in the occlusal one-third of the crown.
5. **Shape of the root:** Two roots are seen in this aspect: palatal and mesiobuccal roots. The palatal root is longer, thinner, more slender and more divergent than the mesiobuccal root. The mesiobuccal root is broad in the buccopalatal direction and hides the distobuccal root. The level of furcation of the roots is near the cervix and the root trunk is either small or indistinct.
6. **Outlines of the roots:** For the mesiobuccal root, the buccal outline is convex from the cervical line up to the blunt apex and the palatal outline is concave from the point of furcation up to the apex. For the palatal root, the palatal outline is concave from the cervical line up to the middle third and from there it is convex up to the blunt apex, and the buccal outline is concave from the point of furcation up to the apex. There is a sharp buccal inclination of the palatal root at the middle third.
7. **Mesial surface of the root:** The mesial surface is smooth without any developmental depressions or grooves in both the roots.

Distal Aspect (Fig. 13.7e)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal formed by the buccal, palatal, occlusal and cervical outlines. The buccopalatal width of the crown is more than the cervico-occlusal width. In this aspect, the crown is narrower buccopalatally than the mesial aspect due to the distal convergence of the buccal and palatal surfaces of the crown. The cervico-occlusal width is less than in the mesial aspect.
2. **Outlines of the crown**

(a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third and then becomes flat up to the distobuccal cusp tip. The height of contour is at the cervical third of the crown.

(b) *Palatal outline:* From the cervix, the palatal outline is convex in the cervical and the middle third and then becomes flat up to the distopalatal cusp tip. The height of contour is at the middle third of the crown.

(c) *Cervical outline:* The curvature of the cervical outline is either convex towards the occlusal aspect or it is nearly straight.

(d) *Occlusal outline:* The occlusal outline is not regular and two cusps—distobuccal cusp and distopalatal cusp—are seen with a prominent distal marginal ridge. The distobuccal cusp is longer than the distopalatal cusp. The distal marginal ridge is curved cervically. The occlusal area is also narrow buccolingually as seen in the distal aspect.

3. **Distal surface of the crown:** The distal surface is flat except in the distal contact area where it is slightly convex.
4. **Distal contact area:** The distal contact area is situated in the middle one-third of the crown.
5. **Shape of the roots:** Three roots are seen in this aspect: distobuccal root, palatal root, and part of the buccal aspect and apex of the mesiobuccal root. The palatal root is longer, thinner, more slender and more divergent than the distobuccal root. The distobuccal root is shorter, more slender and narrower than the

mesiobuccal root. The level of furcation of the roots is near the cervix and the root trunk is either small or indistinct.

6. **Outlines of the roots:** For the distobuccal root, the buccal outline is convex from the cervical line up to the blunt apex and the palatal outline is concave from the point of furcation up to the apex. For the palatal root, the palatal outline is concave from the cervical line up to the middle third, and from there it is convex up to the blunt apex and the buccal outline is concave from the point of furcation up to the apex. There is a sharp buccal inclination of the palatal root at the middle third.
7. **Distal surface of the roots:** The distal surface is smooth without any developmental depressions or grooves in the distobuccal and palatal roots.

Occlusal Aspect

1. **Shape of the crown:** The occlusal outline in the four-cusp type is roughly rectangular. In the three-cusp type, the occlusal outline is triangular (**Fig. 13.7f**). The buccopalatal width is more than the mesiodistal width. The mesiodistal width is more in the buccal aspect than in the palatal aspect because of the palatal convergence of the crown.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is broader than the palatal outline and is irregular.
   (b) *Palatal outline:* The palatal outline is narrower than the buccal outline because of the palatal tapering of the crown.
   (c) *Mesial and distal outlines:* The mesial outline is broader than the distal one because of the distal convergence of the crown. The mesial outline is formed by the mesial marginal ridge, whereas the distal outline is formed by the distal marginal ridge.
3. **Occlusal surface of the crown:** The occlusal surface is irregular and the morphology is different in the three-cusp and four-cusp patterns. The grooves serve as escape ways during the process of mastication.

(a) *Three-cusp pattern* (**Fig. 13.7g**)

- Cusps: Three cusps are seen—mesiobuccal, distobuccal and palatal cusps. The palatal cusp is the largest, followed by the mesiobuccal cusp and the distobuccal cusp. The palatal cusp is the only functional cusp which helps during the process of mastication.
- Ridges
  - In all the cusps, the *triangular ridge* is prominent and it extends from the cusp tips to the central fossa. The *transverse ridge* is found extending between the triangular ridges of the mesiobuccal and palatal cusps.
  - The *oblique ridge* may or may not be present. If it is present, it is formed by the union of the triangular ridge of the distobuccal cusp and the distal cusp ridge of the palatal cusp.
  - The *mesial marginal ridge* is well developed and forms the mesial boundary of the occlusal aspect. It is longer than the distal marginal ridge and is distally inclined.
  - The *distal marginal ridge* is not well developed and forms the distal boundary. It is thin and shorter than the mesial marginal ridge.
- Fossae
  - There is one major fossa, the *central fossa*, which is located in the centre of the occlusal surface.
  - There is one minor fossa, the *mesial triangular fossa*, which is located distal to the mesial marginal ridge on the occlusal surface.
- Pits
  - The *central pit* is located in the deeper part of the central fossa.
  - The *mesial pit* is located in the deeper part of the mesial triangular fossa.
- Developmental grooves
  - The *central groove* starts from the central pit and extends in a mesial direction towards the mesial triangular fossa to end in the mesial pit.

  - The *buccal groove* starts from the central pit and extends in a buccal direction between the two buccal cusps.
- Supplemental grooves: Three supplemental grooves are seen radiating from the mesial pit—one in the buccal direction, known as the *mesiobuccal triangular groove*; one in the palatal direction, called the *mesiopalatal triangular groove*; and the last towards the mesial marginal ridge, known as the *mesial marginal developmental groove*.

(b) *Four-cusp pattern* (**Fig. 13.7h**)

- Cusps: Four cusps are seen: mesiobuccal, distobuccal, mesiopalatal and distopalatal cusps. The mesiobuccal cusp is the largest followed by the mesiopalatal cusp, distobuccal cusp and distopalatal cusp. The mesiopalatal cusp is the sharpest cusp followed by the mesiobuccal cusp, distobuccal cusp and distopalatal cusp. The mesiopalatal and the distopalatal cusps are the only functional cusps which help during the process of mastication.
- Ridges
  - In all the cusps, the *triangular ridge* is prominent and it extends from the cusp tips up to the central fossa.
  - The *transverse ridge* is found extending between the mesiobuccal and the mesiopalatal cusps.
  - The *oblique ridge* is present. It is formed by the union of the triangular ridge of the distobuccal cusp and the distal cusp ridge of the mesiopalatal cusp.
  - The *mesial marginal ridge* is well developed and forms the mesial boundary of the occlusal aspect. It is longer than the distal marginal ridge and is distally inclined.
  - The *distal marginal ridge* is not well developed and forms the distal boundary. It is thin and shorter than the mesial marginal ridge.
- Fossae
  - There are one major fossa and two minor fossae in the occlusal surface.
  - The major fossa, the *central fossa*, is located in the centre of the occlusal surface.
  - The *mesial triangular fossa* is one of the minor fossae located distal to the mesial marginal ridge on the occlusal surface.
  - The *distal triangular fossa* is the other minor fossa located mesial to the distal marginal ridge on the occlusal surface, and it is less deep than the mesial triangular fossa.
- Pits
  - The *central pit* is located in the deeper part of the central fossa.
  - The *mesial pit* is located in the deeper part of the mesial triangular fossa.
  - The *distal pit* is located in the deeper part of the distal triangular fossa.
- Developmental grooves
  - The groove pattern is H shaped, formed by the central, mesiobuccal triangular, mesiopalatal triangular, buccal developmental and distopalatal grooves.
  - The *central groove* starts from the central pit and extends in a mesial direction towards the mesial triangular fossa to end in the mesial pit.
  - The *buccal groove* starts from the central pit and extends in a buccal direction between the two buccal cusps.
  - The *distopalatal groove* starts from the distal triangular fossa and extends in a palatal direction between the two palatal cusps.
  - The *distal extension of the central groove* starts from the central pit and extends in a distal direction towards the distal triangular fossa to end in the distal pit.

- Supplemental grooves
  - Three supplemental grooves are seen radiating from the mesial pit: one in the buccal direction, known as the *mesiobuccal triangular groove*; one in the palatal direction, called the *mesiopalatal triangular groove*; and the last one towards the mesial marginal ridge, known as the *mesial marginal developmental groove*.
  - Three supplemental grooves are seen radiating from the distal pit: one in the buccal direction, known as *distobuccal triangular groove*; one in the palatal direction, called the *distopalatal groove*; and the last one towards the distal marginal ridge, called the *distal marginal developmental groove*.

Deciduous Maxillary Second Molar

The deciduous maxillary second molar is situated distal to the maxillary first molar in the right and left quadrants of the maxillary arch. It is the last deciduous tooth to erupt in the oral cavity. It has five cusps—mesiobuccal, distobuccal, mesiopalatal, distopalatal cusps and the cusp of Carabelli—and three roots—mesiobuccal, distobuccal and palatal roots. The deciduous maxillary second molar resembles the permanent maxillary first molar in all aspects except for the dimensions and bulbous appearance of the crown.

The nomenclature, chronology and dimensions of deciduous maxillary second molars are given in **Table 13.8(a–c)**.

Table 13.8a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	A	J
Zsigmondy/ Palmer system	E⌋	⌊E
FDI system	55	65

Table 13.8b Chronology

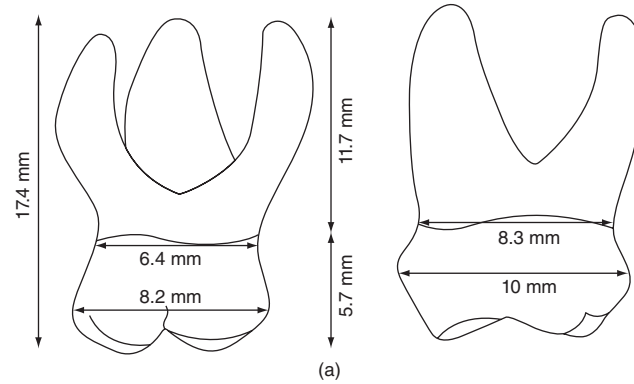
First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
19 (16–24) weeks in utero	11 months	29 (25–33) months	3 years	10 years

Table 13.8c Dimensions (Fig. 13.8a)

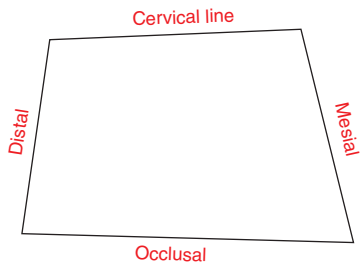
Total length	17.4 mm
Cervicoincisal length of crown	5.7 mm
Cervicoapical length of root	11.7 mm
Mesiodistal diameter of crown	8.2 mm
Mesiodistal diameter of crown at the cervix	6.4 mm
Labiopalatal diameter of crown	10.0 mm
Labiopalatal diameter of crown at the cervix	8.3 mm

Buccal Aspect (Fig. 13.8b)

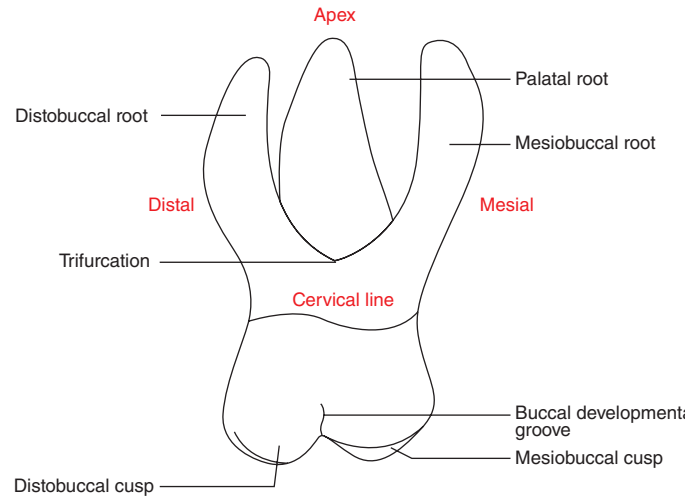
1. **Shape of the crown:** The shape of the crown is roughly trapezoidal, formed by the mesial, distal, occlusal and cervical outlines. The mesiodistal width of the crown is more than the cervico-occlusal width. The mesiodistal width is more in the level of contact areas and is narrower in the cervix of the tooth by about 1.8 mm, making the crown appear constricted at the cervix. The height of contour is present in the cervical third of the crown occupied by the buccal cervical ridge.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line up to the mesial contact area. The mesial cervical ridge is prominent in the cervical third of the crown.
   (b) *Distal outline:* The distal outline of the crown is convex from the cervical line up to the distal contact area.
   (c) *Cervical outline:* The curvature of the cervical outline is irregular with the convexity facing towards the root apex.



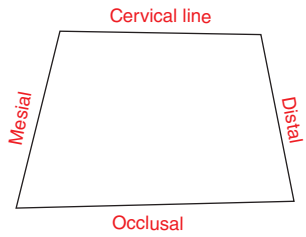
(a)



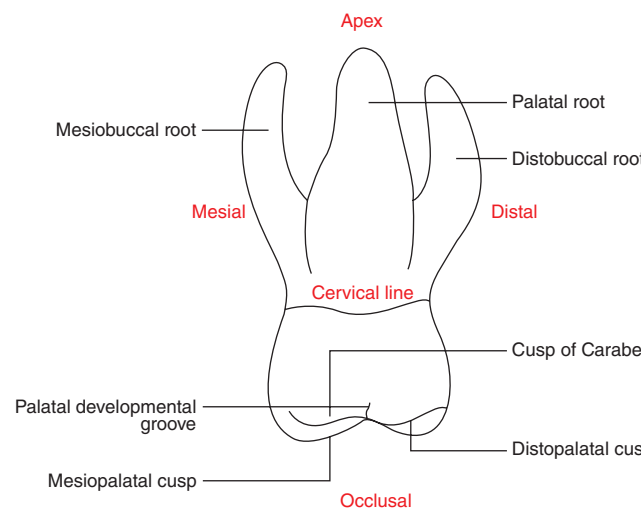
Buccal outline of crown



(b)



Palatal outline of crown



(c)

Figure 13.8 Deciduous maxillary right second molar: (a) dimensions, (b) buccal aspect, (c) palatal aspect. (*Continued*)

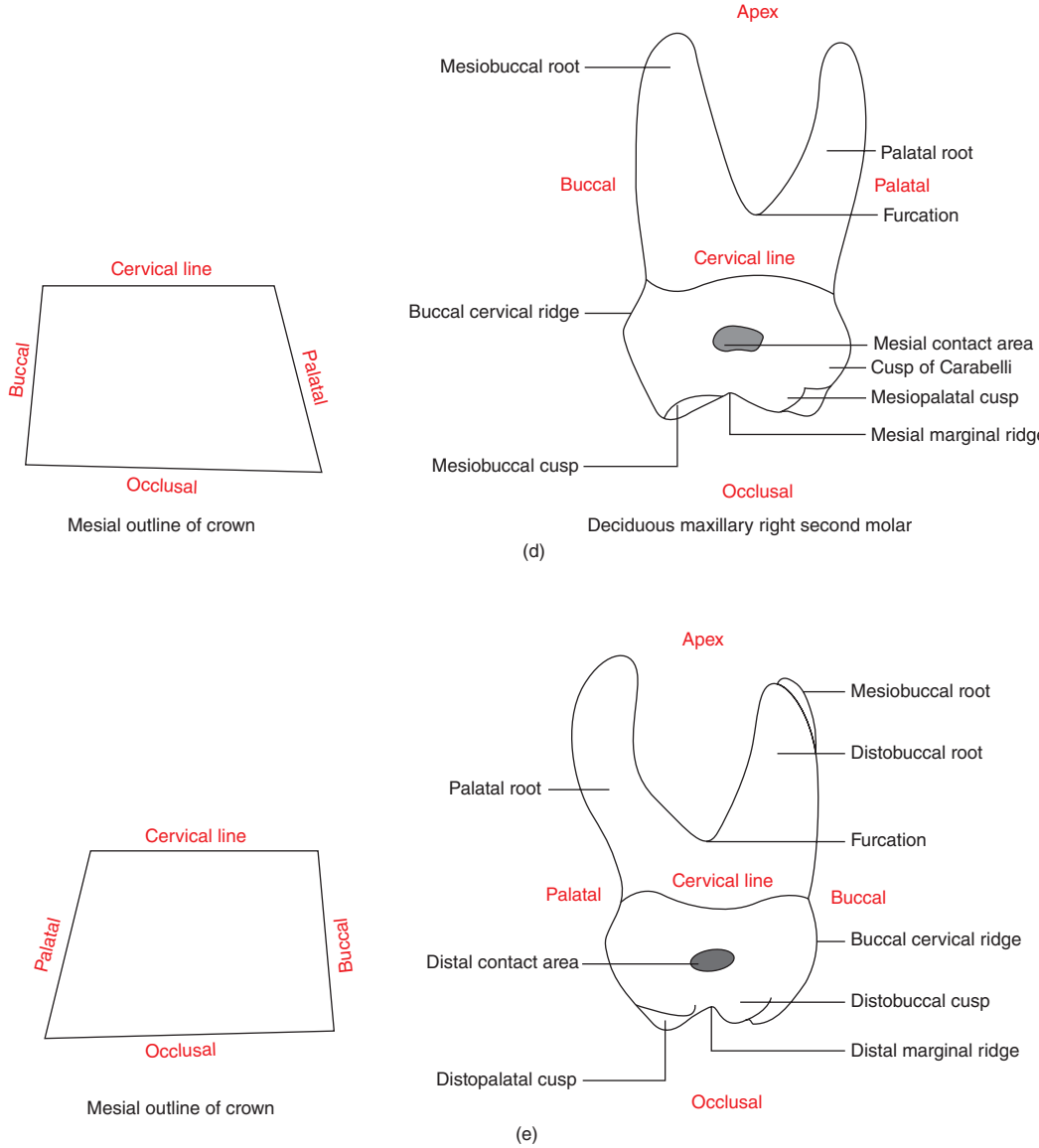


Figure 13.8 (*Continued*) (d) Mesial aspect and (e) distal aspect. (*Continued*)

(d) *Occlusal outline:* Two cusps—large mesiobuccal cusp and small distobuccal cusp—are seen separated by a buccal developmental groove.

3. **Buccal surface of the crown:** The buccal surface of the crown is smooth with a prominent cervical ridge in the cervical third, which runs in a mesiodistal direction and extends to half of the mesial surface of the crown. This well-developed cervical ridge is called the *buccal cingulum*, but it is not as prominent as that in the first molar. The mesiobuccal and distobuccal cusps are seen in this aspect. The mesiobuccal cusp is larger than the distobuccal cusp, and the two cusps are separated by a prominent buccal developmental groove which extends up to the occlusal third of the crown.

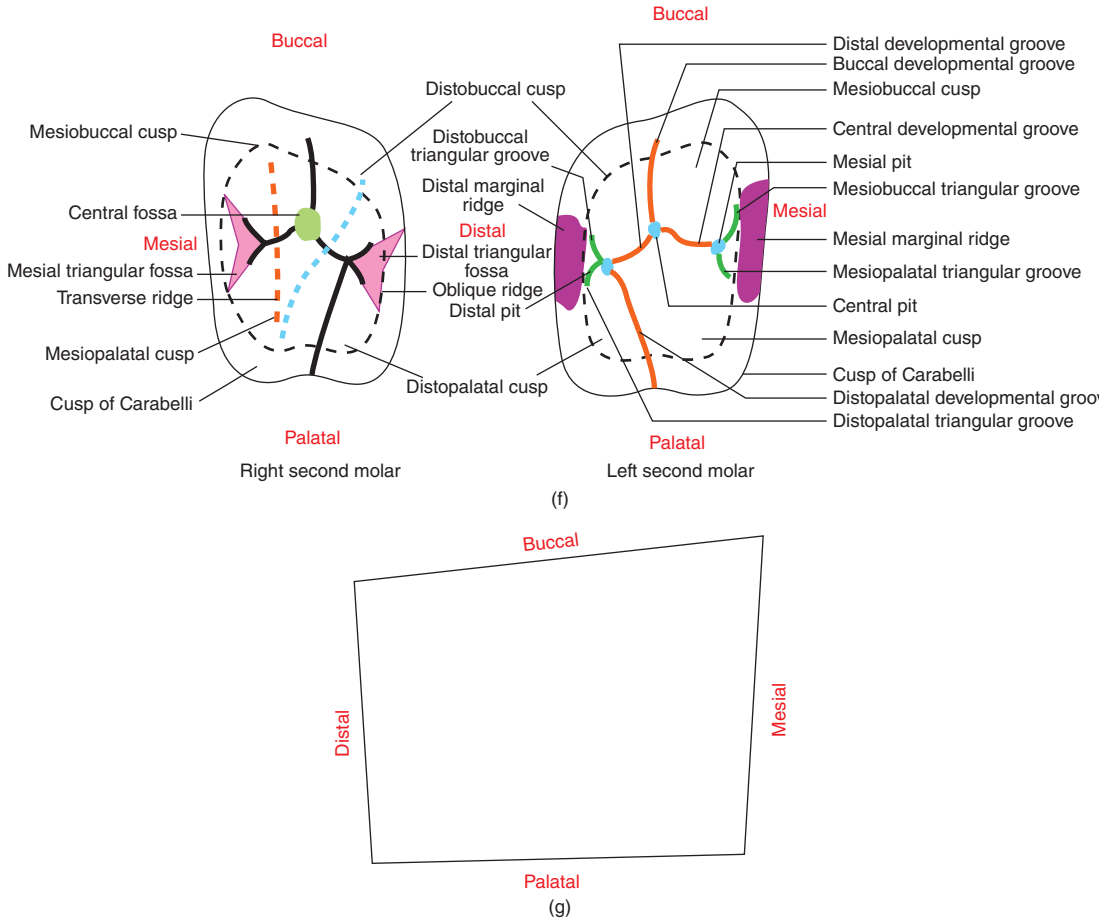


Figure 13.8 (*Continued*) (f) Deciduous maxillary right and left second molars—occlusal aspect and (g) deciduous maxillary right second molar—occlusal outline.

4. **Shape of the roots:** Three roots are present: mesiobuccal, distobuccal and palatal. All the three roots are seen in the buccal aspect and they are long and slender with a blunt apex. The mesiobuccal and palatal roots are longer than the distobuccal root. The level of trifurcation of the three roots is near the cervix and the root trunk is either small or indistinct.
5. **Outlines of the roots:** The mesial outline of the mesiobuccal root and the distal outline of the distobuccal root are convex from the cervical line up to the middle third and then taper evenly up to the apex. The distal outline of the mesiobuccal root and the mesial outline of the distobuccal root are concave from the point of furcation up to the apex. The mesial and distal outlines of the palatal root taper evenly from the point of furcation up to the apex. The thin roots are widely placed and flare beyond the mesiodistal outline of the crown to provide space for the development of the permanent maxillary second premolar.
6. **Buccal surface of the roots:** The buccal surface is flat and smooth without any developmental depressions or grooves in all the three roots.

Palatal Aspect (Fig. 13.8c)

1. **Shape of the crown:** The shape of the crown is similar to that in the buccal aspect. The mesiodistal width of the crown in this aspect is comparatively less than that of the buccal

aspect because of the palatal convergence of the mesial and distal sides of the crown.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is similar to that of the buccal aspect.
   (b) *Distal outline:* The distal outline is similar to that of the buccal aspect.
   (c) *Cervical outline:* The curvature of the cervical outline is irregular with the convexity facing towards the occlusal aspect.
   (d) *Occlusal outline:* A large mesiopalatal cusp and a small distopalatal cusp are seen in this aspect, separated by a palatal developmental groove.
3. **Palatal surface of the crown:** The palatal surface of the crown is smoothly convex mesiodistally and cervico-occlusally. The cervical ridge is not that prominent as in the buccal surface. Three cusps are seen: mesiopalatal cusp, distopalatal cusp and supplementary cusp. The mesiopalatal cusp is longer and sharper than the distopalatal cusp and it is the most prominent cusp of the deciduous maxillary second molar. The distopalatal cusp is small and rounded. The mesiopalatal cusp and the distopalatal cusp are separated by the palatal developmental groove. The supplementary cusp is called the *cusp or tubercle of Carabelli* and is situated cervical to the mesiopalatal cusp on the palatal surface of the crown. This cusp is separated from the mesiopalatal cusp by a developmental groove, which is joined by the palatal developmental groove. The cusp of Carabelli is sometimes absent and appears as a developmental line or 'dimple' on the palatal surface of the mesiopalatal cusp.
4. **Shape of the roots:** All the three roots—mesiobuccal, distobuccal and palatal—are seen in the buccal aspect. They are long and slender with a blunt apex. The mesiobuccal and the palatal roots are longer than the distobuccal root. The level of trifurcation of the three roots is near the cervix and the root trunk is either small or indistinct.
5. **Outlines of the roots:** The mesial and distal outlines of the three roots are similar to those of the buccal aspect.
6. **Palatal surface of the roots:** The palatal surface is flat and smooth without any developmental depressions or grooves in all the three roots.

Mesial Aspect (Fig. 13.8d)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal, formed by the buccal, palatal, occlusal and cervical outlines. The buccopalatal width of the crown is more than the cervico-occlusal width. The buccopalatal width of the crown at the cervical third is more than that at the occlusal third. The greater buccopalatal width at the cervical third is due to the prominent buccal cervical ridge which makes the crown appear bulbous.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is straight up to the mesiobuccal cusp tip. The height of contour is at the cervical third of the crown.
   (b) *Palatal outline:* From the cervix, the palatal outline is convex from the cervical line up to the mesiopalatal cusp tip. The height of the contour is at the middle third of the crown.
   (c) *Cervical outline:* The curvature of the cervical outline is irregular with the convexity facing towards the occlusal aspect.
   (d) *Occlusal outline:* The occlusal outline is not regular and three cusps are seen—mesiobuccal and mesiopalatal cusps and the cusp of Carabelli—with a prominent mesial marginal ridge. The mesiopalatal cusp is longer and sharper than the mesiobuccal cusp. The occlusal area is narrow buccopalatally because of the marked convergence of the buccal and palatal surfaces of the crown. The mesial marginal ridge is wide buccopalatally and placed at a level higher than the distal marginal ridge, and sometimes it may be crossed by a mesial marginal developmental groove.

3. **Mesial surface of the crown:** The mesial surface is flat except in the mesial contact area where it is slightly convex.
4. **Mesial contact area:** The mesial contact area is situated in the middle one-third of the crown.
5. **Shape of the roots:** Two roots are seen in this aspect: palatal and mesiobuccal roots. The palatal root is longer, slender and more divergent than the mesiobuccal root. The mesiobuccal root is broad in the buccopalatal direction and it hides the distobuccal root. The width of the palatal root is the same as the buccopalatal width of the mesiopalatal cusp. The level of furcation of the roots is 2–3 mm from the cervix and the root trunk is small.
6. **Outlines of the roots:** For the mesiobuccal root, the buccal outline is convex from the cervical line up to the blunt apex and the palatal outline is concave from the point of furcation up to the apex. For the palatal root, the palatal outline is concave from the cervical line up to the middle third and from there it is convex up to the blunt apex, and the buccal outline is concave from the point of furcation up to the apex. There is a buccal inclination of the palatal root at the middle third, but it is not as sharp as in the first molar.
7. **Mesial surface of the root:** The mesial surface is smooth without any developmental depressions or grooves in both the roots.

Distal Aspect (Fig. 13.8e)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal, formed by the buccal, palatal, occlusal and cervical outlines. The buccopalatal width of the crown is more than the cervico-occlusal width. In this aspect, the crown is narrower buccopalatally than in the mesial aspect due to the distal convergence of the buccal and palatal surface of the crown. The cervico-occlusal width is less than in the mesial aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is straight up to the distobuccal cusp tip. The height of contour is at the cervical third of the crown.
   (b) *Palatal outline:* From the cervix, the palatal outline is convex from the cervical line up to the distopalatal cusp tip. The height of contour is at the middle third of the crown.
   (c) *Cervical outline:* The curvature of the cervical outline is either convex towards the occlusal aspect or it is nearly straight.
   (d) *Occlusal outline:* The occlusal outline is not regular and two cusps—distobuccal and distopalatal cusps—are seen along with a prominent distal marginal ridge. The distobuccal cusp is larger than the distopalatal cusp. The occlusal area is also narrow buccolingually as seen in the distal aspect.
3. **Distal surface of the crown:** The distal surface is flat except in the distal contact area where it is slightly convex.
4. **Distal contact area:** The distal contact area is situated in the middle one-third of the crown.
5. **Shape of the roots:** Three roots are seen in this aspect: distobuccal and palatal roots and part of the mesiobuccal root. The palatal root is longer, thinner, more slender and more divergent than the distobuccal root. The distobuccal root is shorter, slender and narrower than the mesiobuccal root. The level of furcation of the roots is 2–3 mm from the cervix and the root trunk is small.
6. **Outlines of the roots:** For the distobuccal root, the buccal outline is convex from the cervical line up to the blunt apex and the palatal outline is concave from the point of furcation up to the apex. For the palatal root, the palatal outline is concave from the cervical line up to the middle third and from there it is convex up to the blunt apex, and the buccal outline is concave from the point of furcation up to the apex. There is a buccal inclination of the palatal root at the middle third but it is not as sharp as in the first molar.

7. **Distal surface of the roots:** The distal surface is smooth without any developmental depressions or grooves in both the roots.

Occlusal Aspect (Fig. 13.8f)

1. **Shape of the crown:** The occlusal outline is rhomboidal in shape, formed by the mesial and distal marginal ridges and the buccal and palatal surfaces (**Fig. 13.8g**). The buccopalatal width is more than the mesiodistal width. The mesiodistal width is more in the buccal aspect than the palatal aspect due to the palatal convergence of the crown.
2. **Outlines of the crown**
   (a) *Buccal outline:* The irregular buccal outline is broader than the palatal outline.
   (b) *Palatal outline:* The palatal outline is narrower than the buccal outline because of the palatal tapering of the crown.
   (c) *Mesial and distal outlines:* The mesial outline is broader than the distal outline due to the distal convergence of the crown. The mesial outline is formed by the mesial marginal ridge, and the distal outline is formed by the distal marginal ridge.
3. **Occlusal surface of the crown:** The occlusal surface is irregular with well-developed cusps, ridges and grooves. The grooves serve as escape-ways during the process of mastication.
   (a) *Cusps:* Five cusps are seen—mesiobuccal, distobuccal, mesiopalatal and distopalatal cusps and the cusp of Carabelli. The mesiopalatal is the largest cusp followed by the mesiobuccal cusp, distobuccal cusp, distopalatal cusp and lastly the cusp of Carabelli. The mesiopalatal and distopalatal cusps are the only functional cusps which help during the process of mastication.
   (b) *Ridges*
   - The *triangular ridge* is prominent and extends from the cusp tips to the central fossa.
   - The *transverse ridge* is found extending between the mesiobuccal and the mesiopalatal cusps.
   - The *oblique ridge* is present and formed by the union of the triangular ridge of the distobuccal cusp and the distal cusp ridge of the mesiopalatal cusp.
   - The *mesial marginal ridge* is well developed and forms the mesial boundary of the occlusal aspect. It is longer than the distal marginal ridge and distally inclined.
   - The *distal marginal ridge* is not well developed and forms the distal boundary. It is thin and shorter than the mesial marginal ridge.
   - *Fossae* There are two major fossae and two minor fossae in the occlusal surface.
   - Of the two major fossae, one is the *central fossa* located mesial to the oblique ridge.
   - The other major fossa is the distal fossa and it is located distal to the oblique.
   - The *mesial triangular fossa* is one of the two minor fossae, located distal to the mesial marginal ridge on the occlusal surface, and it is deeper.
   - The *distal triangular fossa* is the other minor fossa which is located mesial to the distal marginal ridge on the occlusal surface and it is shallow.

   (c) *Pits*
   - The *central pit* is located in the deeper part of the central fossa.
   - The *mesial pit* is located in the deeper part of the mesial triangular fossa.
   - The *distal pit* is located in the deeper part of the distal triangular fossa.

   (d) *Developmental grooves*
   - The *central groove* starts from the central pit and extends in a mesial direction towards the mesial triangular fossa to end in the mesial pit.
   - The *buccal groove* starts from the central pit and extends in a buccal direction between the two buccal cusps.
   - The *distopalatal groove* starts from the distal triangular fossa and extends in a palatal direction between the two

palatal cusps and continues as the *palatal groove* on the palatal surface.

- The *distal developmental groove* starts from the central pit and extends in a distal direction crossing the oblique ridge towards the distal triangular fossa to end in the distal pit.

(e) *Supplemental grooves*

- Three supplemental grooves are seen radiating from the mesial pit: one in the buccal direction, called the *mesiobuccal triangular groove*; one in the palatal direction, known as the *mesiopalatal triangular groove*; and the last one towards the mesial marginal ridge, called the *mesial marginal developmental groove*.
- Two supplemental grooves are seen radiating from the distal pit: one in the buccal direction, called the *distobuccal triangular groove*, and the other towards the distal marginal ridge, called the *distal marginal developmental groove*.

DECIDUOUS MANDIBULAR MOLARS

The deciduous mandibular molars constitute the posterior teeth in the mandibular arch. They are four in number with two teeth each in the right and left mandibular quadrants: the first and the second molars. The mandibular first molar is the fourth tooth to erupt in the mandibular arch followed by the mandibular second molar. The main function of deciduous mandibular molars is the process of mastication (chewing) and facial appearance. The deciduous mandibular molars are larger than the deciduous mandibular incisors and canine in all aspects. The mesiodistal width of the crown is relatively broad and the cervical ridge is very prominent in the buccal surface and half of the mesial surface of the crown. It has five cusps: mesiobuccal, distobuccal, mesiolingual, distolingual and distal cusps. In the cervix of the tooth, there is a marked cervical constriction seen. The deciduous mandibular molars have two roots: mesial and distal. The level of bifurcation of the roots is near the cervix in deciduous mandibular molars, and the roots are thin and flare beyond the mesiodistal and buccolingual outlines of the crown to allow space for the development of permanent mandibular premolar crowns.

Deciduous Mandibular First Molar

The deciduous mandibular first molar is situated distal to the mandibular canine in the right and left quadrants of the mandibular arch. The deciduous mandibular first molar is unique in shape and does not resemble any other tooth in the human dentition. It is smaller than the deciduous mandibular second molar in all aspects.

The nomenclature, chronology and dimensions of deciduous mandibular first molars are given in **Table 13.9(a–c)**.

Table 13.9a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	S	L
Zsigmondy/ Palmer system	D|	|D
FDI system	84	74

Table 13.9b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
15 (14–17) weeks in utero	5½ months	16 (14–18) months	2½ years	9 years

Table 13.9c Dimensions (Fig. 13.9a)

Total length	15.8 mm
Cervicoincisal length of crown	6.0 mm
Cervicoapical length of root	9.8 mm
Mesiodistal diameter of crown	7.7 mm
Mesiodistal diameter of crown at the cervix	6.5 mm
Labiopalatal diameter of crown	7.0 mm
Labiopalatal diameter of crown at the cervix	5.3 mm

Buccal Aspect (Fig. 13.9b)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal, formed by the mesial, distal, occlusal and cervical outlines. The mesiodistal width of the crown is more than the cervico-occlusal width. The mesiodistal width is more in the level of contact areas and is narrower in the cervix of the tooth by about 2 mm, making the crown appear constricted at the cervix. The cervico-occlusal width in the mesial half of the crown is longer than the distal half. The height of contour is present in the cervical third of the crown occupied by the buccal cervical ridge.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line along with the mesial contact area up to the mesiobuccal cusp and is longer than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is convex from the cervical line along with the distal contact area and is shorter than the mesial outline. The distal outline is more distally inclined and the distal contact area is more distally placed.
   (c) *Cervical outline:* The cervical line dips towards the root apex of the mesial root in the mesial half and is straight in the distal half.
   (d) *Occlusal outline:* The occlusal outline is not regular but appears scalloped, and two cusps are seen—large mesiobuccal cusp and small distobuccal cusp—separated by a developmental depression instead of a groove.
3. **Buccal surface of the crown:** The buccal surface of the crown is convex in the cervical third and flat in the middle and occlusal third. The cervical ridge is prominent in the cervical third, which runs in a mesiodistal direction and extends to half of the mesial surface of the crown. This well-developed cervical ridge is called the *buccal cingulum*. Two buccal cusps are seen: mesiobuccal and distobuccal cusps. The mesiobuccal cusp is larger than the distobuccal cusp and the two cusps are separated by a developmental depression. Sometimes, instead of the developmental depression a buccal developmental groove is seen separating the two buccal cusps.
4. **Shape of the roots:** The mesial root is longer and wider than the distal root ending in a blunt apex.
5. **Outlines of the roots:** The mesial outline of the mesial root is concave in the cervical third and convex in the middle and apical third. The distal outline of the mesial root is concave from the point of furcation up to the apex. The mesial outline of the distal root is also concave from the point of furcation up to the apex. The distal outline of the distal root is concave in the cervical third and straight in the middle and apical third. The roots are widely placed and flare beyond the mesiodistal outline of the crown to provide space for the development of the permanent mandibular first premolar.
6. **Buccal surface of the roots:** The buccal surface is flat and smooth without any developmental depressions or grooves in both the roots.

Lingual Aspect (Fig. 13.9c)

1. **Shape of the crown:** The shape of the crown is similar to that in the buccal aspect. The mesiodistal width of the crown in this aspect is comparatively less than in the buccal aspect because of the lingual convergence of the mesial side of the crown and as a result, the mesial surface is also visible in this aspect. The height of contour is present in the middle third of the crown.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is similar to that of the buccal aspect.
   (b) *Distal outline:* The distal outline of the crown is similar to that of the buccal aspect.
   (c) *Cervical outline:* The cervical line is straight in this aspect.

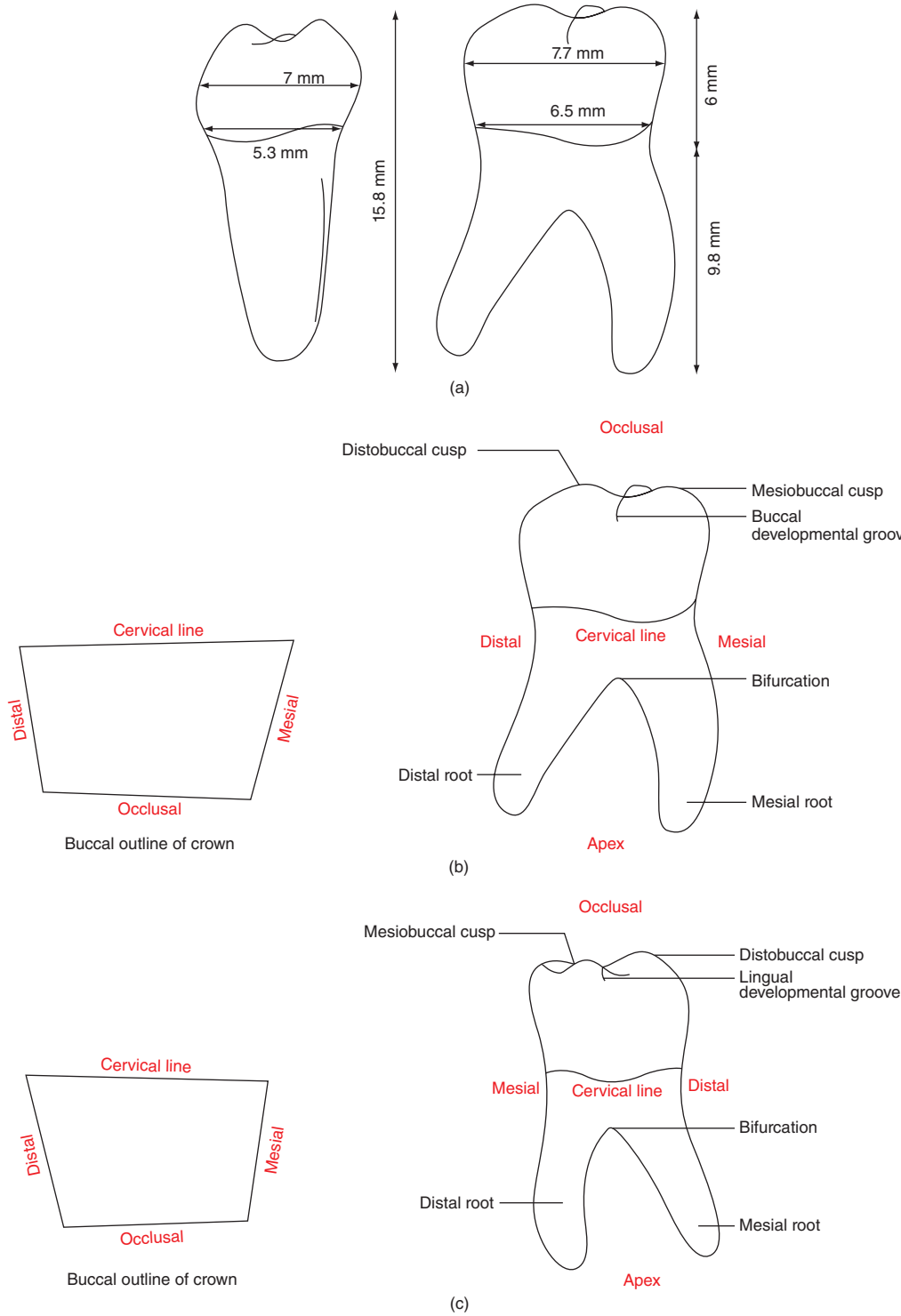


Figure 13.9 Deciduous mandibular right first molar: (a) dimensions, (b) buccal aspect, (c) lingual aspect. (*Continued*)

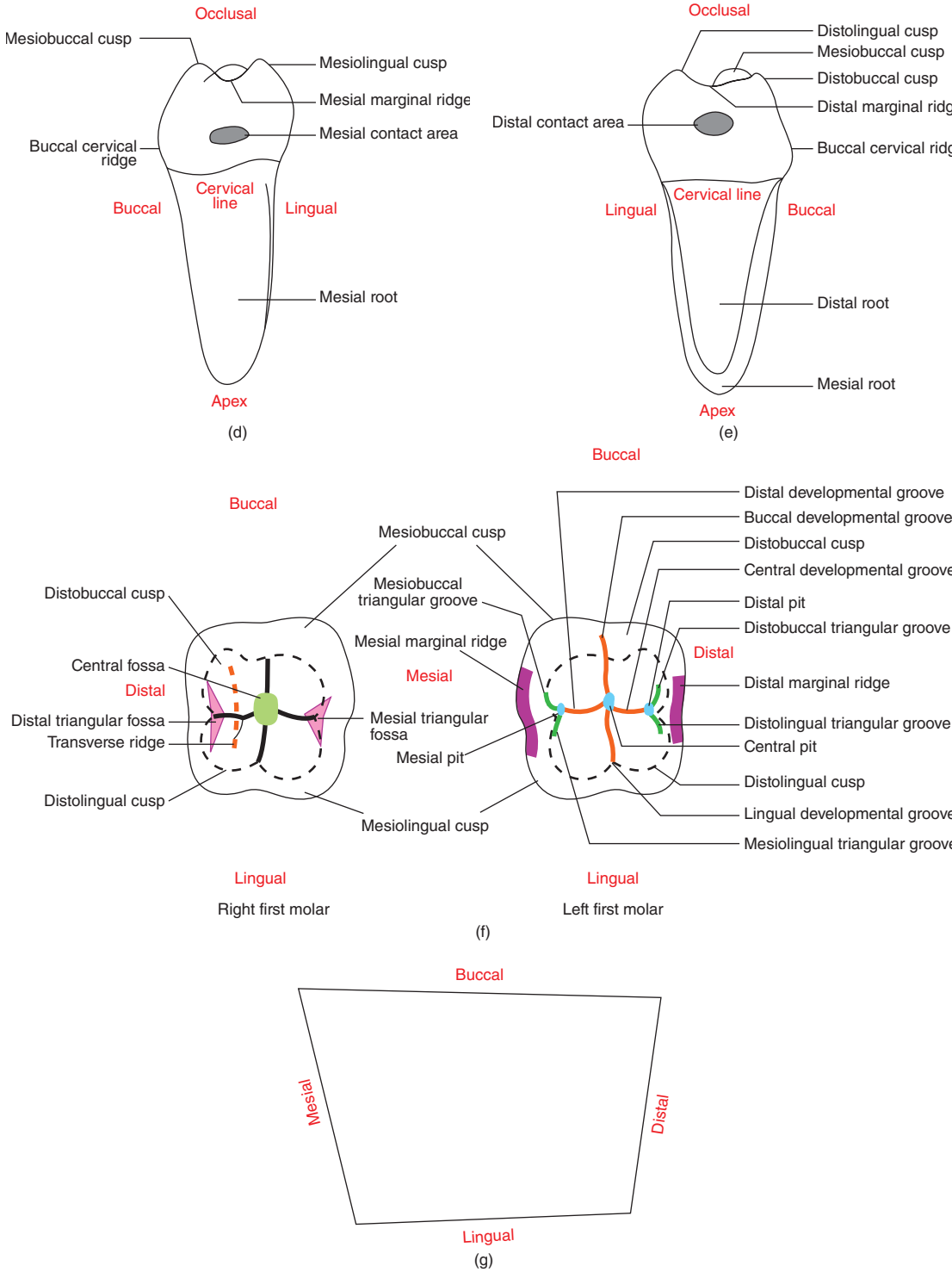


Figure 13.9 (*Continued*) (d) Mesial aspect and (e) distal aspect. (f) Deciduous mandibular right and left first molar: occlusal aspect and (g) deciduous mandibular right first molar—occlusal outline. The level of bifurcation of the roots is near the cervix and the root trunk is either small or indistinct.

(d) *Occlusal outline:* The occlusal outline is not regular but appears scalloped. Two cusps are seen—large mesiolingual cusp and small distolingual cusp—separated by a lingual developmental groove. The cusp tips of the mesiobuccal and distobuccal cusps are also seen. The mesial marginal ridge is well developed and occlusally placed and appears as another cusp in the lingual aspect.

3. **Lingual surface of the crown:** The lingual surface of the crown is smoothly convex mesiodistally and cervico-occlusally. The cervical ridge is not as prominent as that in the buccal surface. Two lingual cusps are seen: mesiolingual and distolingual cusps. The mesiolingual cusp is longer and sharper than the distolingual cusp and is the most prominent cusp of the deciduous mandibular first molar. The distolingual cusp is small and rounded. The two lingual cusps are separated by the lingual developmental groove.
4. **Shape of the roots:** Two roots are present: mesial and distal. The mesial root is longer and wider than the distal root ending in a blunt apex. The level of bifurcation of the roots is near the cervix and the root trunk is either small or indistinct.
5. **Outlines of the roots:** The mesial and distal outlines of the mesial and distal roots are similar to those of the buccal aspect.
6. **Lingual surface of the roots:** The lingual surface is flat and smooth without any developmental depressions or grooves in both the roots.

Mesial Aspect (Fig. 13.9d)

1. **Shape of the crown:** The buccolingual width of the crown is more than the cervico-occlusal width. The buccolingual width of the crown at the cervical third is more than that at the occlusal third. The greater buccolingual width at the cervical third is due to the prominent buccal cervical ridge which makes the crown appear bulbous. The crown appears to be inclined lingually, as a result of which the buccal half is longer than the lingual half of the mesial aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is flat up to the mesiobuccal cusp tip. The height of contour is at the cervical third of the crown. The buccal outline is longer and more lingually inclined than the lingual outline.
   (b) *Lingual outline:* From the cervix, the lingual outline is convex in the cervical and the middle third and then becomes flat up to the mesiolingual cusp tip. The height of contour is at the middle third of the crown. The lingual outline is shorter than the buccal outline, is lingually inclined and extends beyond the lingual outline of the root.
   (c) *Cervical outline:* The cervical outline is irregular with the convexity facing towards the occlusal aspect and it slants from the buccal surface to the lingual surface.
   (d) *Occlusal outline:* The occlusal outline is not regular and two cusps are seen—mesiobuccal and mesiolingual cusps—with a prominent mesial marginal ridge. The mesiobuccal cusp is within the buccal outline of the root, and the mesiolingual cusp is either in line with the lingual outline of the root or extends beyond it. The mesiolingual cusp is larger than the mesiobuccal cusp. The occlusal area is narrow buccolingually because of the marked convergence of the buccal and lingual surfaces of the crown. The mesial marginal ridge is well developed, wide and concave buccopalatally, and more occlusally placed.
3. **Mesial surface of the crown:** The mesial surface is flat except in the mesial contact area where it is slightly convex.
4. **Mesial contact area:** The mesial contact area is flat and situated in the cervical one-third of the crown.
5. **Shape of the root:** Only the mesial root is seen in this aspect and it is square shaped. The mesial root is broad in the cervical and middle third and tapers in the apical third ending in a broad and blunt apex.

6. **Outlines of the root:** The buccal and lingual outlines of the mesial root are straight from the cervical line up to the middle third and then these taper up to the broad apex.
7. **Mesial surface of the root:** A deep developmental depression is seen on the mesial surface of the root extending from the cervical line up to the apical third.

Distal Aspect (Fig. 13.9e)

1. **Shape of the crown:** The buccolingual width of the crown is more than the cervico-occlusal width. The buccolingual width of the crown at the cervical third is more than the buccolingual width at the occlusal third. The buccal cervical ridge is not prominent in this aspect. The crown is not inclined lingually, and as a result, the cervico-occlusal width is the same in the buccal half and the lingual half of the distal aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is flat up to the distobuccal cusp tip. The height of contour is at the cervical third of the crown.
   (b) *Lingual outline:* From the cervix, the lingual outline is convex in the cervical and the middle third and then becomes flat up to the distolingual cusp tip. The height of the contour is at the middle third of the crown.
   (c) *Cervical outline:* The cervical line is nearly straight.
   (d) *Occlusal outline:* The occlusal outline is not regular and two cusps are seen—distobuccal and distolingual cusps—with a distal marginal ridge. The two distal cusps are within the confines of the distal root outline. This outline is thin and curves cervically and so part of the occlusal surface can be seen. The occlusal area is narrow buccolingually as seen in the distal aspect.
3. **Distal surface of the crown:** The distal surface is convex with the height of contour in the distal contact area.
4. **Distal contact area:** The distal contact area is situated in the middle one-third of the crown.
5. **Shape of the roots:** The distal root and part of the mesial root are seen in this aspect. The distal root is narrow and rounded, ending in a blunt apex.
6. **Outlines of the roots:** The buccal and lingual outlines of the distal root are straight from the cervical line up to the apex.
7. **Distal surface of the root:** The distal surface is smooth without any developmental depressions or grooves in both the roots.

Occlusal Aspect (Fig. 13.9f)

1. **Shape of the crown:** The occlusal outline is trapezoidal, formed by the buccal surface, lingual surface, and mesial and distal marginal ridges (**Fig. 13.9g**). The mesiodistal width is more than the buccolingual width. The mesiodistal width is more in the distal half than the mesial half of the occlusal surface. The mesiobuccal angle is acute, the distobuccal angle is obtuse and the mesiolingual angle is more rounded than the other line angles.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is broader than the lingual outline and it is irregular.
   (b) *Lingual outline:* The lingual outline is narrower than the buccal outline because of the lingual tapering of the crown.
   (c) *Mesial and distal outlines:* The mesial outline is broader than the distal outline due to the distal convergence of the crown. The mesial outline is formed by the mesial marginal ridge and the distal outline is formed by the distal marginal ridge.
3. **Occlusal surface of the crown:** The occlusal surface is irregular with well-developed cusps, ridges and grooves. The grooves serve as escapeways during the process of mastication.
   (a) *Cusps*: Four cusps are seen—mesiobuccal, distobuccal, mesiolingual and distolingual cusps. The mesiolingual cusp is the largest cusp followed by the mesiobuccal cusp, distobuccal cusp and lastly the distolingual cusp. The mesiolingual and distolingual

cusps are the only functional cusps which help during the process of mastication.

(b) *Ridges*
- In all the cusps, the *triangular ridge* is prominent and extends from all the four cusp tips to the central fossa.
- The *transverse ridge* is found extending between the mesiobuccal and the mesiolingual cusps.
- The *mesial marginal ridge* is well developed and forms the mesial boundary of the occlusal aspect. It is longer than the distal marginal ridge and is occlusally placed.
- The *distal marginal ridge* forms the distal boundary. It is thinner, shorter, more cervically placed and not as well developed as the mesial marginal ridge.

(c) *Fossae* There is one major fossa and two minor fossae in the occlusal surface.
- The major fossa is the *central fossa*, located in the centre of the occlusal surface.
- The *mesial triangular fossa* is one of the two minor fossae located distal to the mesial marginal ridge on the occlusal surface and is deeper.
- The *distal triangular fossa* is the other minor fossa which is located mesial to the distal marginal ridge on the occlusal surface and is shallow.

(d) *Pits*
- The *central pit* is located in the deeper part of the central fossa.
- The *mesial pit* is located in the deeper part of the mesial triangular fossa.
- The *distal pit* is located in the deeper part of the distal triangular fossa.

(e) *Developmental grooves*
- The *central groove* starts from the mesial pit and extends in the distal direction to end in the central pit, thereby separating the mesiobuccal and mesiolingual cusps.
- The *buccal groove* starts from the central pit and extends in a buccal direction between the two buccal cusps. But it does not extend onto the buccal surface of the crown.
- The *lingual groove* starts from the central pit and extends in a lingual direction between the two lingual cusps and may or may not extend onto the lingual surface.
- The *distal developmental groove* starts from the central pit and extends in a distal direction to end in the distal pit.

(f) *Supplemental grooves*
- Two supplemental grooves are seen radiating from the mesial pit: one in the buccal direction, called the *mesiobuccal triangular groove*, and one in the lingual direction, called the *mesiolingual triangular groove*.
- Two supplemental grooves are seen radiating from the distal pit: one in the buccal direction, called the *distobuccal triangular groove*, and the other in the lingual direction, called the *distolingual triangular groove*.

Deciduous Mandibular Second Molar

The deciduous mandibular second molar is located distal to the mandibular first molar in the right and left quadrants of the mandibular arch. It is larger in dimensions and different in morphology when compared to the deciduous mandibular first molar. It has five cusps—mesiobuccal, distobuccal, mesiolingual, distolingual and distal cusps—and two roots—mesial and distal. The deciduous mandibular second molar resembles the permanent mandibular first molar in all aspects except for the following variations:

1. Dimensions are less than the permanent mandibular first molar.
2. The buccal and the mesial cervical ridges are more prominent in the deciduous mandibular second molar.
3. Three buccal cusps are seen in the deciduous mandibular second molar.
4. There is marked cervical constriction in the deciduous mandibular second molar.

Table 13.10a Nomenclature

Nomenclature	Right Maxillary Central Incisor	Left Maxillary Central Incisor
Universal system	T	K
Zsigmondy/ Palmer system	$\overline{\text{E}}\vert$	$\vert\overline{\text{E}}$
FDI system	85	75

Table 13.10b Chronology

First Evidence of Calcification	Crown Completion	Eruption	Root Completion	Shedding
18 (17–19) weeks in utero	10 months	27 (23–31) months	3 years	10 years

Table 13.10c Dimensions (Fig. 13.10a)

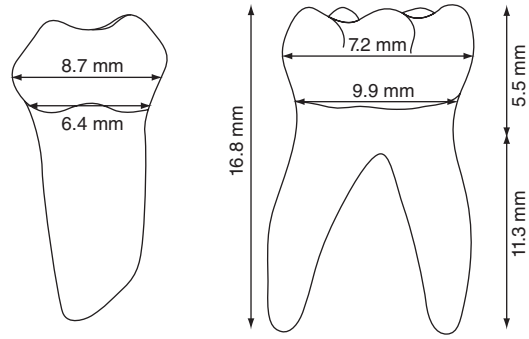
Total length	16.8 mm
Cervicoincisal length of crown	5.5 mm
Cervicoapical length of root	11.3 mm
Mesiodistal diameter of crown	9.9 mm
Mesiodistal diameter of crown at the cervix	7.2 mm
Labiopalatal diameter of crown	8.7 mm
Labiopalatal diameter of crown at the cervix	6.4 mm

5. The roots are slender and more divergent in deciduous mandibular second molar.

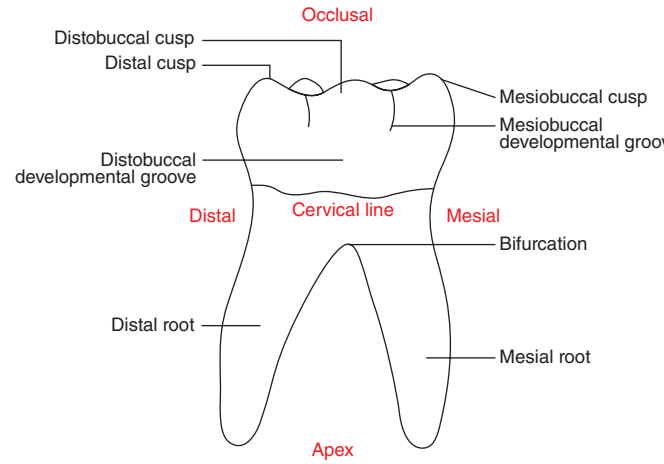
The nomenclature, chronology and dimensions of deciduous mandibular second molars are given in **Table 13.10(a–c)**.

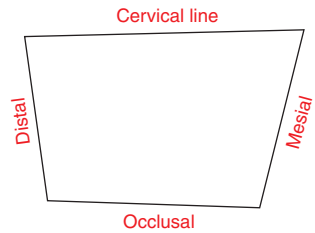
Buccal Aspect (Fig. 13.10b)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal formed by the mesial, distal, occlusal and cervical outlines. The mesiodistal width of the crown is more than the cervicoocclusal width. The mesiodistal width is more in the level of contact areas and is narrower in the cervix of the tooth by about 2.7 mm, making the crown appear constricted at the cervix. The crown is slightly tilted to the distal aspect in relation to the long axis of the tooth. The height of contour is present in the cervical third of the crown occupied by the buccal cervical ridge just beneath the cervical line.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is straight from the cervical line along with the mesial contact area up to the mesiobuccal cusp and is longer than the distal outline.
   (b) *Distal outline:* The distal outline of the crown is convex from the cervical line along with the distal contact area and it is shorter than the mesial outline.
   (c) *Cervical outline:* The cervical line is either irregular or straight.
   (d) *Occlusal outline:* The occlusal outline is not regular but appears scalloped, and three cusps are seen—mesiobuccal, distobuccal and distal cusps—separated by developmental grooves. The cusp tips of the mesiolingual and distolingual cusps are also seen, as they are at a higher level than the buccal cusps.
3. **Buccal surface of the crown:** The buccal surface of the crown is convex in the cervical third and then slopes flat up to the cusp tips. The cervical ridge is prominent in the cervical third, which runs in a mesiodistal direction and extends to half of the mesial surface of the crown. This well-developed cervical ridge is called the *buccal cingulum*. Three buccal cusps—mesiobuccal, distobuccal and distal—are seen in this aspect. All the three cusps are of the same width, but the distobuccal cusp is longer than the other two cusps. Sometimes, the distal cusp is smaller than the other two cusps. The mesiobuccal and distobuccal cusps are separated by the mesiobuccal developmental groove. The distobuccal and the distal cusps are separated by the distobuccal groove.
4. **Shape of the roots:** Two roots are present: mesial and distal. The roots are twice the length of the crown but narrow mesiodistally. The mesial root is longer and wider than the distal root ending in a blunt apex. The level of bifurcation of the roots is near the cervix and the root trunk is either small or indistinct.



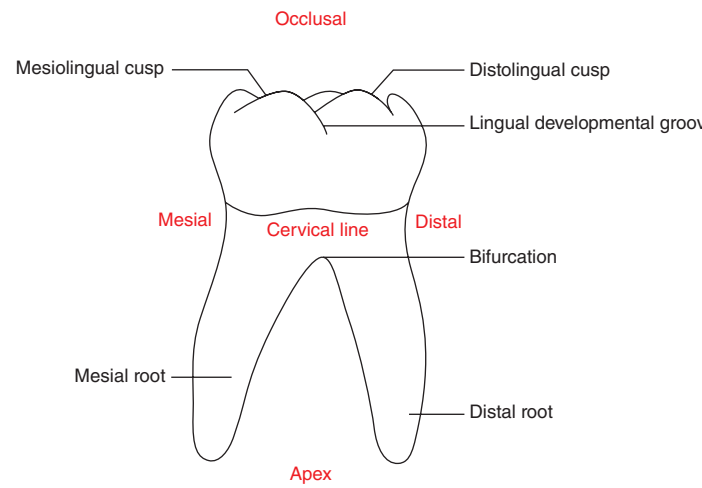
(a)

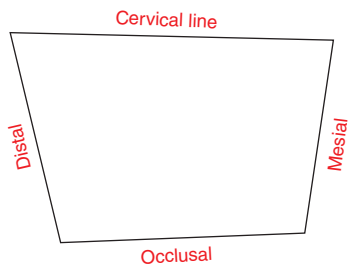




Buccal outline of crown

(b)





Buccal outline of crown

(c)

Figure 13.10 Deciduous mandibular right second molar: (a) dimensions, (b) buccal aspect, (c) lingual aspect. (*Continued*)

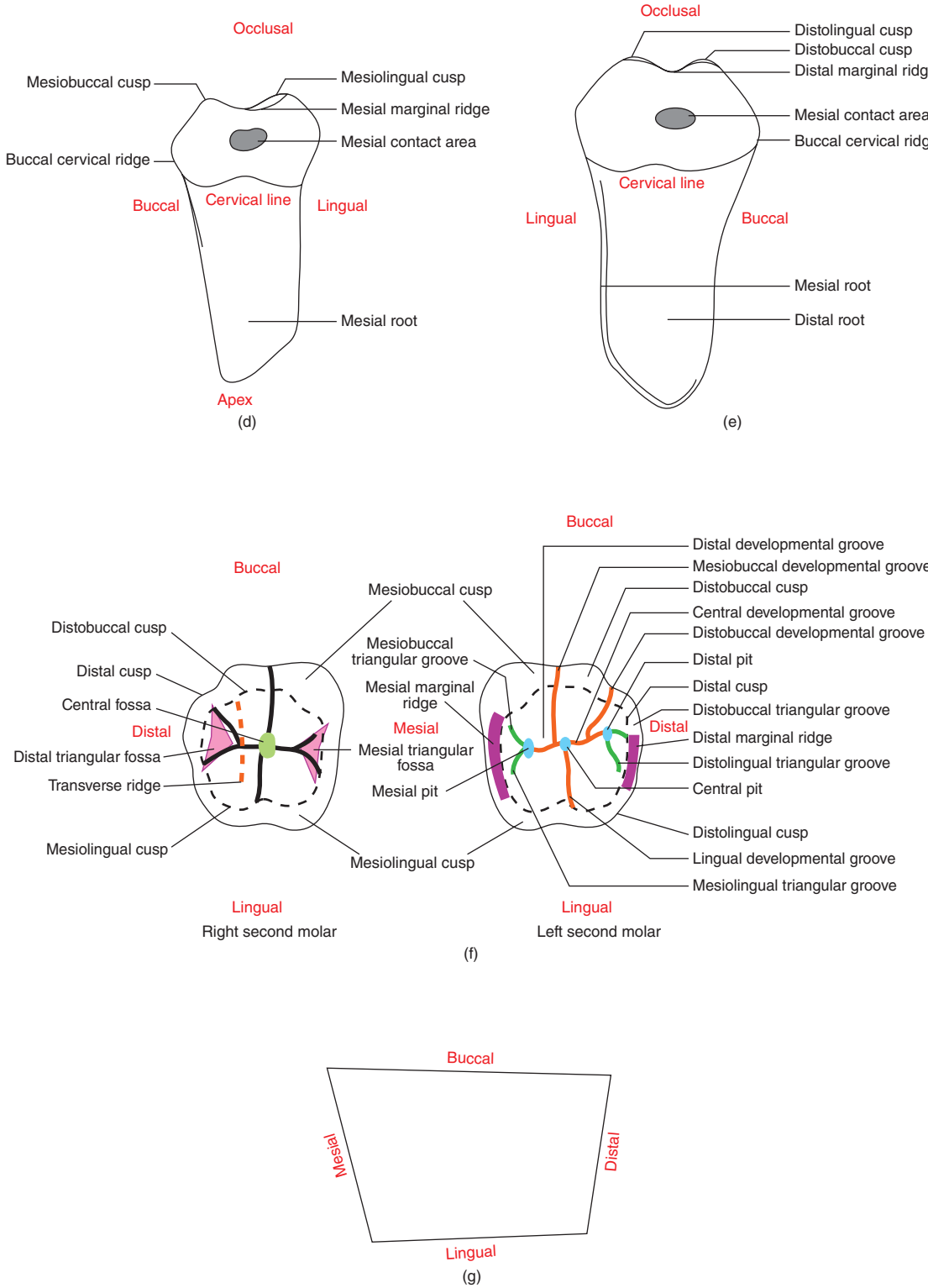


Figure 13.10 (*Continued*) (d) Mesial aspect and (e) distal aspect. (f) Deciduous mandibular right and left second molars—occlusal aspect and (g) deciduous mandibular right second molar—occlusal outline.

5. **Outlines of the roots:** The mesial outline of the mesial root is concave in the cervical third and convex in the middle and apical third. The distal outline of the mesial root is concave from the point of furcation up to the blunt apex. The mesial outline of the distal root is concave from the point of furcation up to the sharp apex. The distal outline of the distal root is concave in the cervical third and straight in the middle and apical third. The roots are widely placed and flare beyond the mesiodistal outline of the crown to provide space for the development of the permanent mandibular second premolar.
6. **Buccal surface of the roots:** The buccal surface is flat and smooth without any developmental depressions or grooves in both the roots.

Lingual Aspect (Fig. 13.10c)

1. **Shape of the crown:** The shape of the crown is similar to that in the buccal aspect. The mesiodistal width of the crown in this aspect is comparatively less than that of the buccal aspect because of the palatal convergence of the mesial side of the crown. The mesial half of the crown is at a higher level than the distal half and so it appears as if the crown is tilted distally. The height of contour is present in the middle third of the crown.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline of the crown is similar to that of the buccal aspect.
   (b) *Distal outline:* The distal outline of the crown is similar to that of the buccal aspect.
   (c) *Cervical outline:* The cervical outline is straight in this aspect.
   (d) *Occlusal outline:* The occlusal outline is not regular but appears scalloped. Mesiolingual cusp and distolingual cusp are seen separated by a lingual developmental groove. Part of the mesiobuccal, distobuccal and distal cusps is also seen. The mesial marginal ridge is well developed and occlusally placed and it appears as another cusp in the lingual aspect.
3. **Lingual surface of the crown:** The lingual surface of the crown is smoothly convex mesiodistally and cervico-occlusally. The cervical ridge is not that prominent as in the buccal surface. Mesiolingual and distolingual cusps are seen in this aspect, and they are of the same dimensions. The two lingual cusps are separated by the lingual developmental groove.
4. **Shape of the roots:** Two roots are present: mesial and distal. The roots are twice the length of the crown but narrow mesiodistally. The mesial root is longer and wider than the distal root ending in a blunt apex. The level of bifurcation of the roots is near the cervix and the root trunk is either small or indistinct.
5. **Outlines of the roots:** The mesial and distal outlines of the mesial and distal roots are similar to those of the buccal aspect.
6. **Lingual surface of the roots:** The lingual surface is flat and smooth without any developmental depressions or grooves in both the roots.

Mesial Aspect (Fig. 13.10d)

1. **Shape of the crown:** The mesial aspect is rhomboidal in outline and is tilted lingually. The buccolingual width of the crown is more than the cervico-occlusal width. The buccolingual width of the crown at the cervical third is more than that at the occlusal third. The greater buccolingual width at the cervical third is due to the prominent buccal cervical ridge which makes the crown appear bulbous.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is flat up to the mesiobuccal cusp tip. The height of contour is at the cervical third of the crown. The buccal outline is longer and lingually inclined than the lingual outline.
   (b) *Lingual outline:* From the cervix, the lingual outline is convex in the cervical and the middle third and then becomes flat up to the mesiolingual cusp tip. The height of contour is at the middle third of the crown. The lingual outline is shorter than the buccal outline, is lingually inclined and extends beyond the lingual outline of the root.
   (c) *Cervical outline:* The cervical outline is convex towards the occlusal surface.
   (d) *Occlusal outline:* The occlusal outline is not regular and two cusps—mesiobuccal and mesiolingual—are seen with a

prominent mesial marginal ridge. The mesiobuccal cusp is within the buccal outline of the root and the mesiolingual cusp is outside the lingual outline of the root. The mesiolingual cusp is longer and sharper than the mesiobuccal cusp. The occlusal area is narrow buccolingually because of the marked convergence of the buccal and lingual surfaces of the crown. The mesial marginal ridge is well developed, wide and more occlusally placed.

3. **Mesial surface of the crown:** The mesial surface is flat except in the mesial contact area where it is slightly convex.
4. **Mesial contact area:** The mesial contact area is flat and is situated in the middle one-third of the crown.
5. **Shape of the root:** Only the mesial root is seen in this aspect and it is square shaped. The mesial root is broad in the cervical and middle third and tapers in the apical third ending in a broad and blunt apex.
6. **Outlines of the root:** The buccal and lingual outlines of the mesial root are straight from the cervical line up to the middle third and then taper up to the broad apex.
7. **Mesial surface of the root:** The mesial surface is flat and a deep developmental depression is seen on the mesial surface of the root extending from the cervical line up to the apical third.

Distal Aspect (Fig. 13.10e)

1. **Shape of the crown:** The buccolingual width of the crown is more than the cervico-occlusal width. The buccolingual width of the crown at the cervical third is more than that at the occlusal third. The buccal cervical ridge is not prominent in this aspect. The buccolingual width is less in this aspect than the mesial aspect because of the distal convergence of the buccal aspect. Because of this distal convergence, part of the buccal surface is also seen in this aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* From the cementoenamel junction or the cervix, the buccal outline is convex in the cervical third, and from the height of contour, it is flat up to the distal cusp tip. The height of contour is at the cervical third.
   (b) *Lingual outline:* From the cervix, the lingual outline is convex in the cervical and the middle third and then becomes flat up to the distolingual cusp tip. The height of contour is at the middle third of the crown. The lingual outline is shorter than the buccal outline, is lingually inclined and is in line with the lingual outline of the distal root.
   (c) *Cervical outline:* The cervical line is regular and is convex towards the occlusal aspect.
   (d) *Occlusal outline:* The occlusal outline is not regular and two cusps are seen—distal and distolingual cusps—with a distal marginal ridge. The two distal cusps are within the confines of the distal root outline. The distal marginal ridge is not that prominent and is thin and curves cervically and so part of the occlusal surface can be seen. The occlusal area is narrow buccolingually as seen in the distal aspect.
3. **Distal surface of the crown:** The distal surface is convex with the height of contour in the distal contact area.
4. **Distal contact area:** The distal contact area is situated in the middle one-third of the crown.
5. **Shape of the roots:** The distal root and part of the mesial root are seen in this aspect. The distal root is narrow and rounded ending in a blunt apex.
6. **Outlines of the roots:** The buccal and lingual outlines of the distal root are straight from the cervical line up to the apex.
7. **Distal surface of the roots:** The distal surface is flat without any developmental depressions or grooves in both the roots.

Occlusal Aspect (Fig. 13.10f)

1. **Shape of the crown:** The occlusal outline is trapezoidal, formed by the buccal surface, lingual surface, and mesial and distal marginal ridges (**Fig. 13.10g**). The mesiodistal width is more than the buccolingual width. The distal and lingual convergence of the crown is seen in the occlusal aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is broader than the lingual outline and it is irregular.

(b) *Lingual outline:* The lingual outline is narrower than the buccal outline because of the lingual tapering of the crown.

(c) *Mesial and distal outlines:* The mesial outline is broader than the distal outline due to the distal convergence of the crown. The mesial outline is formed by the mesial marginal ridge and the distal outline is formed by the distal marginal ridge.

3. **Occlusal surface of the crown:** The occlusal surface is irregular with well-developed cusps, ridges and grooves. The grooves serve as escapeways during the process of mastication.

(a) *Cusps:* Five cusps are seen—mesiobuccal, distobuccal, distal, mesiolingual and distolingual cusps. Three cusps are seen in the buccal aspect and two cusps are seen in the lingual aspect. The mesiolingual cusp is the longest and sharpest cusp of the four cusps. The mesiolingual and distolingual cusps are the only functional cusps which help during the process of mastication.

(b) *Ridges*

- In all the cusps, the *triangular ridge* is prominent and extends from the five cusp tips to the central fossa.
- The *transverse ridge* is found extending between the mesiobuccal and the mesiolingual cusps.
- The *mesial marginal ridge* is well developed and forms the mesial boundary of the occlusal aspect. It is longer than the distal marginal ridge and is occlusally placed, and sometimes a mesial marginal developmental groove is seen crossing the mesial marginal ridge.
- The *distal marginal ridge* forms the distal boundary. It is thinner, shorter and not as well developed as the mesial marginal ridge and is cervically placed.

(c) *Fossae*

- There is one major fossa and two minor fossae in the occlusal surface.
- The major fossa, the *central fossa,* is located in the centre of the occlusal surface.
- The *mesial triangular fossa* is one of the two minor fossae, located distal to the mesial marginal ridge on the occlusal surface, and it is deeper.
- The *distal triangular fossa* is the other minor fossa which is located mesial to the distal marginal ridge on the occlusal surface and it is shallow.

(d) *Pits*

- The *central pit* is located in the deeper part of the central fossa.
- The *mesial pit* is located in the deeper part of the mesial triangular fossa.
- The *distal pit* is located in the deeper part of the distal triangular fossa.

(e) *Developmental grooves*

- The *central groove* starts from the mesial pit and extends in the distal direction up to the central pit, thereby separating the mesiobuccal and mesiolingual cusps, and then extends from the central pit towards the distal direction to end in the distal pit, thereby dividing the distobuccal and distal cusps from the distolingual cusp.
- The *mesiobuccal groove* starts from the mesial part of the central groove and extends in a buccal direction between the mesiobuccal and distobuccal cusps and extends onto the buccal surface of the crown.
- The *distobuccal groove* starts from the distal part of the central groove and extends in a distobuccal direction between the distobuccal and distal cusps and further extends onto the buccal surface of the crown.
- The *lingual groove* starts from the central pit and extends in a lingual direction between the two lingual cusps and then extends onto the lingual surface.

(f) *Supplemental grooves*

- Two supplemental grooves are seen radiating from the mesial pit: one in the buccal direction, called the *mesiobuccal triangular groove*, and one in the palatal direction, called the *mesiolingual triangular groove*. Sometimes, a mesial marginal developmental groove extends from the mesial pit and crosses the mesial marginal ridge.

- Two supplemental grooves are seen radiating from the distal pit: one in the buccal direction, called the *distobuccal triangular groove*, and the other in the lingual direction, called the *distolingual triangular groove*.

CLINICAL CONSIDERATIONS

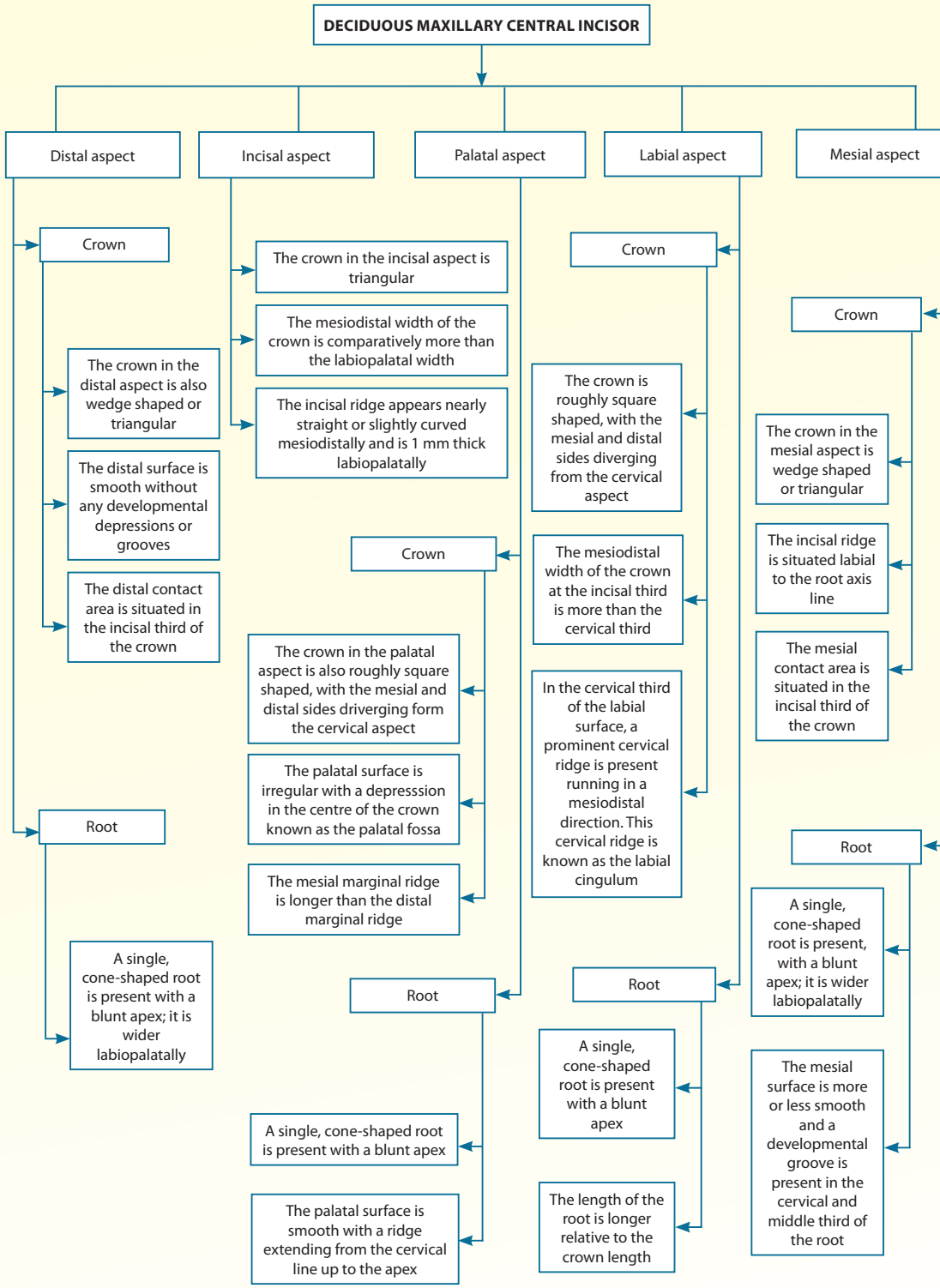
1. The high peak for dental caries occurs when the children are in their developmental period.
2. Early childhood caries, also known as *baby bottle caries, baby bottle tooth decay* and *bottle rot*, is a syndrome characterized by severe decay in the teeth of infants or young children caused by children going to bed with a bottle filled with anything but water (e.g. milk or juice). It usually affects children between the ages of 1 and 2 years.
3. The premature loss of primary teeth because of caries may lead to lack of space for the permanent dentition and can result in *malocclusion*.
4. Periapical infection of the deciduous teeth can cause enamel hypoplasia of the permanent teeth called *Turner's hypoplasia*.
5. Sometimes, the deciduous teeth may erupt prematurely in the oral cavity and are called *natal* and *neonatal teeth*. Natal teeth are the teeth which are present in the oral cavity of the child at birth while neonatal teeth are those teeth which erupt within 30 days after birth. The deciduous mandibular central incisors are the most common teeth to erupt prematurely.
6. Sometimes, the deciduous mandibular second molar does not undergo exfoliation and is retained in the adult life and appears to be below the level of occlusion and is known as *submerged teeth*.

Key Points

1. The primary or deciduous dentition is the first set of dentition in the lifetime of humans and the term *deciduous* comes from a Latin word which means 'fall off'.
2. The deciduous dentition plays an important part in the growth and development of the child.
3. The maxillary and mandibular central incisors are the only teeth where the two mesial surfaces of the adjacent teeth contact each other.
4. The cervical ridge is prominent in the labial surface of the incisors and is called the labial cingulum.
5. Instead of an incisal ridge, the deciduous canines have a well-developed cusp called the canine cusp and hence are also called *cuspids*.
6. The deciduous maxillary molars are larger than the deciduous maxillary anterior teeth in all aspects and have three roots.
7. The cervical ridge is prominent in the buccal surface of the molars and is called the *buccal cingulum*.
8. The deciduous maxillary first molar is uniquely shaped and resembles an intermediate between the permanent maxillary premolar and molar.
9. Two occlusal patterns are seen in the deciduous maxillary first molar: four-cusp type and three-cusp type.
10. The deciduous maxillary second molar resembles the permanent maxillary first molar and has five cusps: mesiobuccal, distobuccal, mesiopalatal and distopalatal cusps and the cusp of Carabelli.
11. The deciduous mandibular first molar is unique in shape and does not resemble any other tooth in the human dentition.
12. The deciduous mandibular second molar resembles the permanent mandibular first molar.
13. The roots of the deciduous molars are widely placed and flare beyond the mesiodistal and buccopalatal/lingual outline of the crown to provide space for development of permanent premolar crowns.
14. The chronology of human dentition refers to the developmental timeline of teeth.

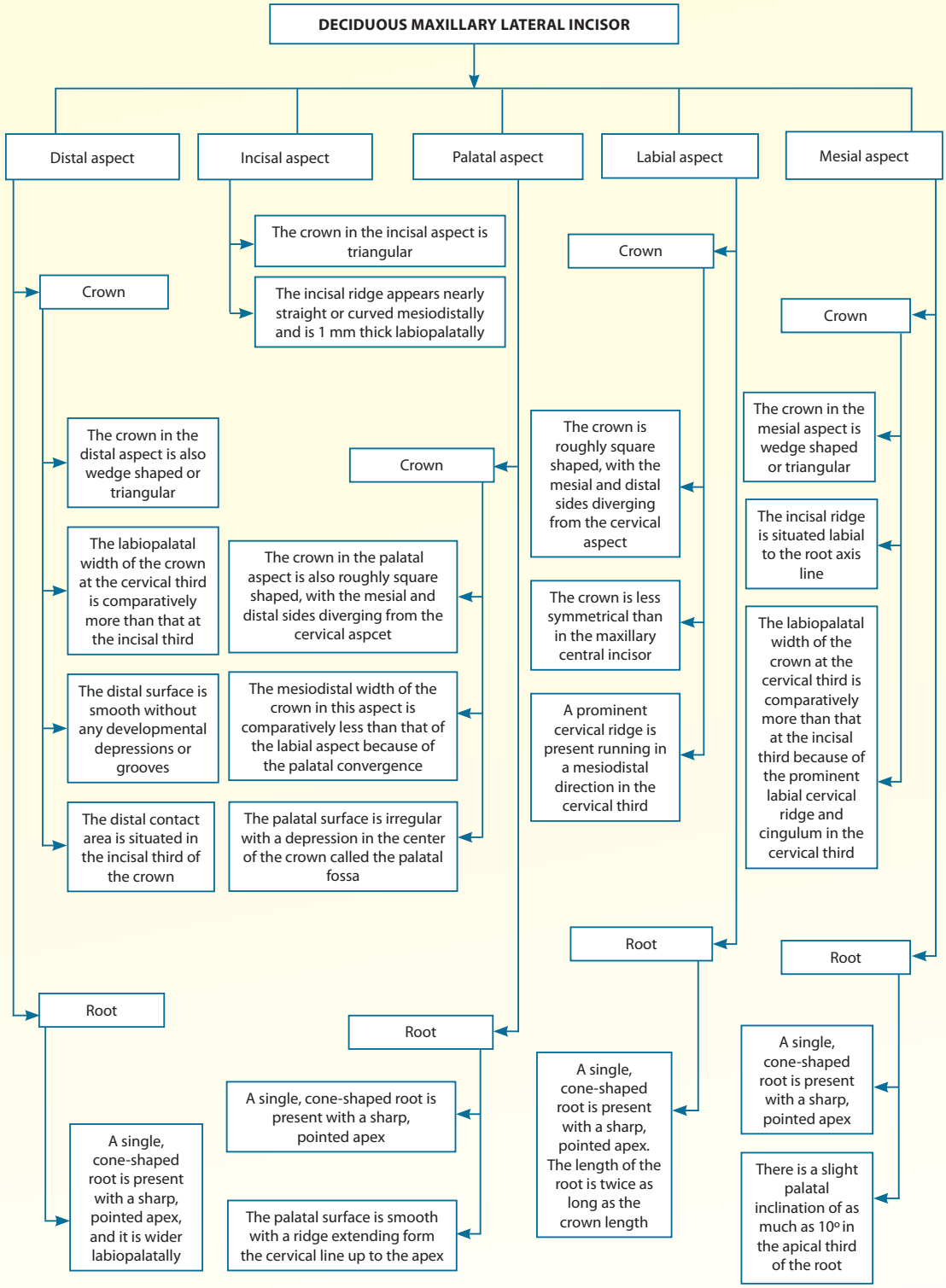
Mind Maps

Mind Map 1

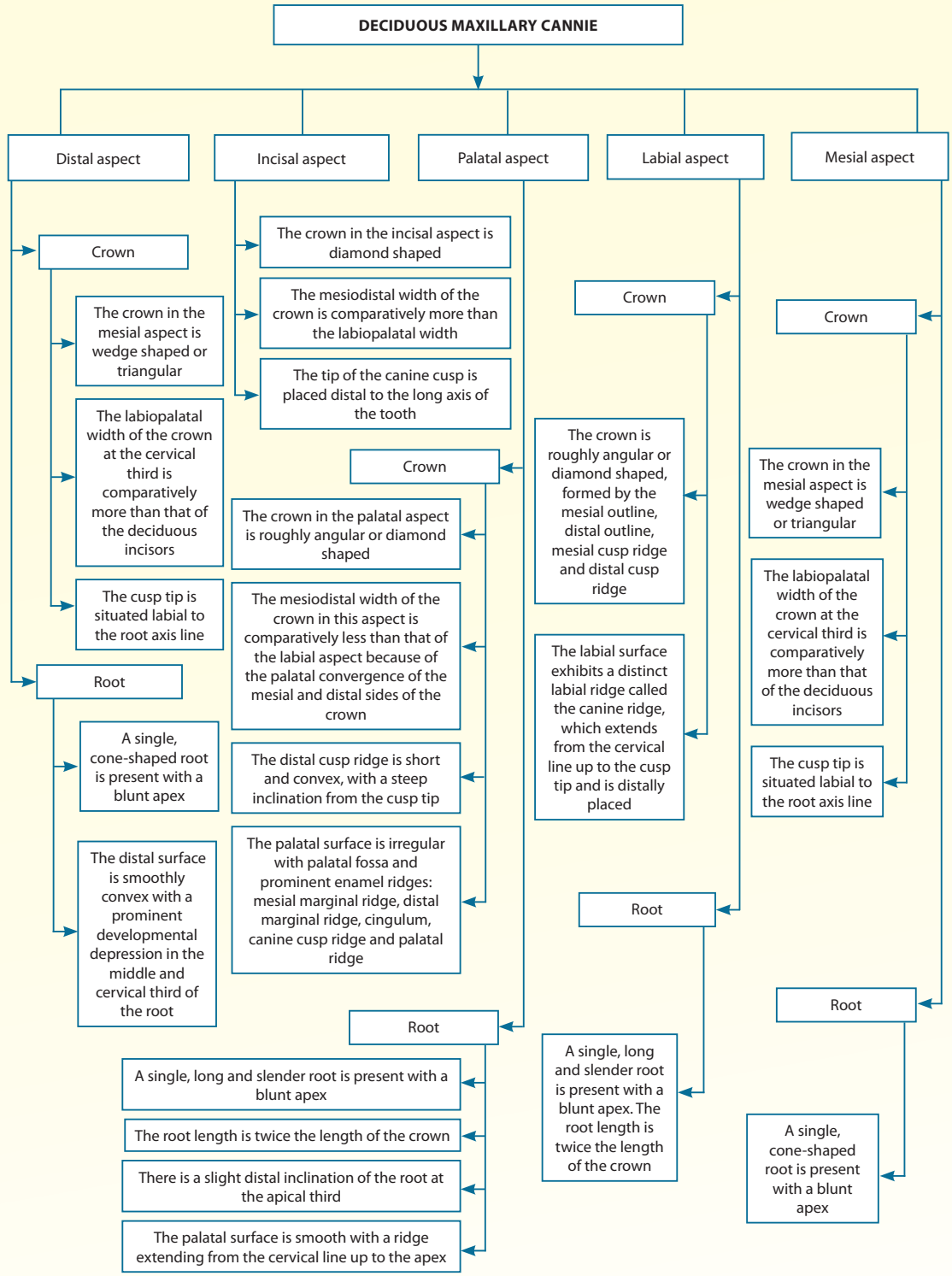


SECTION II

Mind Map 2

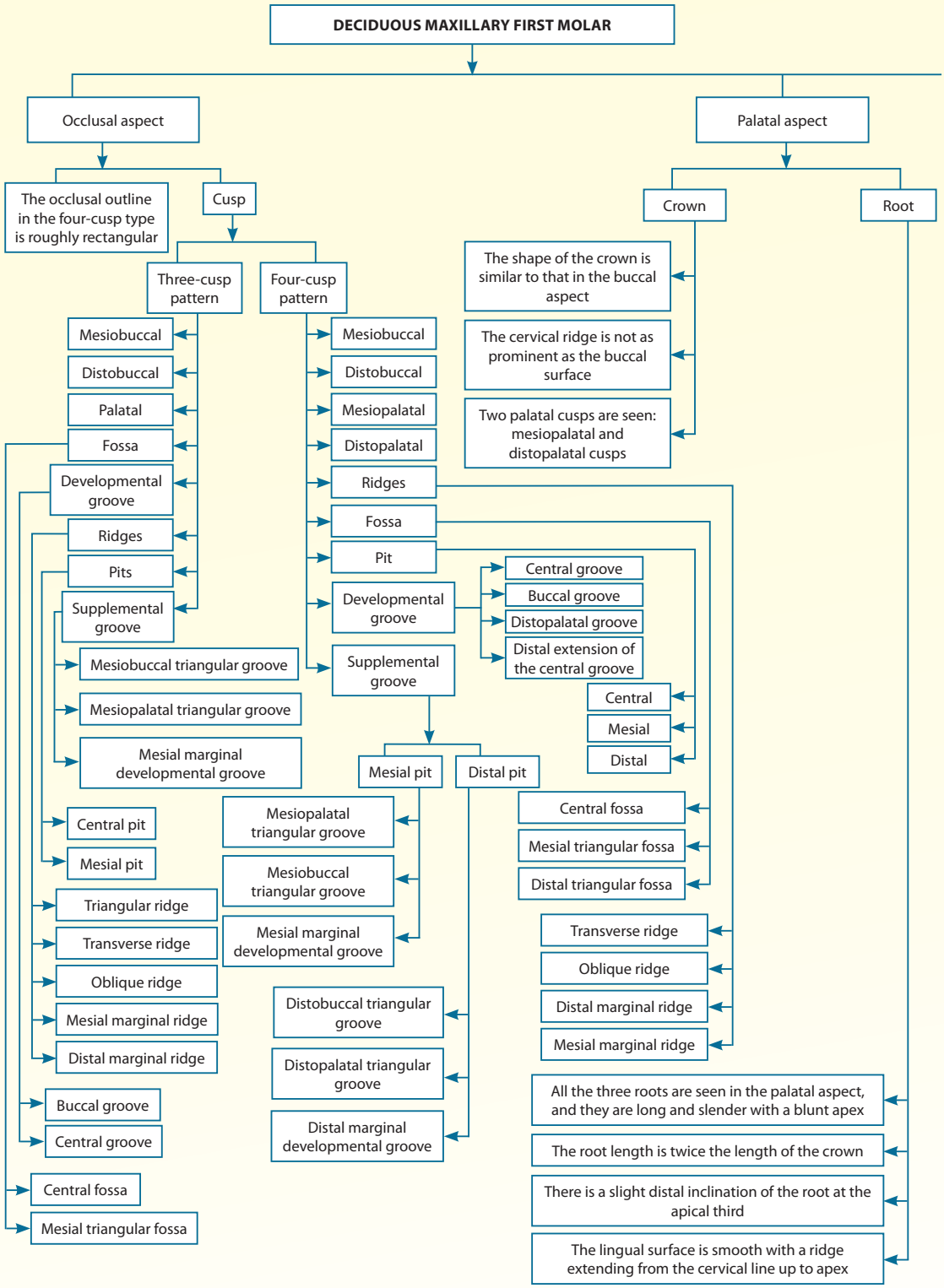

DECIDUOUS MAXILLARY LATERAL INCISOR
Distal aspect
Incisal aspect
Palatal aspect
Labial aspect
Mesial aspect
Crown
The crown in the distal aspect is also wedge shaped or triangular
The labiopalatal width of the crown at the cervical third is comparatively more than that at the incisal third
The distal surface is smooth without any developmental depressions or grooves
The distal contact area is situated in the incisal third of the crown
Root
A single, cone-shaped root is present with a sharp, pointed apex, and it is wider labiopalatally
The crown in the incisal aspect is triangular
The incisal ridge appears nearly straight or curved mesiodistally and is 1 mm thick labiopalatally
Crown
The crown in the palatal aspect is also roughly square shaped, with the mesial and distal sides diverging from the cervical aspcet
The mesiodistal width of the crown in this aspect is comparatively less than that of the labial aspect because of the palatal convergence
The palatal surface is irregular with a depression in the center of the crown called the palatal fossa
Root
A single, cone-shaped root is present with a sharp, pointed apex
The palatal surface is smooth with a ridge extending form the cervical line up to the apex
Crown
The crown is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect
The crown is less symmetrical than in the maxillary central incisor
A prominent cervical ridge is present running in a mesiodistal direction in the cervical third
Root
A single, cone-shaped root is present with a sharp, pointed apex. The length of the root is twice as long as the crown length
Crown
The crown in the mesial aspect is wedge shaped or triangular
The incisal ridge is situated labial to the root axis line
The labiopalatal width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third
Root
A single, cone-shaped root is present with a sharp, pointed apex
There is a slight palatal inclination of as much as 10° in the apical third of the root

Mind Map 3



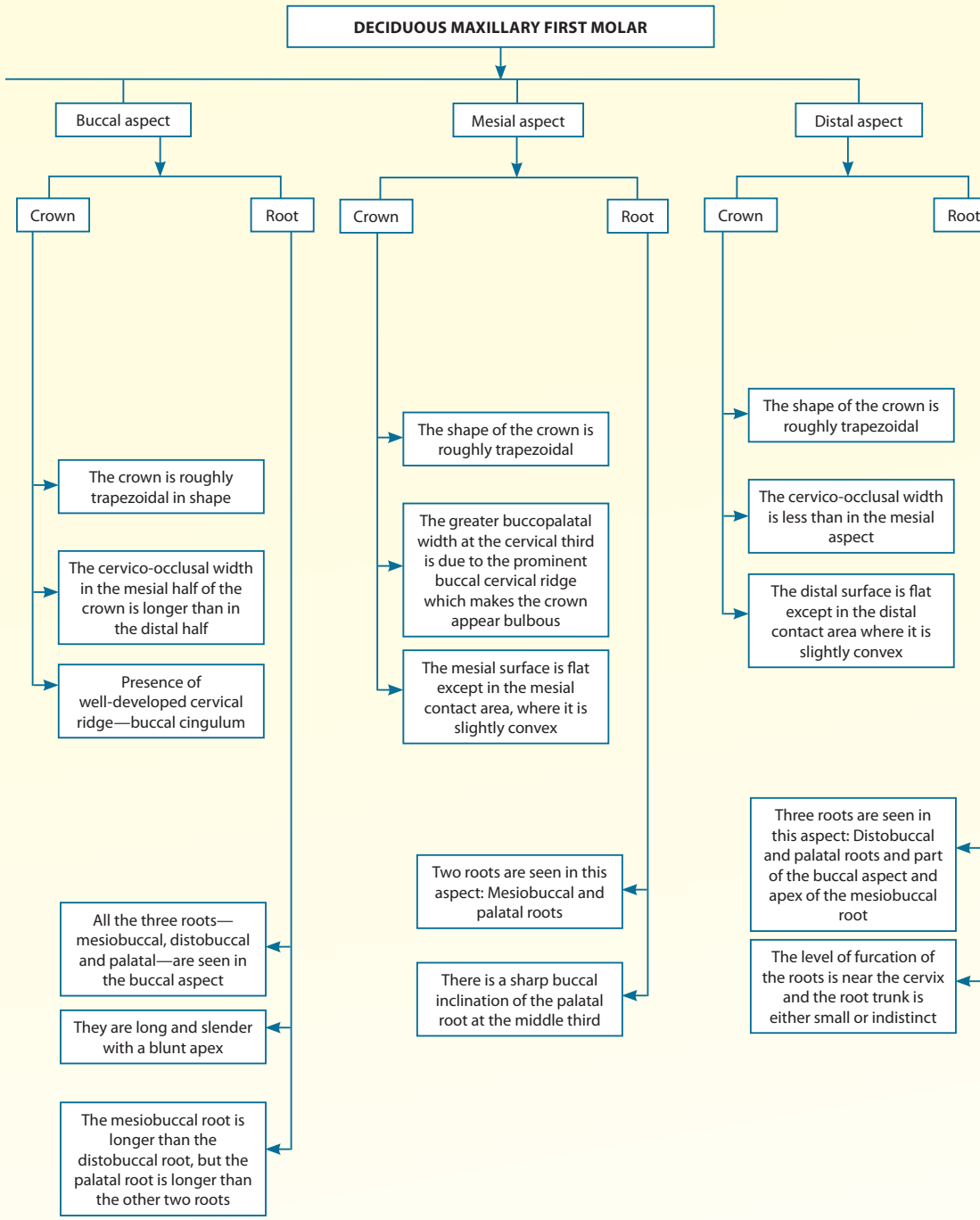
SECTION II

Mind Map 4

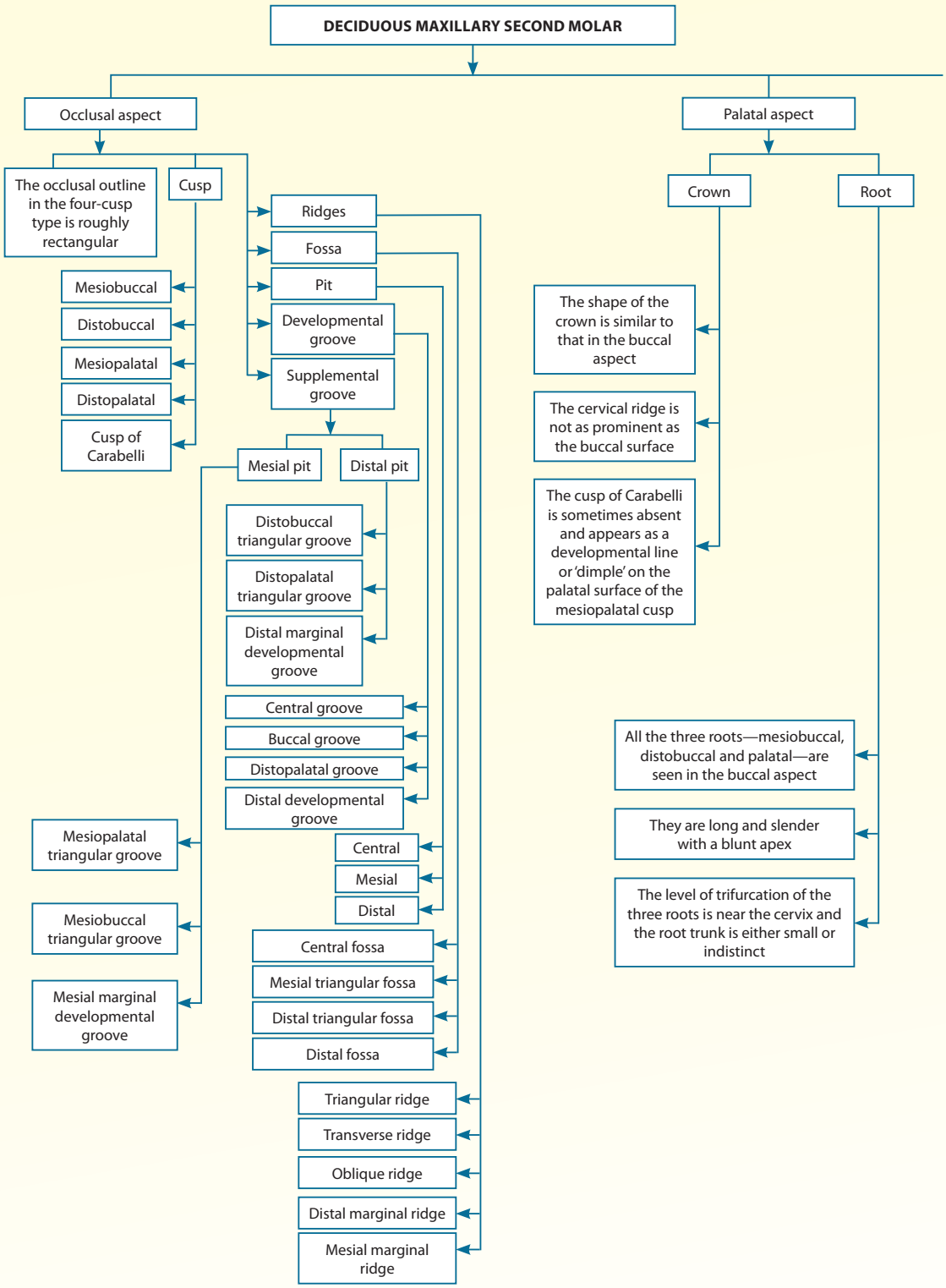


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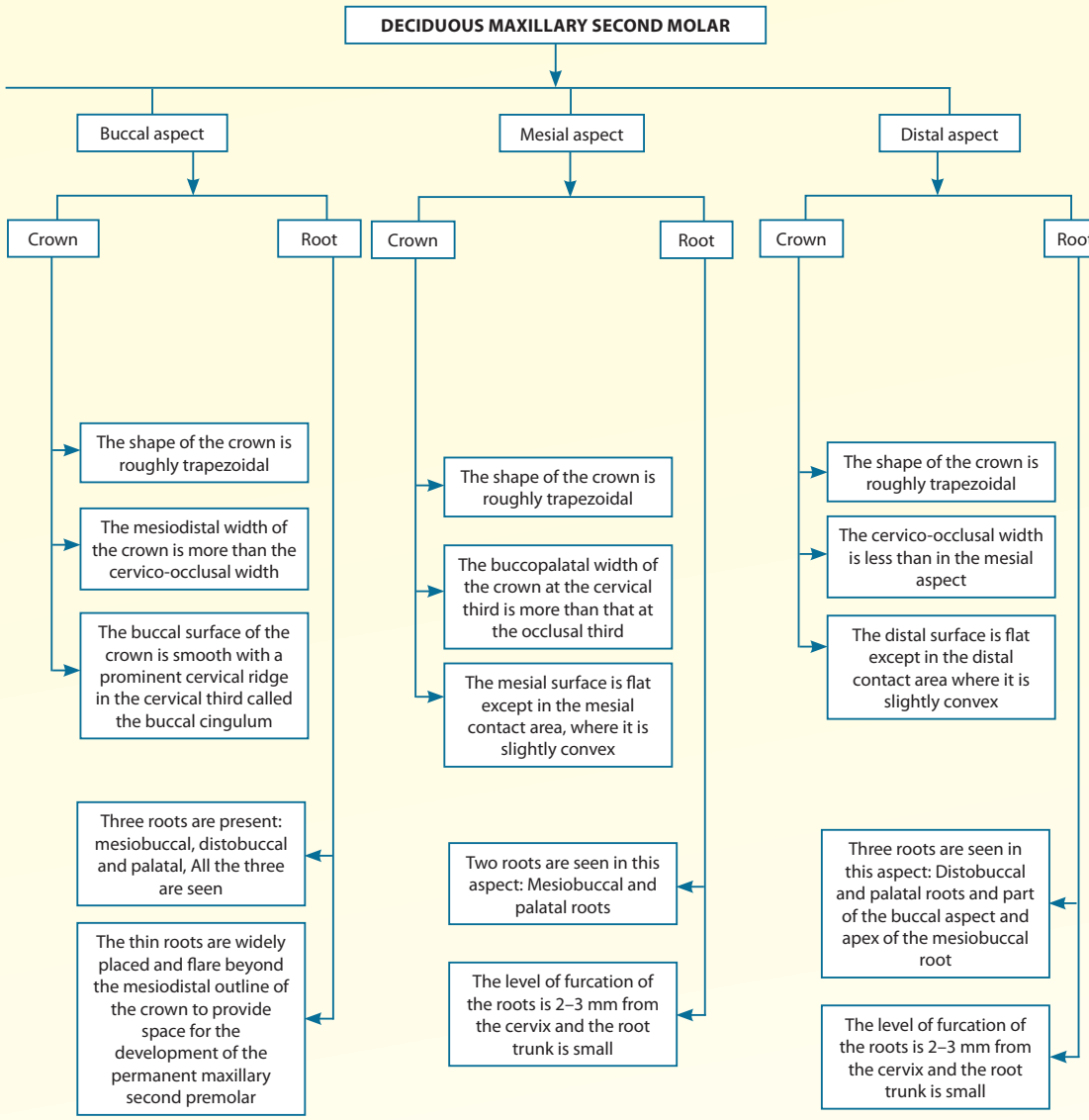

DECIDUOUS MAXILLARY FIRST MOLAR
Buccal aspect
Mesial aspect
Distal aspect
Crown
Root
Crown
Root
Crown
Root
The crown is roughly trapezoidal in shape
The cervico-occlusal width in the mesial half of the crown is longer than in the distal half
Presence of well-developed cervical ridge—buccal cingulum
All the three roots—mesiobuccal, distobuccal and palatal—are seen in the buccal aspect
They are long and slender with a blunt apex
The mesiobuccal root is longer than the distobuccal root, but the palatal root is longer than the other two roots
The shape of the crown is roughly trapezoidal
The greater buccopalatal width at the cervical third is due to the prominent buccal cervical ridge which makes the crown appear bulbous
The mesial surface is flat except in the mesial contact area, where it is slightly convex
Two roots are seen in this aspect: Mesiobuccal and palatal roots
There is a sharp buccal inclination of the palatal root at the middle third
The shape of the crown is roughly trapezoidal
The cervico-occlusal width is less than in the mesial aspect
The distal surface is flat except in the distal contact area where it is slightly convex
Three roots are seen in this aspect: Distobuccal and palatal roots and part of the buccal aspect and apex of the mesiobuccal root
The level of furcation of the roots is near the cervix and the root trunk is either small or indistinct

Mind Map 5

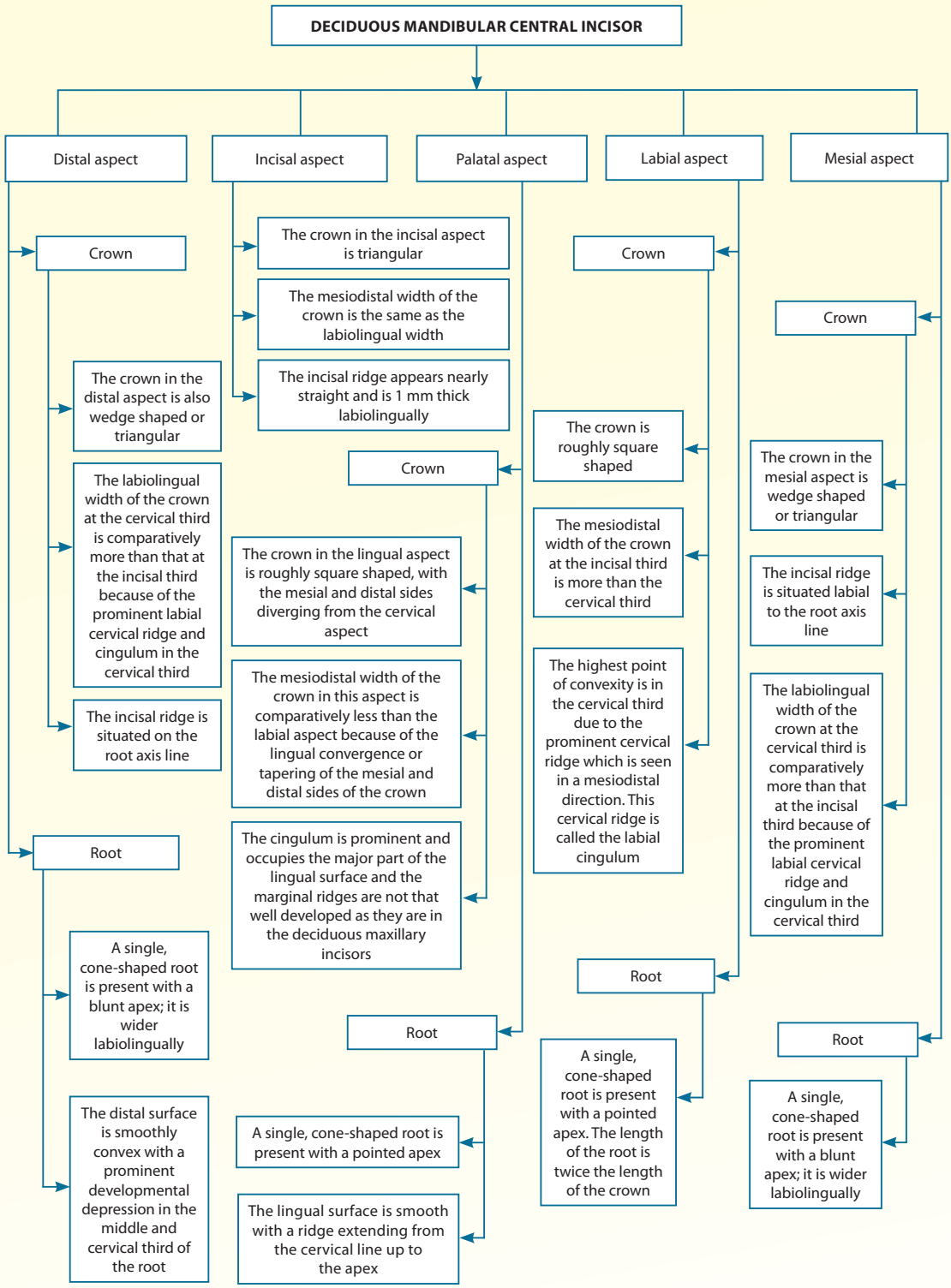


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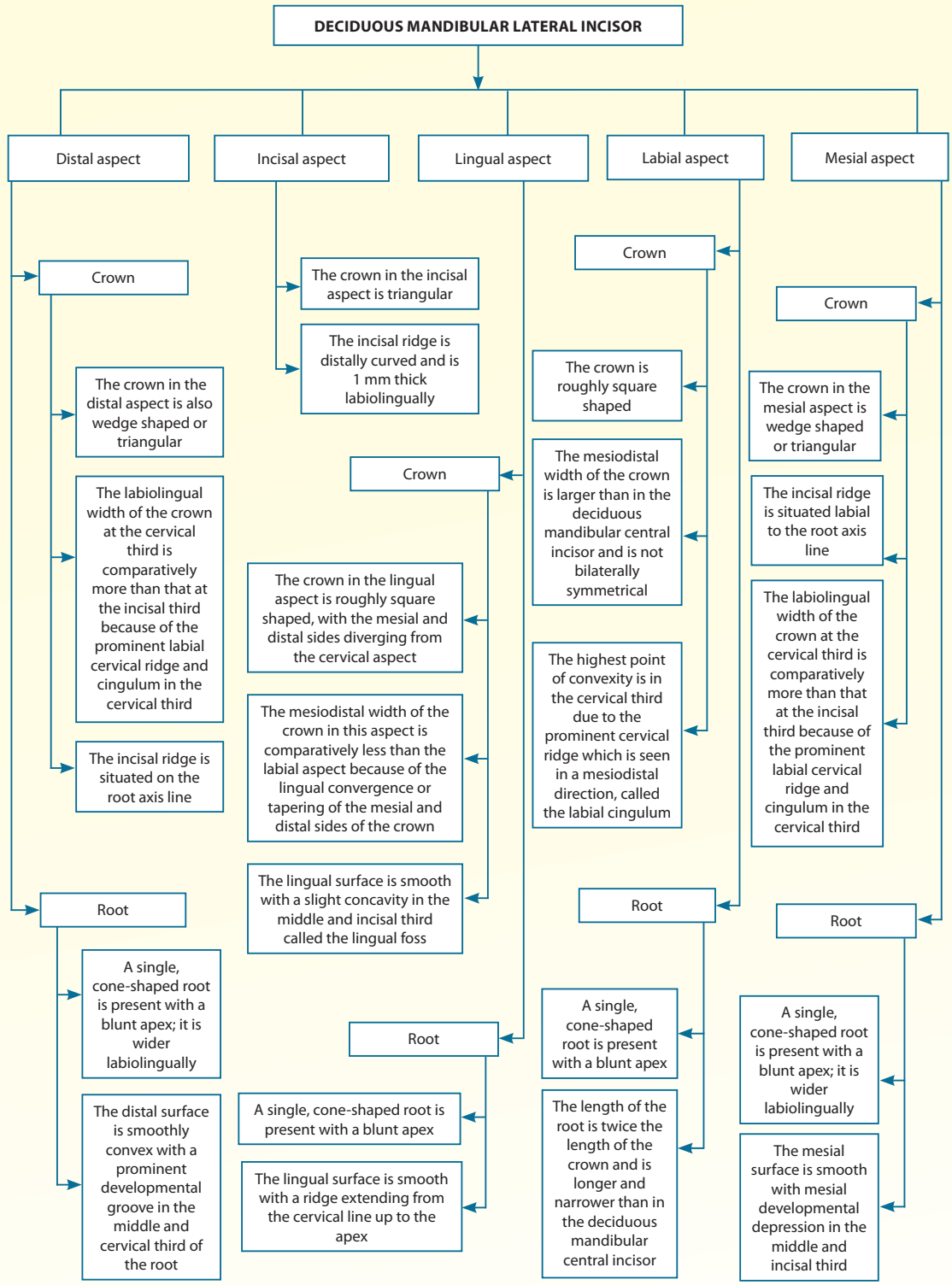
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DECIDUOUS MAXILLARY SECOND MOLAR
Buccal aspect
Mesial aspect
Distal aspect
Crown
Root
Crown
Root
Crown
Root
The shape of the crown is roughly trapezoidal
The mesiodistal width of the crown is more than the cervico-occlusal width
The buccal surface of the crown is smooth with a prominent cervical ridge in the cervical third called the buccal cingulum
Three roots are present: mesiobuccal, distobuccal and palatal, All the three are seen
The thin roots are widely placed and flare beyond the mesiodistal outline of the crown to provide space for the development of the permanent maxillary second premolar
The shape of the crown is roughly trapezoidal
The buccopalatal width of the crown at the cervical third is more than that at the occlusal third
The mesial surface is flat except in the mesial contact area, where it is slightly convex
Two roots are seen in this aspect: Mesiobuccal and palatal roots
The level of furcation of the roots is 2–3 mm from the cervix and the root trunk is small
The shape of the crown is roughly trapezoidal
The cervico-occlusal width is less than in the mesial aspect
The distal surface is flat except in the distal contact area where it is slightly convex
Three roots are seen in this aspect: Distobuccal and palatal roots and part of the buccal aspect and apex of the mesiobuccal root
The level of furcation of the roots is 2–3 mm from the cervix and the root trunk is small

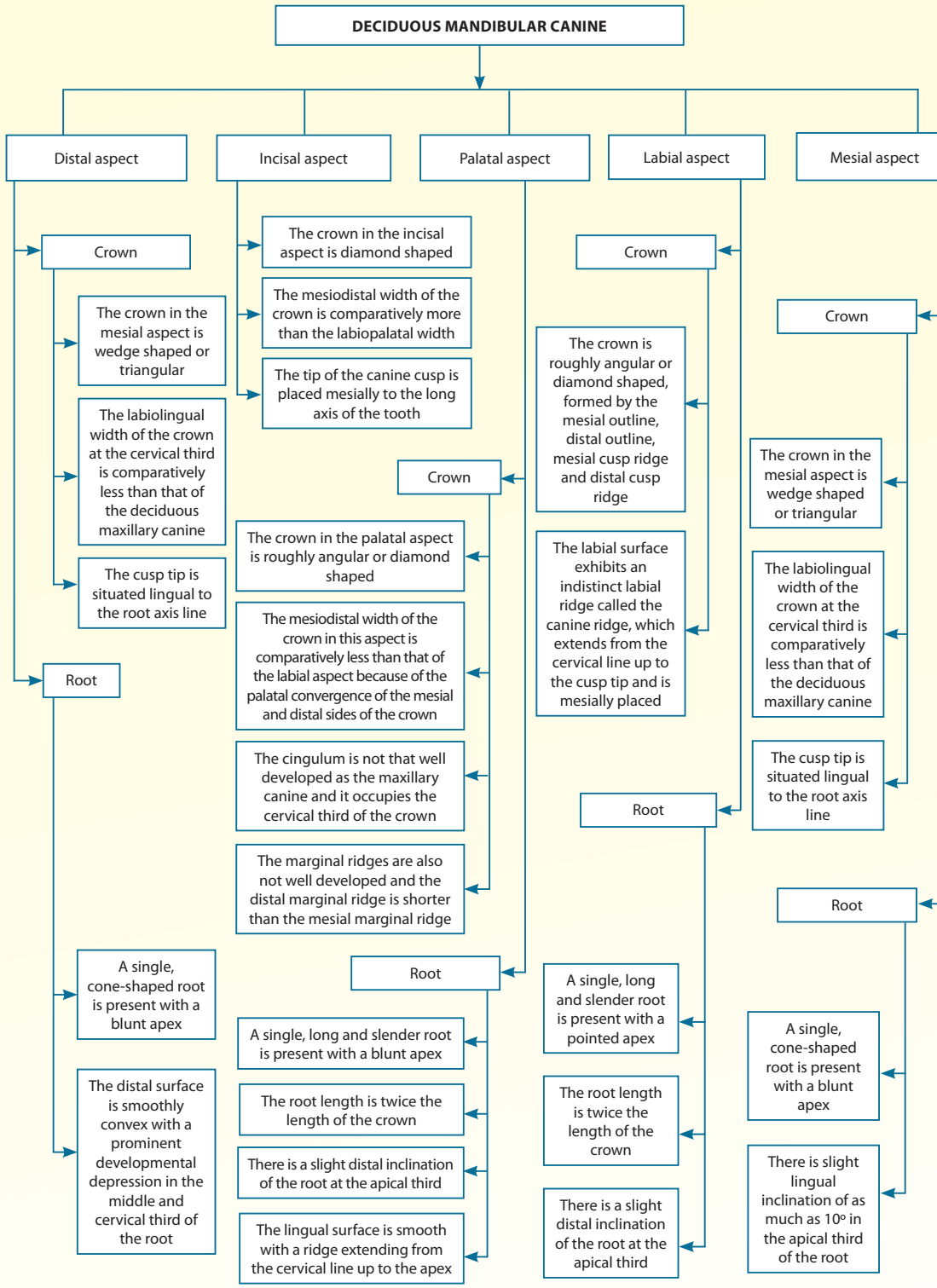
Mind Map 6


DECIDUOUS MANDIBULAR CENTRAL INCISOR
Distal aspect
Incisal aspect
Palatal aspect
Labial aspect
Mesial aspect
Crown
The crown in the distal aspect is also wedge shaped or triangular
The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third
The incisal ridge is situated on the root axis line
Root
A single, cone-shaped root is present with a blunt apex; it is wider labiolingually
The distal surface is smoothly convex with a prominent developmental depression in the middle and cervical third of the root
The crown in the incisal aspect is triangular
The mesiodistal width of the crown is the same as the labiolingual width
The incisal ridge appears nearly straight and is 1 mm thick labiolingually
Crown
The crown in the lingual aspect is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect
The mesiodistal width of the crown in this aspect is comparatively less than the labial aspect because of the lingual convergence or tapering of the mesial and distal sides of the crown
The cingulum is prominent and occupies the major part of the lingual surface and the marginal ridges are not that well developed as they are in the deciduous maxillary incisors
Root
A single, cone-shaped root is present with a pointed apex
The lingual surface is smooth with a ridge extending from the cervical line up to the apex
Crown
The crown is roughly square shaped
The mesiodistal width of the crown at the incisal third is more than the cervical third
The highest point of convexity is in the cervical third due to the prominent cervical ridge which is seen in a mesiodistal direction. This cervical ridge is called the labial cingulum
Root
A single, cone-shaped root is present with a pointed apex. The length of the root is twice the length of the crown
Crown
The crown in the mesial aspect is wedge shaped or triangular
The incisal ridge is situated labial to the root axis line
The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third
Root
A single, cone-shaped root is present with a blunt apex; it is wider labiolingually

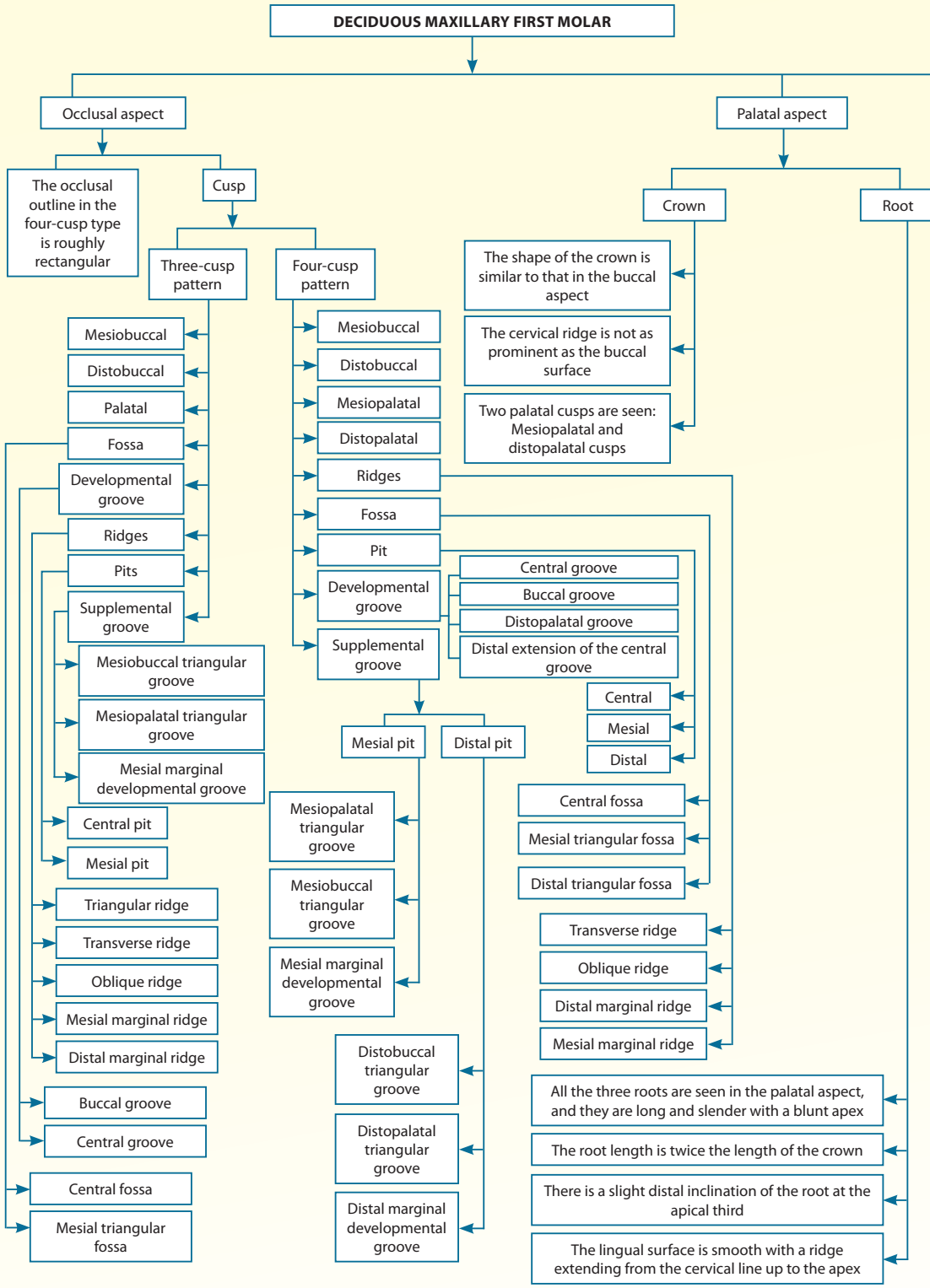
Mind Map 7


DECIDUOUS MANDIBULAR LATERAL INCISOR
Distal aspect
Incisal aspect
Lingual aspect
Labial aspect
Mesial aspect
Crown
The crown in the distal aspect is also wedge shaped or triangular
The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third
The incisal ridge is situated on the root axis line
Root
A single, cone-shaped root is present with a blunt apex; it is wider labiolingually
The distal surface is smoothly convex with a prominent developmental groove in the middle and cervical third of the root
Crown
The crown in the incisal aspect is triangular
The incisal ridge is distally curved and is 1 mm thick labiolingually
Crown
The crown in the lingual aspect is roughly square shaped, with the mesial and distal sides diverging from the cervical aspect
The mesiodistal width of the crown in this aspect is comparatively less than the labial aspect because of the lingual convergence or tapering of the mesial and distal sides of the crown
The lingual surface is smooth with a slight concavity in the middle and incisal third called the lingual foss
Root
A single, cone-shaped root is present with a blunt apex
The lingual surface is smooth with a ridge extending from the cervical line up to the apex
Crown
The crown is roughly square shaped
The mesiodistal width of the crown is larger than in the deciduous mandibular central incisor and is not bilaterally symmetrical
The highest point of convexity is in the cervical third due to the prominent cervical ridge which is seen in a mesiodistal direction, called the labial cingulum
Root
A single, cone-shaped root is present with a blunt apex
The length of the root is twice the length of the crown and is longer and narrower than in the deciduous mandibular central incisor
Crown
The crown in the mesial aspect is wedge shaped or triangular
The incisal ridge is situated labial to the root axis line
The labiolingual width of the crown at the cervical third is comparatively more than that at the incisal third because of the prominent labial cervical ridge and cingulum in the cervical third
Root
A single, cone-shaped root is present with a blunt apex; it is wider labiolingually
The mesial surface is smooth with mesial developmental depression in the middle and incisal third

Mind Map 8

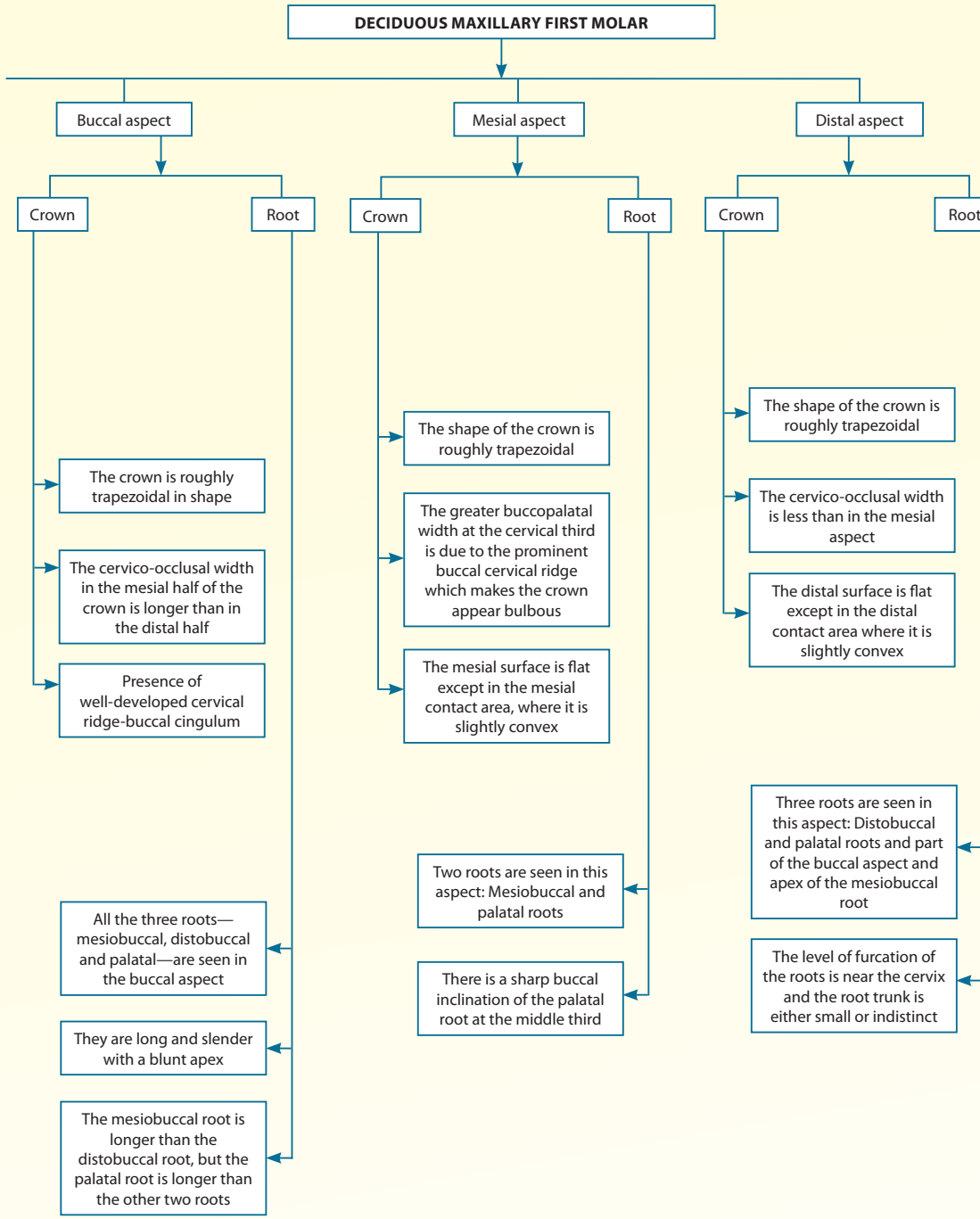

DECIDUOUS MANDIBULAR CANINE
Distal aspect
Incisal aspect
Palatal aspect
Labial aspect
Mesial aspect
Crown
The crown in the mesial aspect is wedge shaped or triangular
The labiolingual width of the crown at the cervical third is comparatively less than that of the deciduous maxillary canine
The cusp tip is situated lingual to the root axis line
Root
A single, cone-shaped root is present with a blunt apex
The distal surface is smoothly convex with a prominent developmental depression in the middle and cervical third of the root
The crown in the incisal aspect is diamond shaped
The mesiodistal width of the crown is comparatively more than the labiopalatal width
The tip of the canine cusp is placed mesially to the long axis of the tooth
Crown
The crown in the palatal aspect is roughly angular or diamond shaped
The mesiodistal width of the crown in this aspect is comparatively less than that of the labial aspect because of the palatal convergence of the mesial and distal sides of the crown
The cingulum is not that well developed as the maxillary canine and it occupies the cervical third of the crown
The marginal ridges are also not well developed and the distal marginal ridge is shorter than the mesial marginal ridge
Root
A single, long and slender root is present with a blunt apex
The root length is twice the length of the crown
There is a slight distal inclination of the root at the apical third
The lingual surface is smooth with a ridge extending from the cervical line up to the apex
Crown
The crown is roughly angular or diamond shaped, formed by the mesial outline, distal outline, mesial cusp ridge and distal cusp ridge
The labial surface exhibits an indistinct labial ridge called the canine ridge, which extends from the cervical line up to the cusp tip and is mesially placed
Root
A single, long and slender root is present with a pointed apex
The root length is twice the length of the crown
There is a slight distal inclination of the root at the apical third
Crown
The crown in the mesial aspect is wedge shaped or triangular
The labiolingual width of the crown at the cervical third is comparatively less than that of the deciduous maxillary canine
The cusp tip is situated lingual to the root axis line
Root
A single, cone-shaped root is present with a blunt apex
There is slight lingual inclination of as much as 10° in the apical third of the root

Mind Map 9

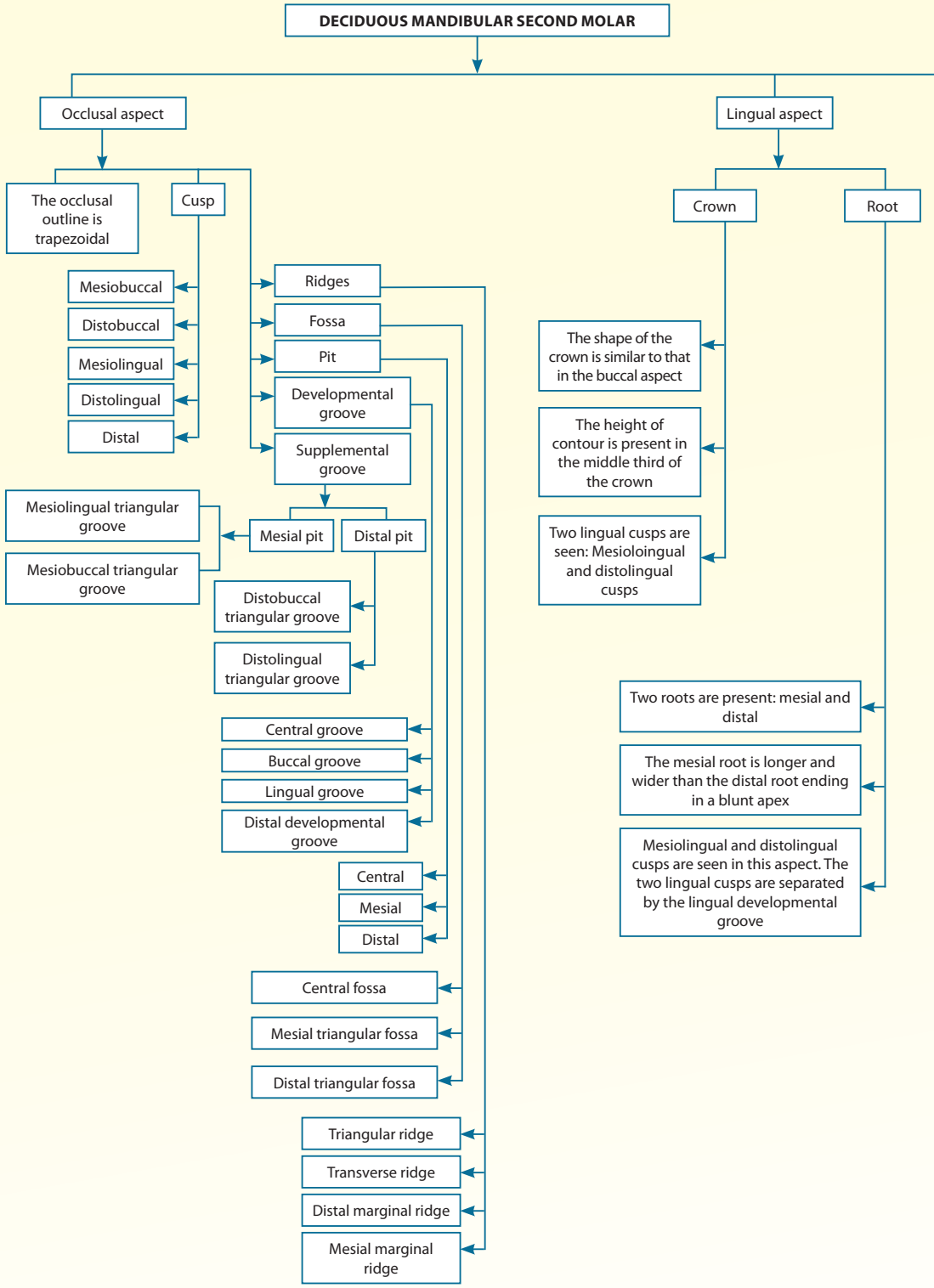


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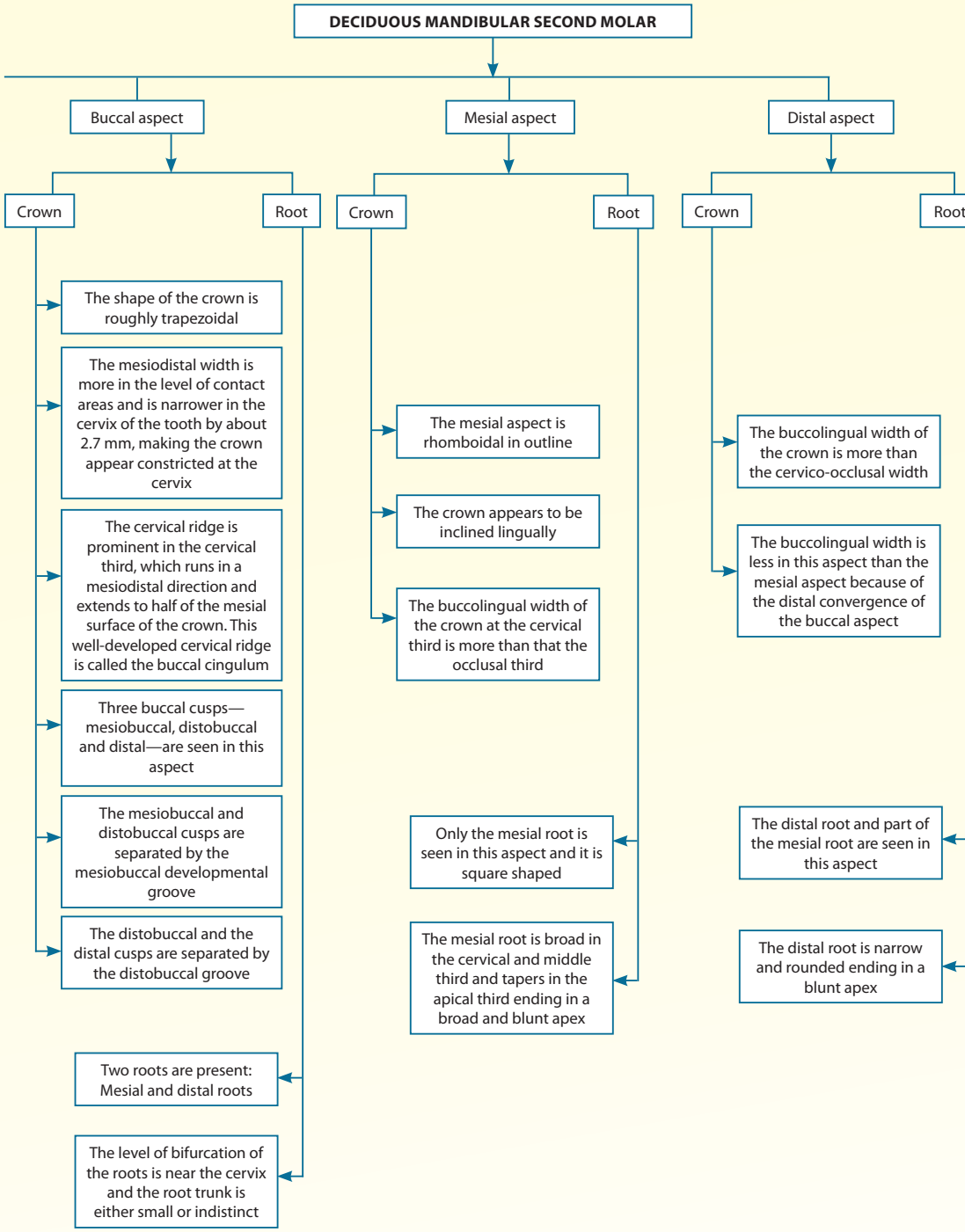

DECIDUOUS MAXILLARY FIRST MOLAR
Buccal aspect
Mesial aspect
Distal aspect
Crown
Root
Crown
Root
Crown
Root
The crown is roughly trapezoidal in shape
The cervico-occlusal width in the mesial half of the crown is longer than in the distal half
Presence of well-developed cervical ridge-buccal cingulum
All the three roots—mesiobuccal, distobuccal and palatal—are seen in the buccal aspect
They are long and slender with a blunt apex
The mesiobuccal root is longer than the distobuccal root, but the palatal root is longer than the other two roots
The shape of the crown is roughly trapezoidal
The greater buccopalatal width at the cervical third is due to the prominent buccal cervical ridge which makes the crown appear bulbous
The mesial surface is flat except in the mesial contact area, where it is slightly convex
Two roots are seen in this aspect: Mesiobuccal and palatal roots
There is a sharp buccal inclination of the palatal root at the middle third
The shape of the crown is roughly trapezoidal
The cervico-occlusal width is less than in the mesial aspect
The distal surface is flat except in the distal contact area where it is slightly convex
Three roots are seen in this aspect: Distobuccal and palatal roots and part of the buccal aspect and apex of the mesiobuccal root
The level of furcation of the roots is near the cervix and the root trunk is either small or indistinct

Mind Map 10



(*Continued*)

(*Continued*)


DECIDUOUS MANDIBULAR SECOND MOLAR
Buccal aspect
Mesial aspect
Distal aspect
Crown
Root
Crown
Root
Crown
Root
The shape of the crown is roughly trapezoidal
The mesiodistal width is more in the level of contact areas and is narrower in the cervix of the tooth by about 2.7 mm, making the crown appear constricted at the cervix
The cervical ridge is prominent in the cervical third, which runs in a mesiodistal direction and extends to half of the mesial surface of the crown. This well-developed cervical ridge is called the buccal cingulum
Three buccal cusps—mesiobuccal, distobuccal and distal—are seen in this aspect
The mesiobuccal and distobuccal cusps are separated by the mesiobuccal developmental groove
The distobuccal and the distal cusps are separated by the distobuccal groove
Two roots are present: Mesial and distal roots
The level of bifurcation of the roots is near the cervix and the root trunk is either small or indistinct
The mesial aspect is rhomboidal in outline
The crown appears to be inclined lingually
The buccolingual width of the crown at the cervical third is more than that the occlusal third
Only the mesial root is seen in this aspect and it is square shaped
The mesial root is broad in the cervical and middle third and tapers in the apical third ending in a broad and blunt apex
The buccolingual width of the crown is more than the cervico-occlusal width
The buccolingual width is less in this aspect than the mesial aspect because of the distal convergence of the buccal aspect
The distal root and part of the mesial root are seen in this aspect
The distal root is narrow and rounded ending in a blunt apex

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Multiple Choice Questions

1. Developmental spaces or primate spaces are present between _____ teeth in the mandibular arch.
   (a) The canine and first molar
   (b) The first and second molar
   (c) The lateral incisor and canine
   (d) The central and lateral incisor
2. The deciduous teeth are seen between the ages of _____ in the oral cavity before their exfoliation.
   (a) 1 and 5 years
   (b) 2 and 6 years
   (c) 2 and 8 years
   (d) 7 and 11 years
3. The sequence of eruption of the deciduous incisors is
   (a) Mandibular central incisor → mandibular lateral incisor → maxillary central incisor → maxillary lateral incisor
   (b) Mandibular central incisor → maxillary central incisor → mandibular lateral incisor → maxillary lateral incisor
   (c) Mandibular central incisor → mandibular lateral incisor → maxillary lateral incisor → maxillary central incisor
   (d) Maxillary central incisor → maxillary lateral incisor → mandibular central incisor → mandibular lateral incisor
4. The mesioincisal angle and the distoincisal angle of the deciduous maxillary central incisors are
   (a) Obtuse angle and right angle, respectively
   (b) Acute angle and right angle, respectively
   (c) Right angle and acute angle, respectively
   (d) Right angle and obtuse angle, respectively
5. The labial cervical ridge of the incisors is called the
   (a) Mesiodistal cingulum
   (b) Labial cingulum
   (c) Buccal cingulum
   (d) None of the above
6. The palatal/lingual outline of the incisors is _____ shaped.
   (a) C
   (b) S
   (c) U
   (d) None of the above
7. The mesial and distal contact areas of the deciduous maxillary central incisors are situated in the
   (a) Middle third
   (b) Cervical third
   (c) Incisal third
   (d) Junction of the middle and incisal third

8. The smallest tooth in the deciduous dentition is the
   (a) Mandibular lateral incisor
   (b) Maxillary lateral incisor
   (c) Mandibular central incisor
   (d) Both a and c
9. The outline of the labial surface of the deciduous maxillary canine is
   (a) Diamond shaped
   (b) Rhomboidal
   (c) Angular
   (d) Both a and c
10. The fourth tooth to erupt in the maxillary arch is the
   (a) Canine
   (b) Second molar
   (c) Lateral incisor
   (d) First molar
11. The tooth which resembles an intermediate between permanent premolar and molar is the
   (a) Mandibular first molar
   (b) Maxillary second molar
   (c) Maxillary canine
   (d) Maxillary first molar
12. What are the occlusal patterns seen in the deciduous maxillary first molar?
   (a) Two-cusp type
   (b) Three-cusp type
   (c) Four-cusp type
   (d) Both b and c
13. The primary mandibular left canine is denoted as _____ according to the Universal system.
   (a) R
   (b) M
   (c) 73
   (d) 83
14. The cusp of Carabelli is seen in the
   (a) Deciduous maxillary first molar
   (b) Deciduous maxillary second molar
   (c) Permanent maxillary first molar
   (d) Both b and c
15. Which is the longest and sharpest cusp in the deciduous maxillary second molar?
   (a) Mesiopalatal
   (b) Mesiopalatal and mesiobuccal, respectively
   (c) Mesiobuccal
   (d) Distobuccal
16. The palatal root of the primary maxillary molars exhibits _____ inclination in the middle third
   (a) Mesial
   (b) Distal
   (c) Buccal
   (d) Palatal
17. The level of furcation in the mesial aspect of the deciduous maxillary second molar is
   (a) 3–4 mm from the cervical line
   (b) 2–3 mm from the cervical line
   (c) 1–2 mm from the cervical line
   (d) Next to the cervical line
18. The occlusal outline of the primary mandibular first molar is
   (a) Rhomboidal
   (b) Trapezoidal
   (c) Diamond shaped
   (d) Rectangular
19. How many developmental grooves are seen in the primary mandibular first molar?
   (a) 4
   (b) 6
   (c) 3
   (d) 8
20. The primary mandibular second molar resembles the permanent
   (a) Maxillary first molar
   (b) Mandibular first molar
   (c) Mandibular second molar
   (d) Both b and c



CHAPTER 14

Permanent Maxillary and Mandibular Incisors

Overview

Incisors are teeth with straight cutting edges. There are four incisors per arch and two per quadrant. Their main function is to bite and shear food, articulate speech and support the lips. The central incisors are located in the anteromedial aspect of the upper and lower jaws and the lateral incisors are lateral to the central incisors. The maxillary central incisors have straight edges and are the most prominent teeth in the mouth. The mandibular central incisors are long, narrow and symmetrical, with straight edges and are the smallest teeth in the dental arch. The mandibular lateral incisors are larger and more rounded than the central incisors. The lateral incisors are narrower than the central ones but are otherwise similar in appearance. Maxillary incisors demonstrate a labial convexity which makes the tooth most prominent in the oral cavity while the labial surfaces of mandibular incisors are relatively flat. The lingual surface of the maxillary and mandibular incisors are composed of cingulum and lingual fossa with varying degrees of prominence and slight variation on the location between each tooth. Mamelons are commonly evident in the incisal edges of the incisors. All the incisors are single rooted with the roots of maxillary incisors being conical with a blunt apex while mandibular incisor roots are usually flat with a pointed apex.

INTRODUCTION

Incisors (Latin *incidere*) means 'to cut'. Incisors are teeth with straight cutting edges whose function is to bite and shear food, articulate speech and support the lips. There are four incisors per arch and two per quadrant. The incisors are usually the first teeth to emerge.

The central incisors are located in the anteromedial aspect of the upper and lower jaws and the lateral incisors are lateral to the central incisors. The maxillary central incisors are the most prominent teeth in the mouth and have straight edges. The lateral incisors are narrower than the central ones but are otherwise similar in appearance. The mandibular central incisors are the smallest teeth in the dental arch. These teeth are long, narrow and symmetrical, with straight edges. The mandibular lateral incisors are larger and more rounded than the central incisors.

MAXILLARY CENTRAL INCISORS

The maxillary central incisors are the most prominent teeth in the oral cavity. The chronology of maxillary central incisors has been provided in **Box 14.1**. They are wider mesiodistally than other anterior teeth and have a single root. The labial convexity is lesser when compared with maxillary lateral incisors and canines (**Box 14.2**).

Box 14.1 Chronology of the Maxillary

- First evidence of calcification: 3–4 months
- Enamel completion: 4–5 years
- Eruption: 7–8 years
- Root completion: 10 years

Box 14.2 Dimensions of the Maxillary Central Incisors (Fig. 14.1)

- Length of the crown: 10.5 mm
- Length of the root: 13 mm
- Mesiodistal width of the crown: 8.5 mm
- Mesiodistal width of crown at cervix: 7.0 mm
- Labiolingual width of the crown: 6.0 mm
- Labiolingual width of the crown at cervix: 7.0 mm
- Depth of curvature at the mesial aspect: 3.5 mm
- Depth of curvature at the distal aspect: 2.5 mm

Labial Aspect

1. **Shape of the crown** (**Fig. 14.2**): The crown is square, tapering or roughly ovoid. The mesiodistal width is more at the incisal third than at the cervical third.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight and often merges with the mesioincisal edge at right angle. The mesial border is longer than the distal border.
   (b) *Distal outline:* The distal outline is rounded or convex and the height of convexity is towards the cervical line. The distoincisal angle is obtuse.
   (c) *Incisal outline* (**Fig. 14.3**): The incisal outline is straight. It is rounded during the initial stages of eruption because of the presence of mamelon.
   (d) *Cervical outline:* The maxillary central incisor has a semicircular cervical outline and the curvature is towards the root.
3. **Labial surface:** It is slightly convex towards the cervical third and relatively less convex in the middle and incisal portions.

   The enamel surface is smooth. Developmental lines that divide the surface into central, mesial and distal lobes are seen in the middle third.
4. **Shape of the root:** The root is cone shaped and has a blunt apex.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third of the root and gradually tapers from the middle third to the apex.
   (b) *Distal outline:* The distal outline is slightly convex from the cervical third to the

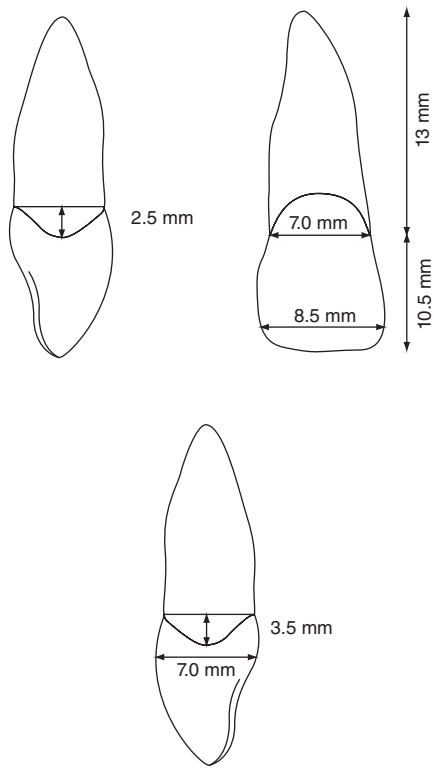


Figure 14.1 Dimensions of the maxillary central incisor.

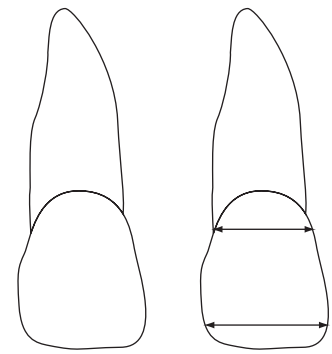


Figure 14.2 Labial aspect of the maxillary central incisor.

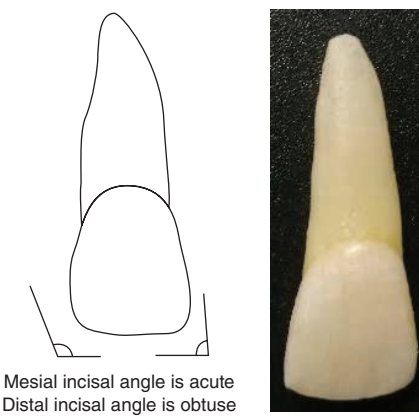


Figure 14.3 Incisal outline of the maxillary central incisor.

middle third and gradually tapers from the middle third to the apex.

Lingual Aspect

1. **Shape of the crown:** The shape of the crown is the same as on the labial side (**Fig. 14.4**).
2. **Outlines of the crown:** The outlines are similar to the labial aspect.
3. **Lingual surface:** There is a broad depression in the central portion known as the lingual fossa. The lingual fossa is bordered by mesial and distal marginal ridges on the sides and cingulum cervically. Cingulum is a smooth convex area below the cervical line. It is placed slightly towards the distal side, resulting in the mesial marginal ridge measuring longer than the distal marginal ridge.

The prominent ridges and the cingulum give a shovel- or scoop-shaped appearance to the incisor.

4. **Outlines of the root:** The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root leading to a decrease in dimension towards the lingual side.

Mesial Aspect (Fig. 14.5)

1. **Shape of the crown:** The crown is triangular or wedge shaped mesially. The labiolingual width is more at the cervix than at the incisal third. Labiolingual concavity is present in the cervical portion whereas the convexity is present in the incisal portion.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline from the crest of curvature is slightly convex and curves smoothly from the cervical margin to the incisal ridge. The height of convexity is at the cervical third.
   (b) *Lingual outline:* The lingual outline is S shaped. It is convex at the crest of curvature, concave at the mesial marginal ridge and slightly convex at the incisal ridge.
   (c) *Cervical outline:* The cervical curvature is convex towards the incisal edge. The curvature is more in this aspect than on any other teeth.
   (d) *Incisal outline:* The incisal ridge forms the apex of the triangular shape of the mesial aspect of the crown and in line with the root axis.

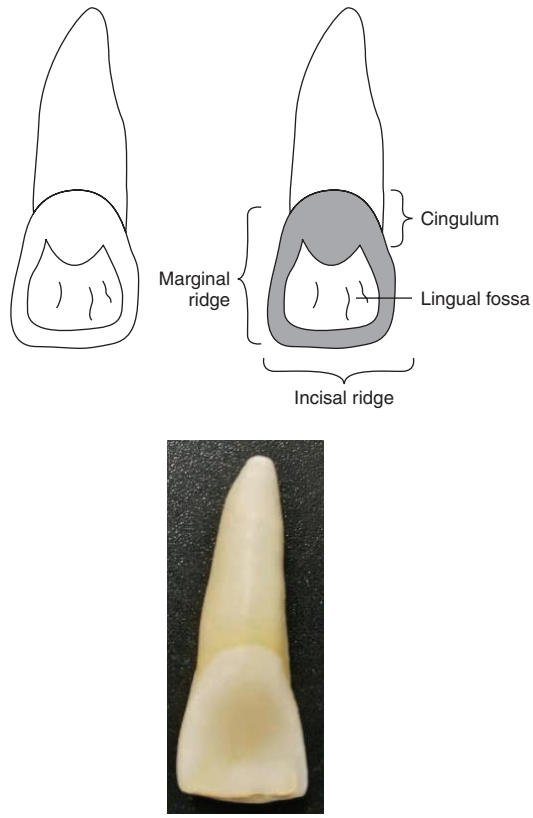


Figure 14.4 Lingual aspect of the maxillary central incisor.

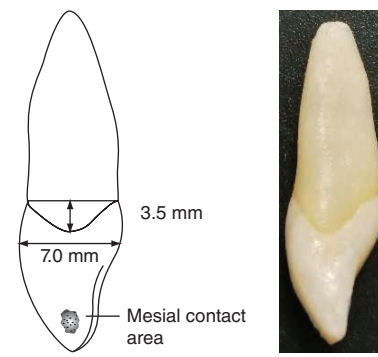


Figure 14.5 Mesial aspect of the maxillary central incisor.

3. **Contact area:** The contact area in the mesial aspect is present in the incisal third, close to the incisal edge.
4. **Outlines of the root**
   (a) *Labial outline:* The labial outline of the crown is slightly convex from the cervical third to the middle third and tapers to the apex.
   (b) *Lingual outline:* The lingual outline is straight from the cervical third to the middle third and there is a gradual taper to the apical third.

Distal Aspect (Fig. 14.6)

1. **Shape of the crown:** The distal aspect of the crown is triangular or wedge shaped.
2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect except that the depth of curvature is less prominent.
3. **Contact area** (Fig. 14.7): The contact area is located at the junction of the incisal and middle third.

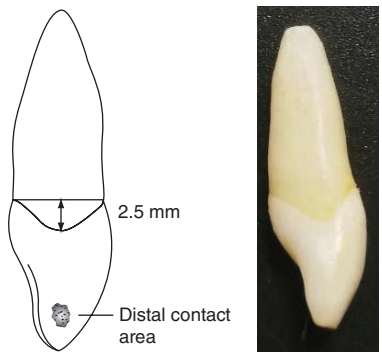


Figure 14.6 Distal aspect of the maxillary central incisor.

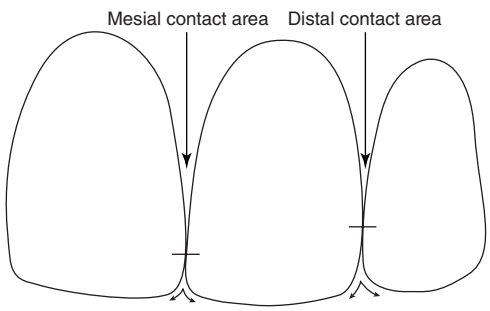


Figure 14.7 Contact area—mesial and distal.

4. **Outlines of the root:** The outlines of the root are similar to those of the mesial aspect.

Incisal Aspect (Fig. 14.8)

1. **Shape of the crown:** The incisal aspect of the crown is roughly triangular.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is broad and flat. The incisal ridge is seen clearly from this aspect. It is formed by joining the labial and lingual margins. The incisal ridge is 1.5–2 mm thick faciolingually. The distoincisal angle is slightly more lingual than the mesioincisal angle.

   Mamelons are seen in a newly erupted tooth and they correspond to the three lobes from which the incisor develops. The mamelons are gradually lost because of wearing away of tooth.

   The crown is wider mesiodistally than it is faciolingually.
   (b) *Lingual outline:* The mesial and distal marginal ridges converge towards the cingulum.

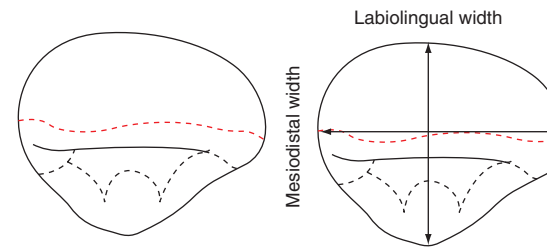




Figure 14.8 Incisal aspect of the maxillary central incisor.

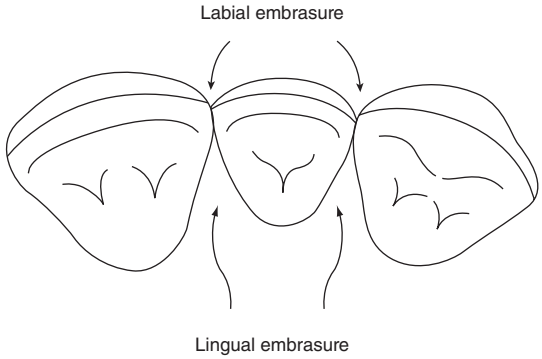


Figure 14.9 Embrasures.

3. **Embrasures** (Fig. 14.9): The incisors have a larger lingual embrasure compared with the smaller facial embrasure. This is the result of the convergence of the crowns towards the lingual aspect.

Applied Morphology

- The maxillary central incisors commonly undergo fracture due to trauma. Restoration of these teeth becomes vital for aesthetics and function.
- The commonest anomalies in maxillary central incisors are a short root, two roots and germination where the crown attempts to divide itself into two.
- Incisal dominance: Maxillary central incisor is the prominent tooth when a person smiles. This is called as incisal dominance.

MAXILLARY LATERAL INCISORS

The maxillary lateral incisors are present on either side of the central incisors. The chronology of maxillary lateral incisors has been provided in Box 14.3. These resemble the central incisors and have a similar function of cutting and shearing food. Like the third molars, these show a wide range of variations in their morphology (Box 14.4).

Box 14.3 Chronology of the Maxillary Lateral Incisors

- First evidence of calcification: 1 year
- Enamel completion: 4–5 years
- Eruption: 8–9 years
- Root completion: 11 years

Box 14.4 Dimensions of the Maxillary Lateral Incisors (Fig. 14.10)

- Length of the crown: 9.0 mm
- Length of the root: 13 mm
- Mesiodistal width of the crown: 6.5 mm
- Mesiodistal width of crown at cervix: 5.0 mm
- Labiolingual width of the crown: 5.0 mm
- Labiolingual width of the crown at cervix: 6.0 mm
- Depth of curvature at the mesial aspect: 3.0 mm
- Depth of curvature at the distal aspect: 2.0 mm

Labial Aspect (Fig. 14.11)

1. **Shape of the crown:** The shape of the crown is roughly ovoid. The mesiodistal width at the cervix is lesser than the mesiodistal width at the incisal third.

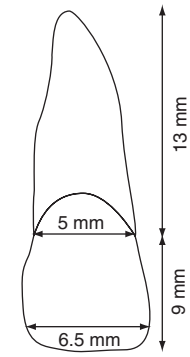
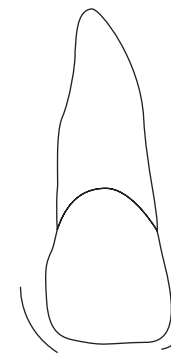


Figure 14.10 Dimensions of the maxillary lateral incisor.



Incisal angles are more rounded when compared with the maxillary central incisor



Figure 14.11 Labial aspect of the maxillary lateral incisor.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight and the mesioincisal angle is more rounded when compared with the maxillary central incisor. The height of convexity is at the junction of middle third and incisal third.
   (b) *Distal outline:* The distal outline is more prominently rounded or convex and the height of convexity is more cervical.
   (c) *Incisal outline:* The incisal outline is rounded when compared with the straight incisal outline of the maxillary central incisors.
   (d) *Cervical outline:* The cervical outline curves towards the root.
3. **Line angles in the crown from the labial aspect**
   (a) *Mesioincisal angle:* The mesioincisal line angle is rounded.
   (b) *Distoincisal angle:* The distoincisal line angle is more prominently rounded than mesioincisal angle and is obtuse.
4. **Labial surface:** The labial surface is more convex when compared with the central incisors.
5. **Shape of the root:** The root is cone shaped and has a pointed apex. The root is slightly distally inclined (**Fig. 14.12**).
6. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is slightly convex from the cervical third to the middle third but the convexity decreases from the middle third to the apex.
   (b) *Distal outline:* The distal outline is convex from the cervical third to the middle third; it gradually tapers and curves distally from the middle third to the apex.

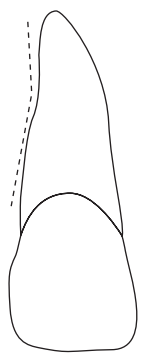


Figure 14.12 Distal inclination of the root of the maxillary lateral incisor.

Lingual Aspect (Fig. 14.13)

1. **Shape of the crown:** The shape of the crown in the lingual aspect is the same as that of the labial side.
2. **Outlines of the crown:** The outlines are similar to those of the labial aspect.
3. **Lingual surface:** The lingual fossa is deeper when compared with the maxillary central incisor. The increase in depth is the result of increased prominence of the mesial and distal marginal ridges on the sides.

   Cingulum is narrower but more prominent than the maxillary central incisor. It is marked by developmental grooves at the side of the cingulum called the *palatogingival groove* or the *palatoradicular groove*. These developmental grooves are usually present on the distal side and might extend up to varying lengths on the root.
4. **Outlines of the root:** The outlines are similar to those of the labial aspect and become narrower towards the lingual side.

Mesial Aspect

1. **Shape of the crown:** The shape of the crown is triangular mesially. The labiolingual width at

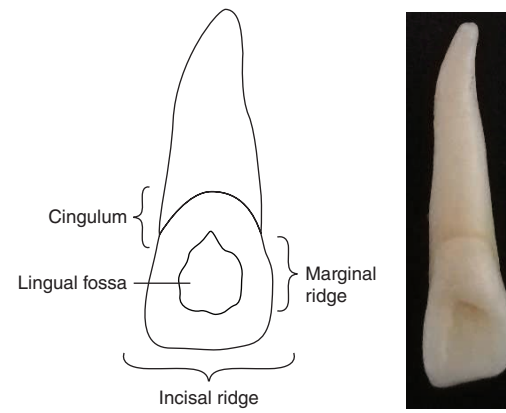


Figure 14.13 Lingual aspect of the maxillary lateral incisor.

cervix is more than the labiolingual width at the incisal third.

2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline from the crest of curvature is slightly convex and curves smoothly from the cervical margin to the incisal ridge. The convexity is more than in the maxillary central incisor.
   (b) *Lingual outline:* The lingual outline is roughly S shaped as in the maxillary central incisor, with a slight increase in convexity in the incisal ridge area.
   (c) *Cervical outline:* The cervical curvature is convex towards the incisal edge but the convexity is less when compared with the maxillary central incisors.
   (d) *Incisal outline:* The incisal ridge is thick and convex and forms the apex of the triangular shape of the mesial aspect of the crown (**Fig. 14.14**).
3. **Contact area:** The contact area in the mesial aspect is present in the junction of the incisal and middle third.
4. **Outlines of the root**
   (a) *Labial outline:* The labial outline of the crown is straight from the cervical third to the middle third, tapers towards the apex and points towards the labial direction.
   (b) *Lingual outline:* The lingual outline is convex from the cervical third to the middle third and there is a gradual taper to the apical third.

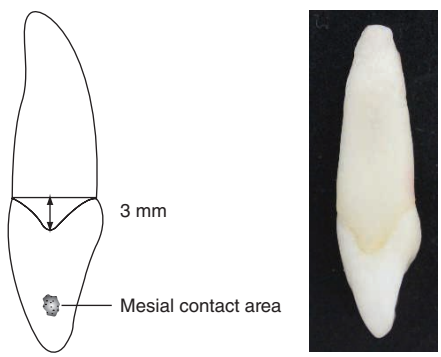


Figure 14.14 Mesial aspect of the maxillary lateral incisor.

Distal Aspect (Fig. 14.15)

1. **Shape of the crown:** The shape of the crown is triangular.
2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect except that the depth of curvature is less prominent.
3. **Contact area:** The contact area is located at the middle third.
4. **Outlines of the root:** The outlines of the root are similar to those of the mesial aspect.

Incisal Aspect (Fig. 14.16)

1. **Shape of the crown:** The crown is round or ovoid in the incisal aspect.

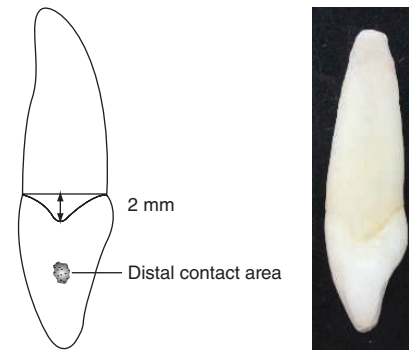


Figure 14.15 Distal aspect of the maxillary lateral incisor.

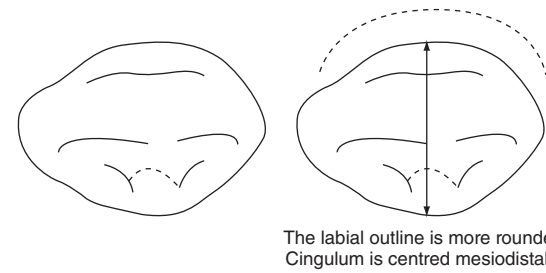




Figure 14.16 Incisal aspect of the maxillary lateral incisor.

SECTION II

2. **Outlines of the crown**
   a. *Labial outline:* The labial outline is more convex when compared with the maxillary central incisor. The incisal ridge is seen clearly from this aspect and is straighter mesiodistally than the central incisors.
   b. *Lingual outline:* The mesial and distal marginal ridges converge towards the cingulum. The cingulum is centred mesiodistally unlike its position in the maxillary central incisors.

Applied Morphology

- The palatogingival groove or the palatoradicular groove may cause periodontal problems since they pave an easy path for the entry of bacteria.
- The maxillary lateral incisors are the second commonest congenitally missing tooth next to third molars.
- The palatoaxial inclination of the maxillary lateral incisor is 29°, which makes it inclined in a palatal direction. Because of such an inclination, abscesses which form in the periapical region of maxillary lateral incisors usually drain palatally rather than in the labial aspect.
- Lingual pits are common on maxillary lateral incisors. Lingual pits are present just above the cingulum.
- An accessary cusp in the lingual surface of incisors is called as Talon's cusp which is a developmental anomaly most commonly affecting permanent maxillary lateral incisor.
- The maxillary lateral incisors show wide variations in morphology, the commonest being the pointed shape of the crown called the peg laterals.

MANDIBULAR CENTRAL INCISORS

The mandibular central incisors are the smallest teeth in the permanent dentition. These are smaller when compared with the maxillary incisors and mandibular lateral incisors. The chronology of mandibular central incisors has been provided in **Box 14.5**. These teeth are bilaterally symmetrical, with similar dimensions both on the mesial and distal aspects of the crown (**Box 14.6**).

Box 14.5 Chronology of the Mandibular Central Incisors

- First evidence of calcification: 3 months
- Enamel completion: 4–5 years
- Eruption: 6–7 years
- Root completion: 9 years

Box 14.6 Dimensions of the Mandibular Central Incisors (Fig. 14.17)

- Length of the crown: 9.0 mm
- Length of the root: 12.5 mm
- Mesiodistal width of the crown: 5.0 mm
- Mesiodistal width of crown at cervix: 3.5 mm
- Labiolingual width of the crown: 6.0 mm
- Labiolingual width of the crown at cervix: 5.3 mm
- Depth of curvature at the mesial aspect: 3 mm
- Depth of curvature at the distal aspect: 2 mm

Labial Aspect (Fig. 14.18)

1. **Shape of the crown:** The shape of the crown is trapezoidal from the labial aspect.

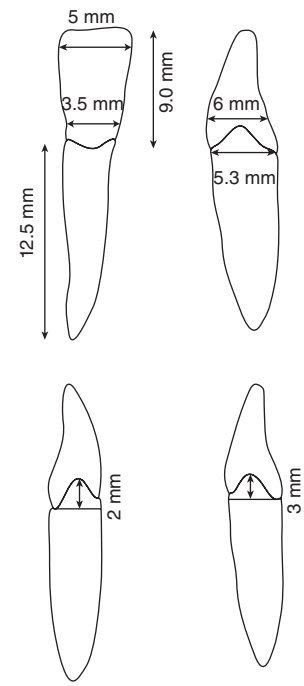


Figure 14.17 Dimensions of the mandibular central incisor.

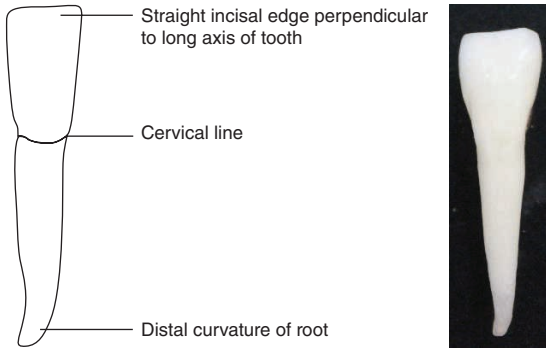


Figure 14.18 Labial aspect of the mandibular central incisor.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight from the incisal edge to the contact area, which is located at the incisal thirds. From the contact area, the outline is straight till the cervical margin. The mesial incisal edge is at right angles to the long axis of the tooth.
   (b) *Distal outline:* The distal outline is also similar to the mesial outline. It is straight from the incisal edge to the cervical line. The distal incisal angle is at right angles to the long axis of the tooth but is more rounded than the mesial incisal angle.
   (c) *Cervical outline:* The mandibular central incisor has a semicircular cervical outline and the curvature is towards the root.
   (d) *Incisal outline:* The incisal outline is straight mesiodistally. Mamelons are present in the newly erupted teeth.
3. **Labial surface:** The labial surface is smooth and flat unlike the maxillary incisors in the incisal third. The middle third shows mild convexity and gradually merges with the root surface.
4. **Shape of the root:** The root is cone shaped and has a blunt apex.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third and then gradually tapers from the middle third to the apex.
   (b) *Distal outline:* The distal outline is very mildly convex from the cervical third to the middle third and gradually tapers from the middle third to the apex. There is a distal tilt in the apical third.

Lingual Aspect (Fig. 14.19)

1. **Shape of the crown:** The crown is trapezoidal as in the labial side.
2. **Outlines of the crown:** The outlines are similar to those of labial aspect.
3. **Lingual surface:** The lingual surface exhibits a cingulum and a lingual fossa bordered by marginal ridges, but they are not as prominent as in the maxillary incisors. The mesial marginal ridge is of the same length as the distal marginal ridge.
4. **Outlines of the root:** The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root. This leads to a decrease in dimension towards the lingual side because of the lingual convergence.

Mesial Aspect (Fig. 14.20)

1. **Shape of the crown:** The crown is triangular or wedge shaped in this aspect.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline from the crest of curvature is straight from the incisal edge to the cervical third and is slightly convex in the cervical third.

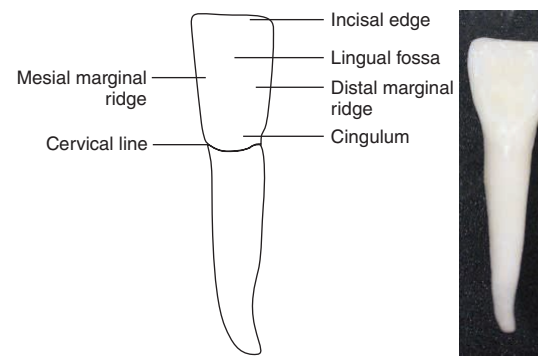


Figure 14.19 Lingual aspect of the mandibular central incisor.

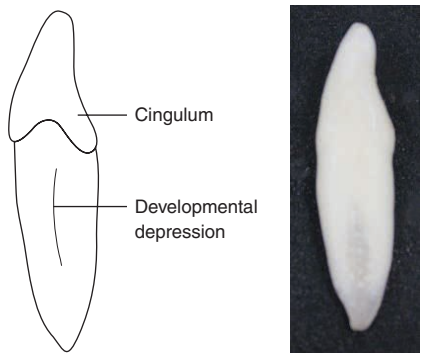


Figure 14.20 Mesial aspect of the mandibular central incisor.

(b) *Lingual outline:* The lingual outline is S shaped, but the curvatures are not as prominent as the maxillary incisors. The incisal third is mildly convex with concavity in the middle third followed by convexity in the cervical third.

(c) *Cervical outline:* The cervical curvature is convex towards the incisal edge.

(d) *Incisal outline:* The incisal ridge forms the apex of the triangular shape of the mesial aspect of the crown and it is placed lingual to the root axis. Thus the crown demonstrates a lingual tilt.

3. **Contact area:** The contact area in the mesial aspect is present in the incisal third.
4. **Outlines of the root:** Root concavity is present on the mesial aspect of the root, extending from the cervical third of the root to the apical third. This concavity gives a dumb-bell shape to the root in cross-section.

(a) *Labial outline:* The labial outline of the crown is straight from the cervical third to the middle third and tapers to the apex.

(b) *Lingual outline:* The lingual outline is straight from the cervical third to the middle third, and there is a gradual taper to the apical third.

Distal Aspect (Fig. 14.21)

1. **Shape of the crown:** The crown is triangular or wedge shaped.

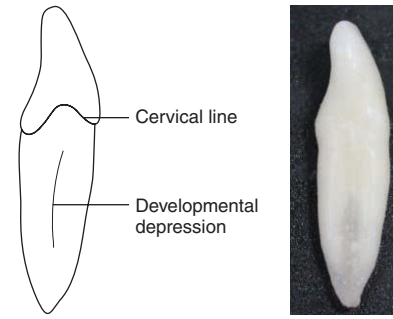


Figure 14.21 Distal aspect of the mandibular central incisor.

2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect except that the depth of curvature is less prominent.
3. **Contact area:** The contact area is located at the incisal third of the crown.
4. **Outlines of the root:** The outlines of the root are similar to those of the mesial aspect.

Incisal Aspect (Fig. 14.22)

1. **Shape of the crown:** The crown is roughly ovoid when viewed from the incisal aspect and bilaterally symmetrical which aids in distinguishing this tooth from mandibular lateral incisor.
2. **Outlines of the crown:** The crown is bilaterally symmetrical from this aspect.

(a) *Labial outline:* The labial outline is straight and is at right angles to a line

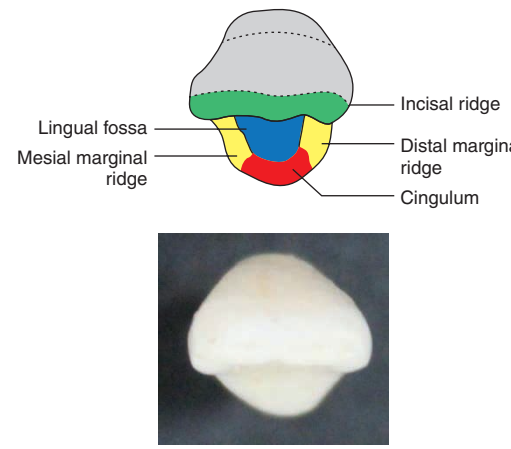


Figure 14.22 Incisal aspect of the mandibular central incisor.

drawn labiolingually. This feature helps in differentiating between the central and lateral mandibular incisors.

(b) *Lingual outline:* The lingual outline is convex, with the mesial and distal marginal ridges converging towards the cingulum.

MANDIBULAR LATERAL INCISORS

The mandibular lateral incisors are located in mesial relation to the central incisors and distal to the canines. The chronology of mandibular lateral incisors has been provided in **Box 14.7**. These are similar to the mandibular central incisors but have increased mesiodistal and incisocervical height in comparison (**Box 14.8**). These also appear slightly twisted on their root base to accommodate themselves to the curved arch form of the mandible.

Box 14.7 Chronology of the Mandibular Lateral Incisors

- First evidence of calcification: 3–4 years
- Enamel completion: 4–5 years
- Eruption: 7–8 years
- Root completion: 10 years

Box 14.8 Dimensions of the Mandibular Lateral Incisors

- Length of the crown: 9.5 mm
- Length of the root: 14 mm
- Mesiodistal width of the crown: 5.5 mm
- Mesiodistal width of crown at cervix: 4.0 mm
- Labiolingual width of the crown: 6.5 mm
- Labiolingual width of the crown at cervix: 5.8 mm
- Depth of curvature at the mesial aspect: 3 mm
- Depth of curvature at the distal aspect: 2 mm

Labial Aspect (Fig. 14.23)

1. **Shape of the crown:** The shape of the crown is trapezoidal.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight from the incisal edge to the cervical line, and the contact area is located at the incisal third and is similar to the mandibular central incisor.
   (b) *Distal outline:* The distal outline is more rounded than the mesial outline. The outline is slightly convex from the incisal edge to the contact area which is located at the incisal third. From the contact area, the outline gradually straightens to the cervical line.
   (c) *Incisal outline:* The incisal outline is slightly curved as a result of a prominent distal developmental lobe. The distoincisal line angle is rounded.
   (d) *Cervical outline:* The labial aspect of the tooth has a semicircular cervical outline and the curvature is towards the root.
3. **Labial surface:** The labial surface is more rounded mesiodistally than the mandibular central incisors. Developmental grooves are present on the labial surface.
4. **Shape of the root:** The root is cone shaped and has a blunt apex.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third and then gradually tapers from the middle third to the apex.
   (b) *Distal outline:* The distal outline is very mildly convex from the cervical third to the middle third and gradually tapers from the middle third to the apex. There is a distal tilt in the apical third.

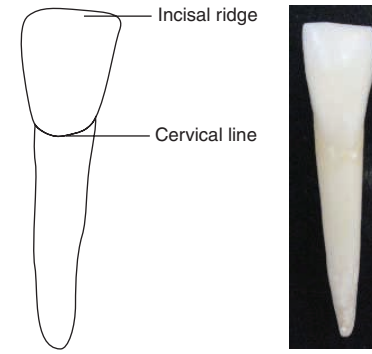


Figure 14.23 Labial aspect of the mandibular lateral incisor.

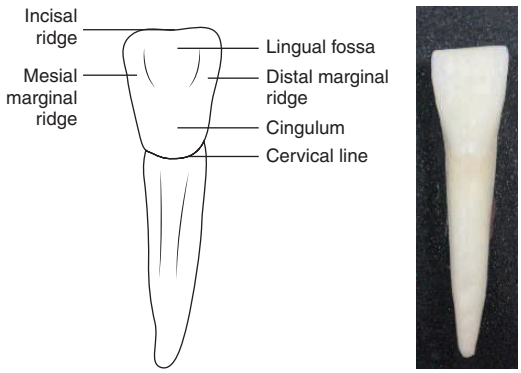


Figure 14.24 Lingual aspect of the mandibular lateral incisor.

Lingual Aspect (Fig. 14.24)

1. **Shape of the crown:** The shape of the crown is trapezoidal as in the labial side.
2. **Outlines of the crown:** The outlines are similar to the labial aspect.
3. **Lingual surface:** The lingual surface exhibits a cingulum and a lingual fossa bordered by marginal ridges, and these are more prominent than those present in the mandibular central incisors. The mesial marginal ridge is longer than the distal marginal ridge.
4. **Outlines of the root:** The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root because of the lingual convergence.

Mesial Aspect (Fig. 14.25)

1. **Shape of the crown:** The crown is triangular or wedge shaped from this aspect.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline from the crest of curvature is straight from the incisal edge to the cervical third and is slightly convex in the cervical third.
   (b) *Lingual outline:* The lingual outline is S shaped.
   (c) *Cervical outline:* The cervical curvature is convex towards the incisal edge.
   (d) *Incisal outline:* The incisal ridge forms the apex of the triangular shape of the mesial aspect of the crown and situated lingual to the root axis.
3. **Contact area:** The contact area in the mesial aspect is present at the incisal third.
4. **Outlines of the root**
   (a) *Labial outline:* The labial outline of the crown is straight from the cervical third to the middle third and tapers to the apex.
   (b) *Lingual outline:* The lingual outline is straight from the cervical third to the middle third, and there is a gradual taper to the apical third.

Distal Aspect (Fig. 14.26)

1. **Shape of the crown:** The crown is triangular or wedge shaped from this aspect.
2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect.
3. **Contact area:** The contact area is located at the incisal third.
4. **Outlines of the root:** The outlines of the root are similar to those of the mesial aspect.

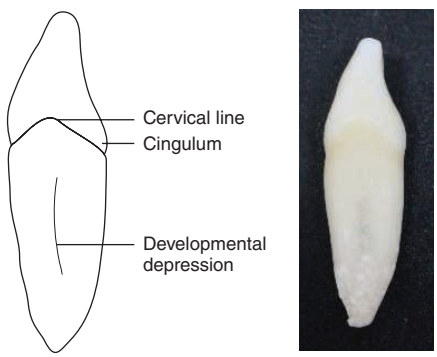


Figure 14.25 Mesial aspect of the mandibular lateral incisor.

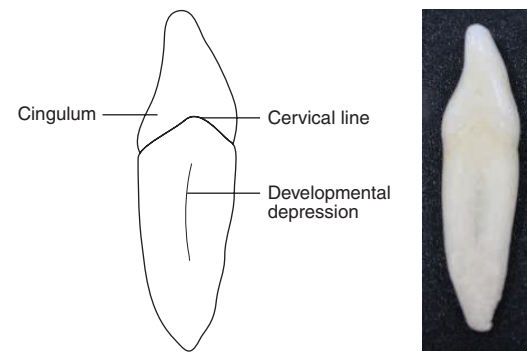


Figure 14.26 Distal aspect of the mandibular lateral incisor.

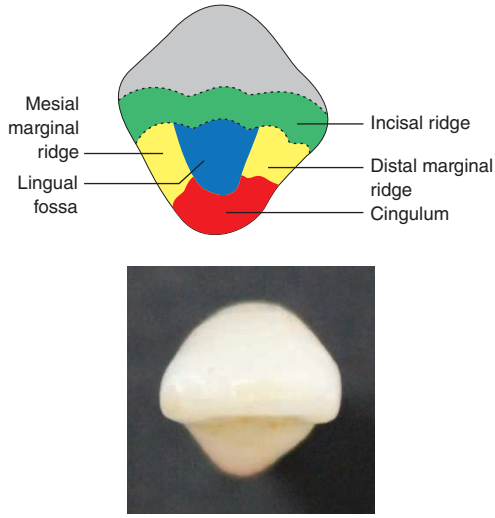


Figure 14.27 Incisal aspect of the mandibular lateral incisor.

Incisal Aspect (Fig. 14.27)

1. **Shape of the crown:** The crown is roughly ovoid in this aspect.
2. **Outlines of the crown:** The crown is not bilaterally symmetrical unlike the crown of the mandibular central incisors.
   a. *Labial outline:* The labial outline curves towards the distal side because of the distal developmental lobe and is not straight as in the mandibular central incisor.
   b. *Lingual outline:* The lingual outline is convex, with the mesial and distal marginal ridges converging towards the cingulum. The marginal ridges are more prominent, and the lingual fossa is slightly deeper than that of the mandibular central incisors.

Applied Morphology

Mandibular Incisors

1. The mandibular incisors are more prone to periodontal problems because their lingual surfaces are closer to the opening of the submandibular and sublingual salivary gland ducts. Calculus is deposited easily on their lingual surfaces leading to the weakening of the periodontal ligament and, hence, tooth mobility.
2. Crowding of mandibular incisors is commonly seen because of inadequate space in the mandible. This makes instrumentation difficult during cavity preparation and scaling procedures.
3. Mandibular central incisors and lateral incisors can demonstrate fusion—a developmental aberration.
4. Variations: Two root canals in a single root are commonly seen in mandibular incisors.
5. Bifurcation of the root at the apical end is also commonly seen in mandibular incisors.

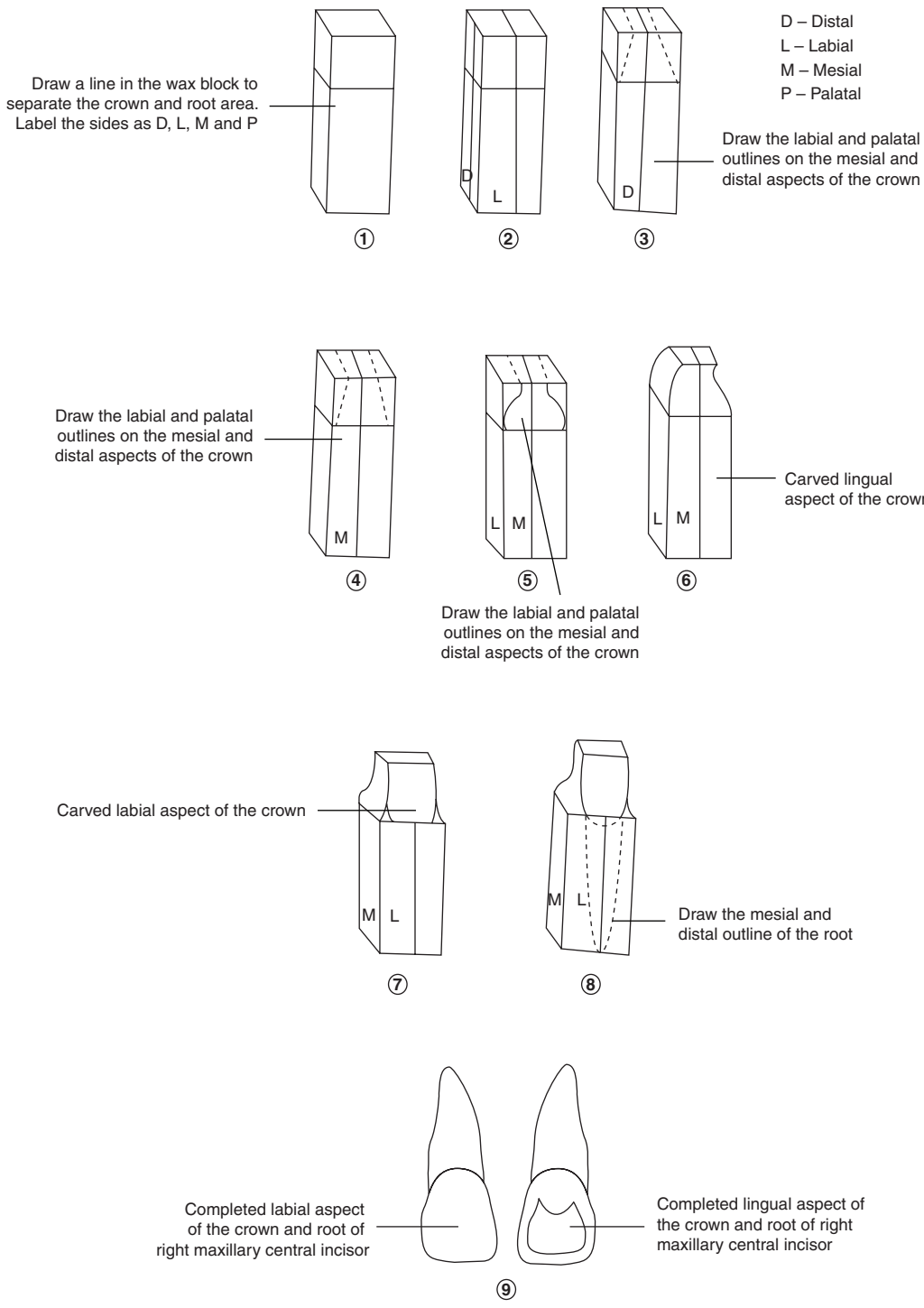
The differences in the incisal, labial and lingual aspects between mandibular central and lateral incisors are listed in **Table 14.1**.

Table 14.1 Differences Between Mandibular Central and Lateral Incisors

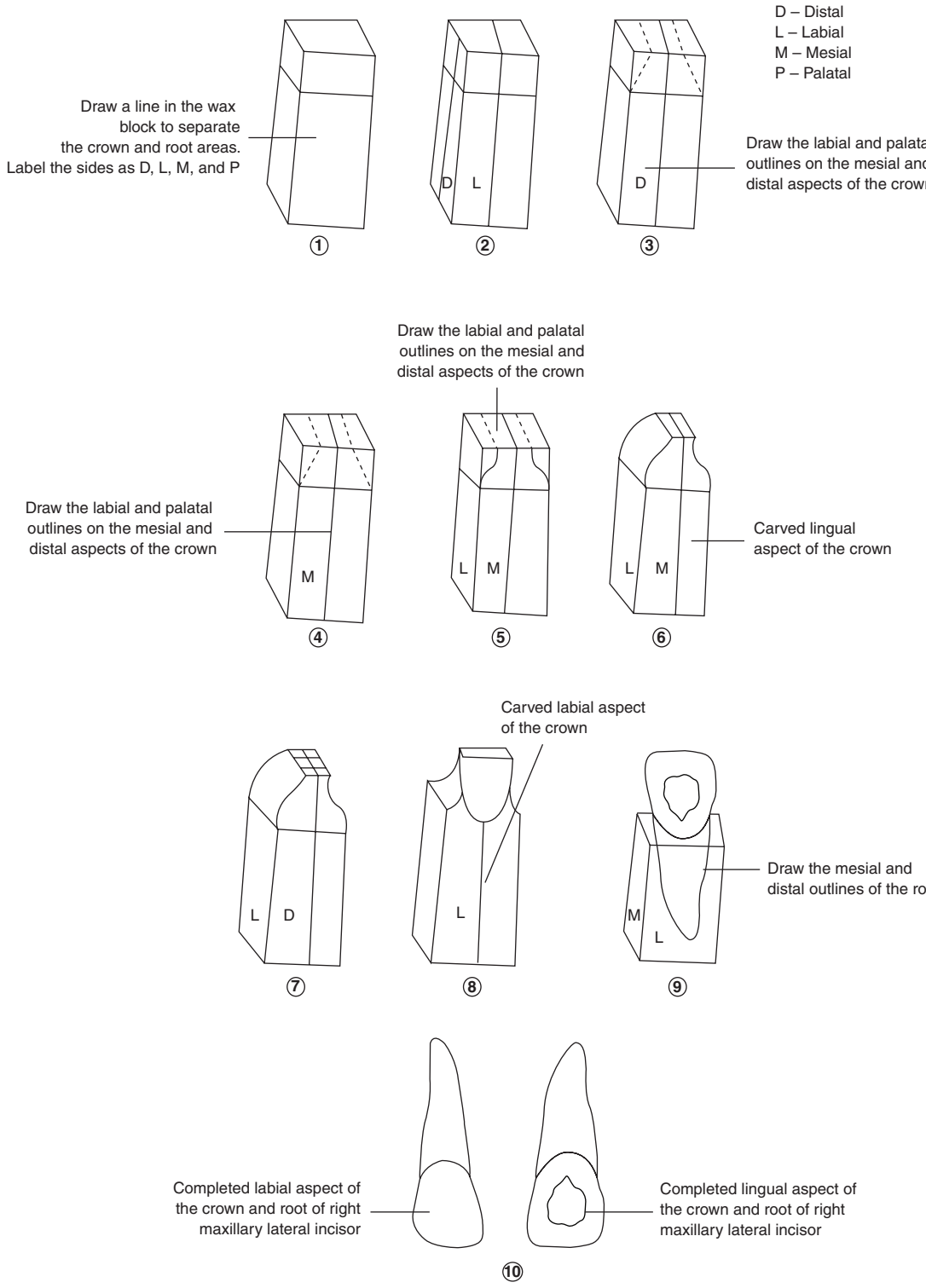
Aspect	Mandibular Central Incisor	Mandibular Lateral Incisor
Incisal aspect	Mesiodistal width is lesser than that in the lateral incisor	Mesiodistal width is more than that in the central incisor
Labial aspect	Mesioincisal and distoincisal angles are at right angles	Distoincisal angle is rounded
	Bilaterally symmetrical	Bilaterally asymmetrical
Lingual aspect	Cingulum is centred	Cingulum is slightly distal
	Mesial and distal marginal ridges are equal in length	Mesial marginal ridge is longer than the distal marginal ridge

SECTION II

STEPS FOR CARVING A MAXILLARY CENTRAL INCISOR



STEPS FOR CARVING A MAXILLARY LATERAL INCISOR



SECTION II

KEY POINTS

Maxillary Central Incisors

1. Central incisors are wider mesiodistally than other anterior teeth.
2. Mamelons are rounded projections corresponding to the developmental lobes and are present in the newly erupted central incisors.
3. The cingulum is a smooth, convex area below the cervical line in the lingual aspect.
4. The cingulum and the prominent ridges give a shovel- or scoop-shaped appearance to the incisor.
5. Contact area on the mesial aspect is present in the incisal third, close to the incisal edge. The distal contact area is located at the junction of the incisal and middle third.
6. Central incisors have two embrasures: labial and lingual. The lingual embrasure is large as a result of the convergence.
7. The root is conical, and the apical third has a mild distal taper.

Maxillary Lateral Incisors

1. Like the third molars, the maxillary lateral incisors show wide variations in morphology.
2. The mesioincisal angle in the maxillary lateral incisor is more rounded when compared with the central incisor.
3. The labiopalatal inclination is 29°.
4. The root shows distal inclination.
5. Developmental grooves known as palatogingival grooves or palatoradicular grooves, are present on the lingual aspect.

Mandibular Central Incisors

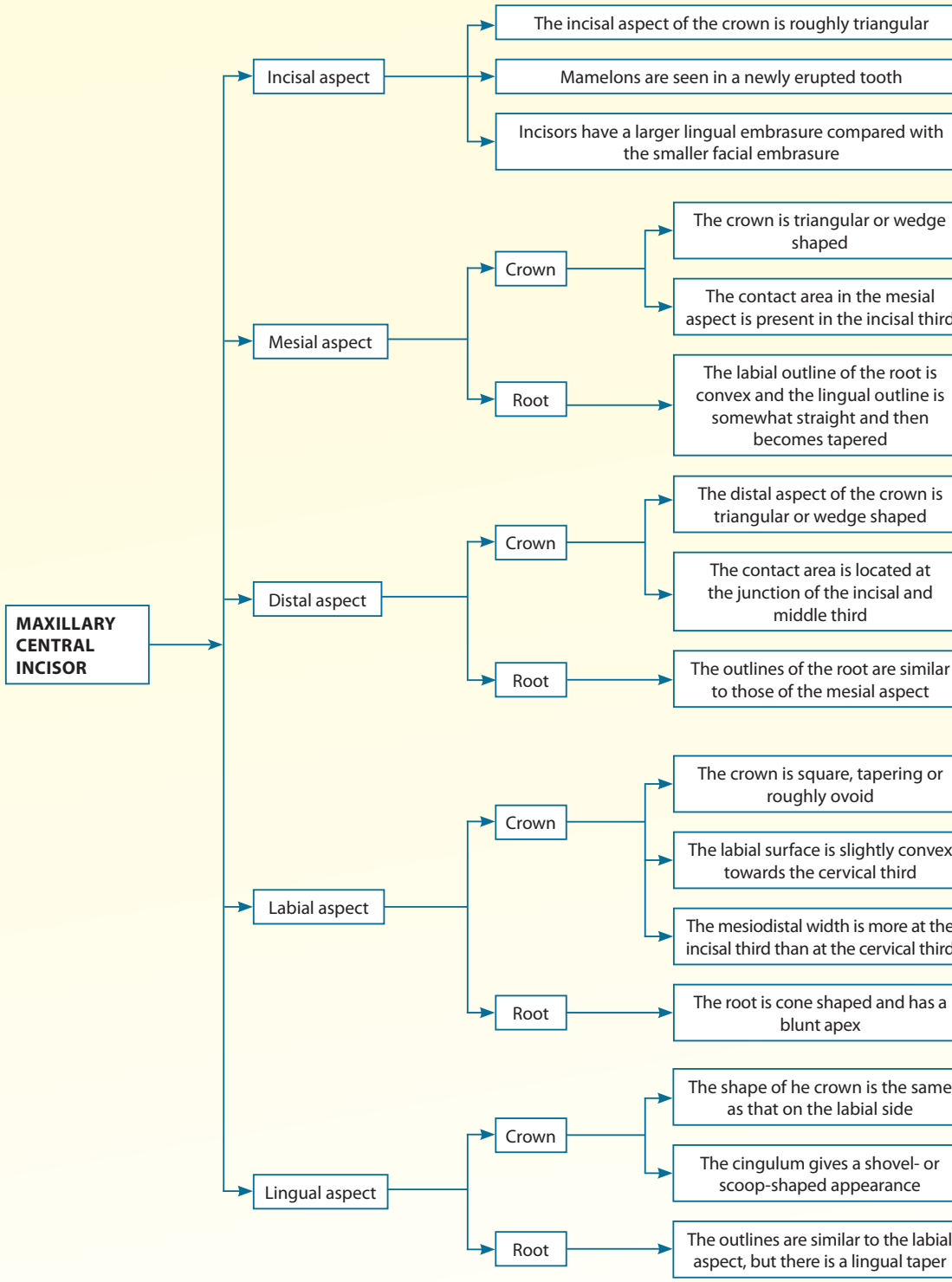
1. The mandibular central incisors are the smallest teeth in the permanent dentition.
2. The mandibular central incisor is symmetrical from the incisal aspect.
3. Root concavities are present both on the mesial and distal root aspects.

Mandibular Lateral Incisors

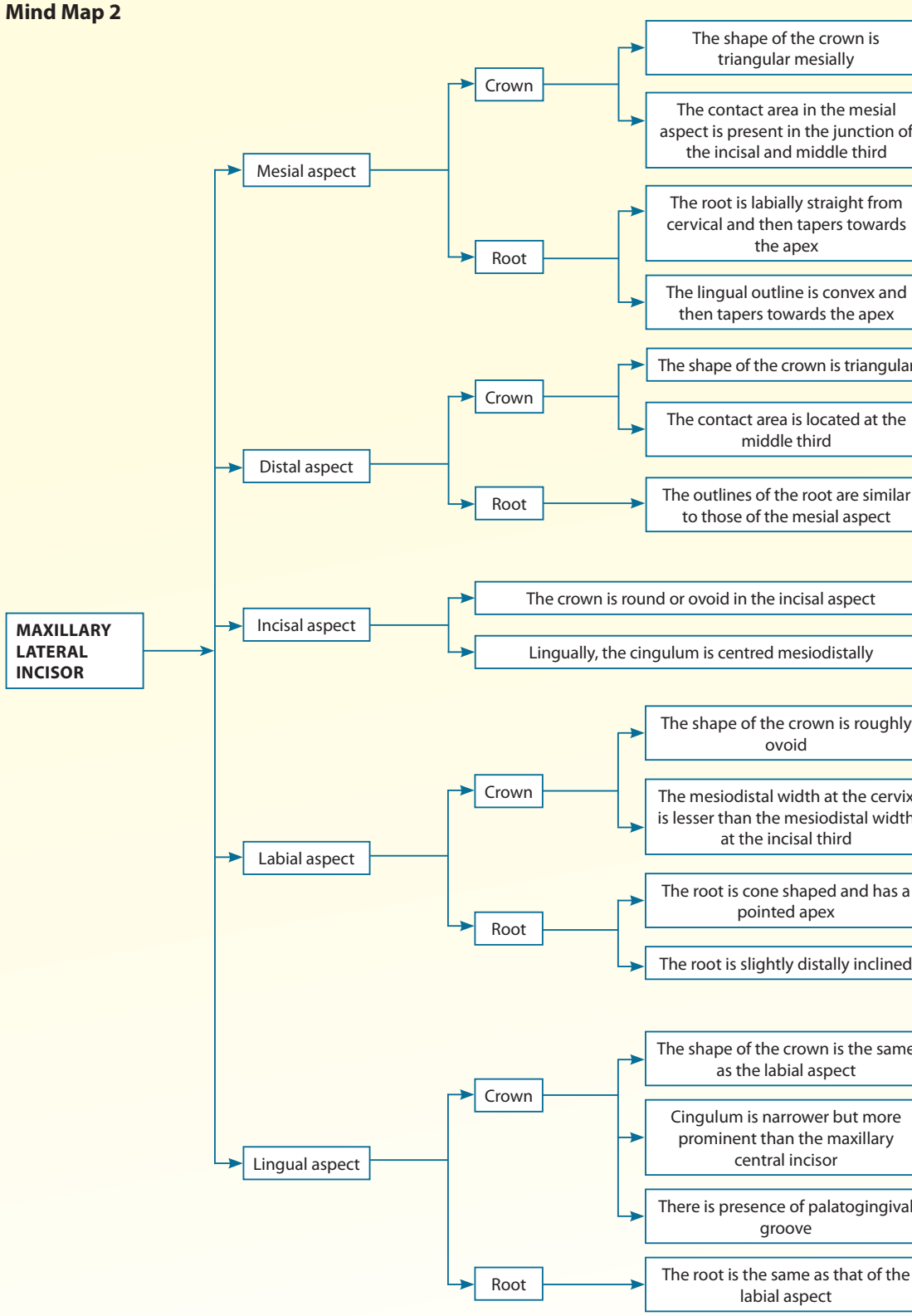
1. The mandibular lateral incisors have increased mesiodistal and incisocervical height when compared with the mandibular central incisors.
2. The lingual aspect is more prominent in the mandibular lateral incisors than in the mandibular central incisors.
3. The incisal ridge is slightly curved lingually near the distal margin.
4. The crown is not bilaterally symmetrical like the mandibular central incisors.

Mind Maps

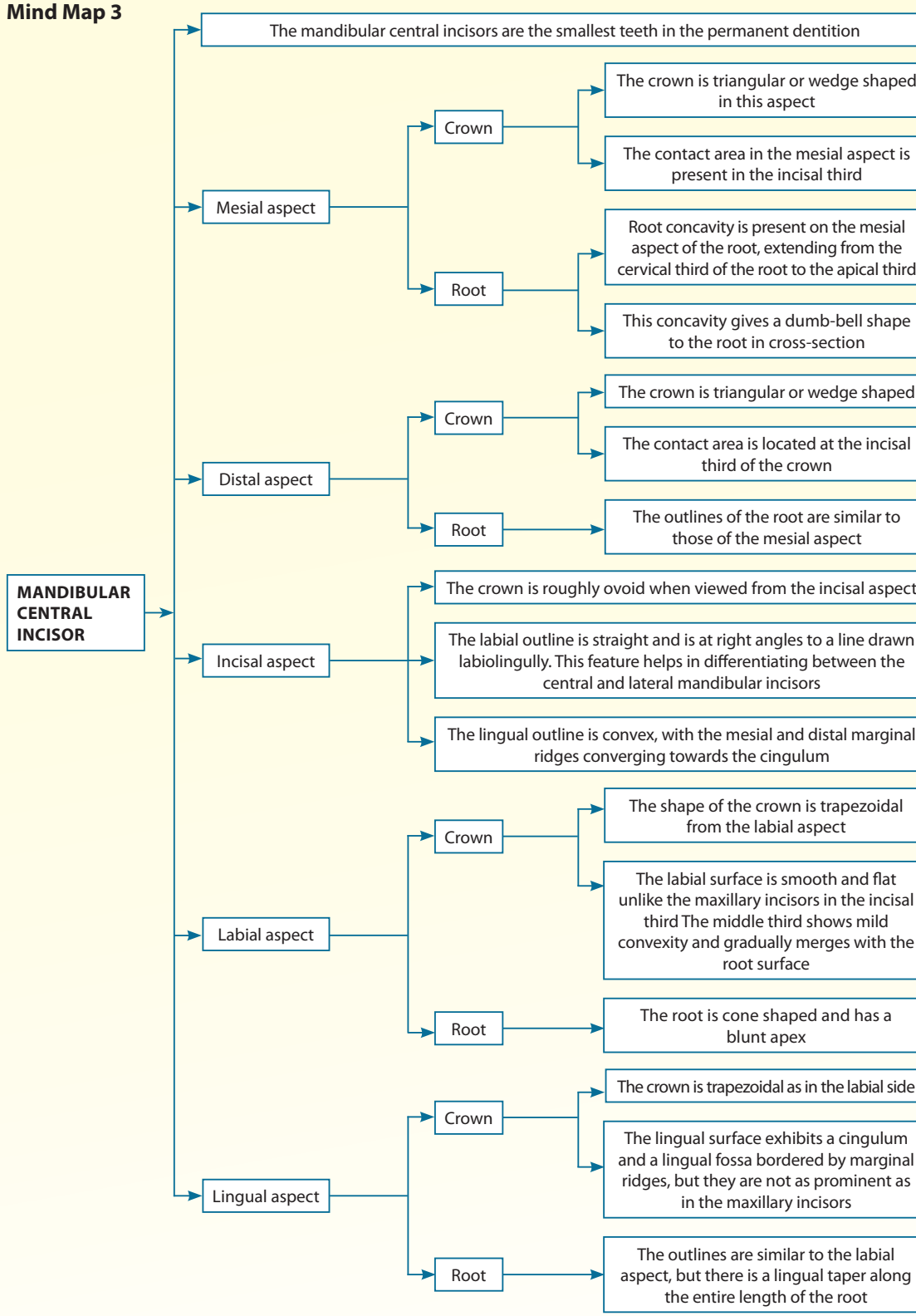
Mind Map 1



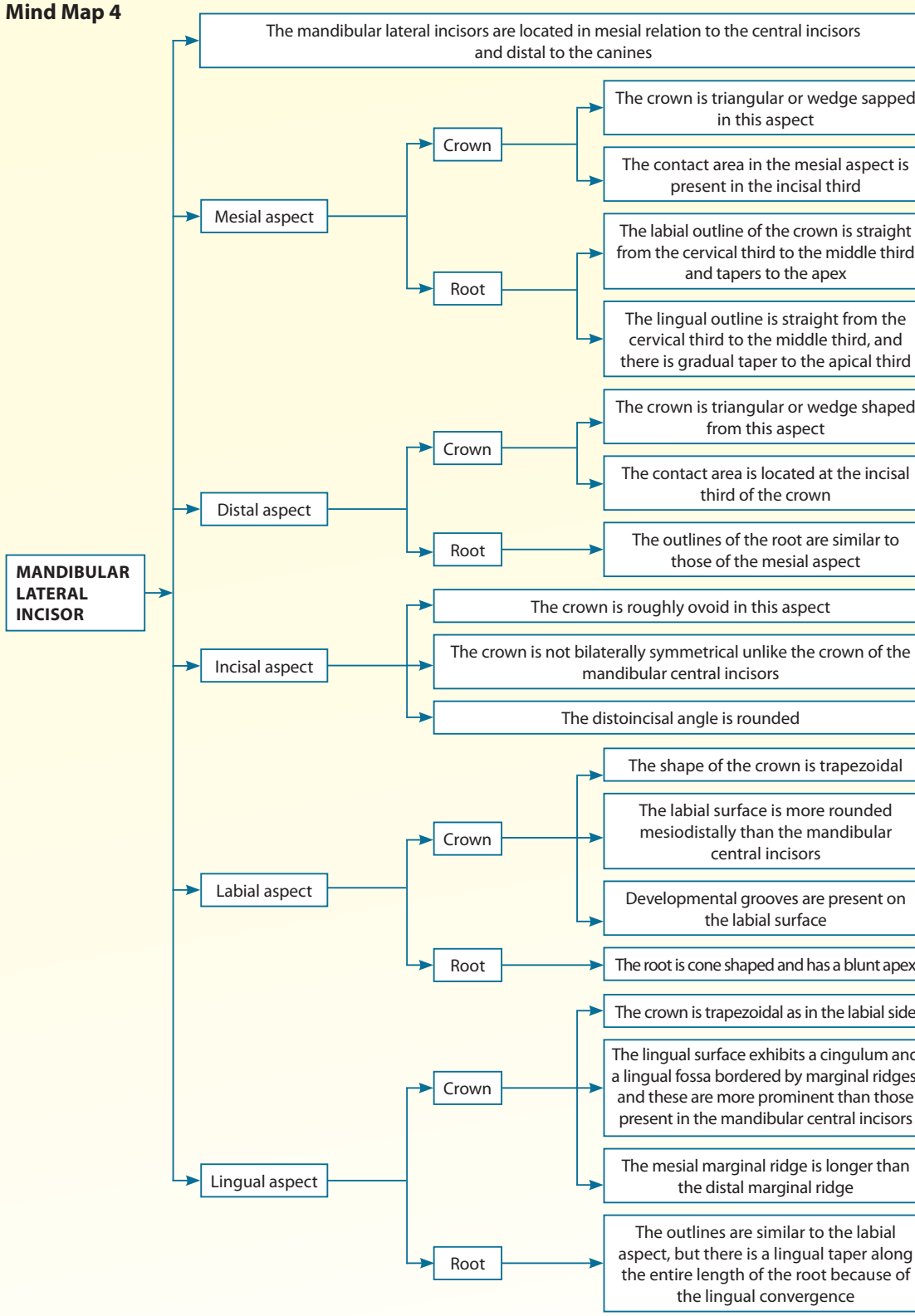
Mind Map 2


MAXILLARY LATERAL INCISOR
Mesial aspect
Crown
The shape of the crown is triangular mesially
The contact area in the mesial aspect is present in the junction of the incisal and middle third
Root
The root is labially straight from cervical and then tapers towards the apex
The lingual outline is convex and then tapers towards the apex
Distal aspect
Crown
The shape of the crown is triangular
The contact area is located at the middle third
Root
The outlines of the root are similar to those of the mesial aspect
Incisal aspect
The crown is round or ovoid in the incisal aspect
Lingually, the cingulum is centred mesiodistally
Labial aspect
Crown
The shape of the crown is roughly ovoid
The mesiodistal width at the cervix is lesser than the mesiodistal width at the incisal third
Root
The root is cone shaped and has a pointed apex
The root is slightly distally inclined
Lingual aspect
Crown
The shape of the crown is the same as the labial aspect
Cingulum is narrower but more prominent than the maxillary central incisor
There is presence of palatogingival groove
Root
The root is the same as that of the labial aspect

Mind Map 3


MANDIBULAR CENTRAL INCISOR
The mandibular central incisors are the smallest teeth in the permanent dentition
Mesial aspect
Crown
The crown is triangular or wedge shaped in this aspect
The contact area in the mesial aspect is present in the incisal third
Root
Root concavity is present on the mesial aspect of the root, extending from the cervical third of the root to the apical third
This concavity gives a dumb-bell shape to the root in cross-section
Distal aspect
Crown
The crown is triangular or wedge shaped
The contact area is located at the incisal third of the crown
Root
The outlines of the root are similar to those of the mesial aspect
Incisal aspect
The crown is roughly ovoid when viewed from the incisal aspect
The labial outline is straight and is at right angles to a line drawn labiolingully. This feature helps in differentiating between the central and lateral mandibular incisors
The lingual outline is convex, with the mesial and distal marginal ridges converging towards the cingulum
Labial aspect
Crown
The shape of the crown is trapezoidal from the labial aspect
The labial surface is smooth and flat unlike the maxillary incisors in the incisal third The middle third shows mild convexity and gradually merges with the root surface
Root
The root is cone shaped and has a blunt apex
Lingual aspect
Crown
The crown is trapezoidal as in the labial side
The lingual surface exhibits a cingulum and a lingual fossa bordered by marginal ridges, but they are not as prominent as in the maxillary incisors
Root
The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root

Mind Map 4


MANDIBULAR LATERAL INCISOR
The mandibular lateral incisors are located in mesial relation to the central incisors and distal to the canines
Mesial aspect
Crown
The crown is triangular or wedge sapped in this aspect
The contact area in the mesial aspect is present in the incisal third
Root
The labial outline of the crown is straight from the cervical third to the middle third and tapers to the apex
The lingual outline is straight from the cervical third to the middle third, and there is gradual taper to the apical third
Distal aspect
Crown
The crown is triangular or wedge shaped from this aspect
The contact area is located at the incisal third of the crown
Root
The outlines of the root are similar to those of the mesial aspect
Incisal aspect
The crown is roughly ovoid in this aspect
The crown is not bilaterally symmetrical unlike the crown of the mandibular central incisors
The distoincisal angle is rounded
Labial aspect
Crown
The shape of the crown is trapezoidal
The labial surface is more rounded mesiodistally than the mandibular central incisors
Developmental grooves are present on the labial surface
Root
The root is cone shaped and has a blunt apex
Lingual aspect
Crown
The crown is trapezoidal as in the labial side
The lingual surface exhibits a cingulum and a lingual fossa bordered by marginal ridges, and these are more prominent than those present in the mandibular central incisors
The mesial marginal ridge is longer than the distal marginal ridge
Root
The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root because of the lingual convergence

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Multiple Choice Questions

1. Which is the smallest tooth in the permanent dentition?
   (a) Maxillary lateral incisor
   (b) Mandibular lateral incisor
   (c) Mandibular central incisor
   (d) Mandibular canine
2. The lingual prominence in an anterior tooth is called the
   (a) Tubercle
   (b) Cingulum
   (c) Ridge
   (d) All of the above
3. Which teeth in the permanent dentition has the maximum labiolingual inclination?
   (a) Maxillary central incisors
   (b) Maxillary lateral incisors
   (c) Mandibular central incisors
   (d) Mandibular canines
4. Evidence of calcification in permanent maxillary central incisors is seen at
   (a) 4 months in utero
   (b) Birth
   (c) 3–4 months
   (d) 10–12 months
5. The roots of which permanent teeth are completed by 10 years?
   (a) Maxillary central incisors
   (b) Maxillary first molars
   (c) Mandibular first molars
   (d) Mandibular lateral incisors
6. Maxillary teeth with the longest crown length are the
   (a) Maxillary canines
   (b) Maxillary first molars
   (c) Maxillary second molars
   (d) Maxillary central incisors
7. The teeth with greater mesiodistal dimensions than labiolingual dimensions are the
   (a) Maxillary central incisors
   (b) Maxillary lateral incisors
   (c) Maxillary central and lateral incisors
   (d) Maxillary canines
8. The widest teeth in the anterior segment of the jaws are the
   (a) Maxillary central incisors
   (b) Maxillary lateral incisors
   (c) Mandibular central incisors
   (d) Mandibular lateral incisors
9. The anterior teeth with the deepest lingual fossa are the
   (a) Maxillary canines
   (b) Maxillary lateral incisors
   (c) Mandibular canines
   (d) Mandibular lateral incisors
10. The depth of curvature of the cervical line at the mesial aspect is highest in the
    (a) Maxillary canine
    (b) Maxillary central incisor
    (c) Mandibular central incisor
    (d) Mandibular first molar

11. The teeth which show wide variations in morphology next to the third molars are the
    (a) Maxillary central incisors
    (b) Maxillary lateral incisors
    (c) Mandibular second molars
    (d) Mandibular lateral incisors
12. Permanent anterior teeth with the smallest mesiodistal dimension are the
    (a) Maxillary central incisors
    (b) Maxillary lateral incisors
    (c) Mandibular central incisors
    (d) Mandibular lateral incisors
13. The lingual aspect of the mandibular incisors has which of the following ridges:
    (a) Incisal, mesial marginal and distal marginal ridges
    (b) Incisal, canine and mesial lingual ridges
    (c) Labial, incisal and mesial marginal ridges
    (d) Transverse, oblique and buccal ridges
14. Contact area of mandibular central incisor is in the
    (a) Junction of middle and cervical third
    (b) Middle third
    (c) Junction of incisal and middle third
    (d) Incisal third
15. Proximal root concavities found on the mandibular central incisors give the following shape to the cross-section of its root:
    (a) Triangular
    (b) Oval
    (c) Dumb-bell
    (d) Square
16. The anterior teeth in which it is difficult to distinguish between the mesial and distal sides are
    (a) Maxillary central incisors
    (b) Maxillary lateral incisors
    (c) Mandibular central incisors
    (d) Mandibular lateral incisors
17. Root depression on the mesial and distal aspects of the root is seen in the
    (a) Mandibular central and lateral incisors
    (b) Maxillary canines
    (c) Maxillary central and lateral incisors
    (d) Maxillary first premolars
18. Which pair of teeth are bilaterally symmetrical?
    (a) Maxillary central incisors
    (b) Mandibular central incisors
    (c) Maxillary lateral incisors
    (d) Mandibular lateral incisors
19. Crown of which tooth gives an appearance of being twisted slightly on its root base?
    (a) Maxillary canines
    (b) Mandibular central incisors
    (c) Mandibular canines
    (d) Mandibular lateral incisors
20. Which of the following is true of the mandibular lateral incisors?
    (a) When viewed incisally, the distal portion of the crown appears twisted lingually.
    (b) The crown is bilaterally asymmetrical when viewed from the labial side with the distal half carrying a major portion of the crown.
    (c) Cervical line is more apically placed on the lingual side than on the labial side.
    (d) All of the above.

CHAPTER 15

Permanent Maxillary and Mandibular Canines

Overview

Canines are the longest and the most stable teeth in the dental arch. One canine tooth is present in each quadrant. Canines are considered the cornerstones of the dental arch. They are the only teeth in the dentition with a single cusp; hence, they are referred to as cuspids. They are also commonly known as 'eye teeth' as they lie directly under the eyes. The labial surface of the permanent maxillary and mandibular canines is convex with a labial ridge. Labial convexity and labial ridge are less prominent in the mandibular counterparts. The lingual surface of the permanent maxillary and mandibular canines is composed of cingulum and lingual ridge with varying degrees of prominence and position. Lingual tubercles are commonly seen in the lingual aspect of permanent maxillary canine. The crowns of the permanent maxillary canine are placed either in line with the root axis or slightly labial to the root axis while that of the permanent mandibular canine are placed lingual to the root axis. The roots of the permanent maxillary canine are long, conical with a blunt apex while those of the mandibular canine are more pointed apically. Developmental depressions are commonly seen in the roots of the permanent mandibular canine.

INTRODUCTION

Canine (Latin *caninus*) means *dog*. Canines are the longest and the most stable teeth in the dental arch. One canine tooth is present in each quadrant. Canines are considered the cornerstones of the dental arch. They are the only teeth in the dentition with a single cusp; hence, they are referred to as cuspids. They are also commonly known as 'eye teeth' as they lie directly under the eyes.

MAXILLARY CANINE (Fig. 15.1)

Maxillary canines, by definition, are the teeth in the maxilla distal to the incisors. They are wider labiolingually than the incisors. Their main function is to help in cutting and shearing of food along with the incisors and premolars.

The chronology and dimensions of maxillary canines are stated in **Boxes 15.1** and **15.2**.

Labial Aspect

1. **Shape of the crown** (**Fig. 15.2**): The crown of the canine is trapezoidal from the labial

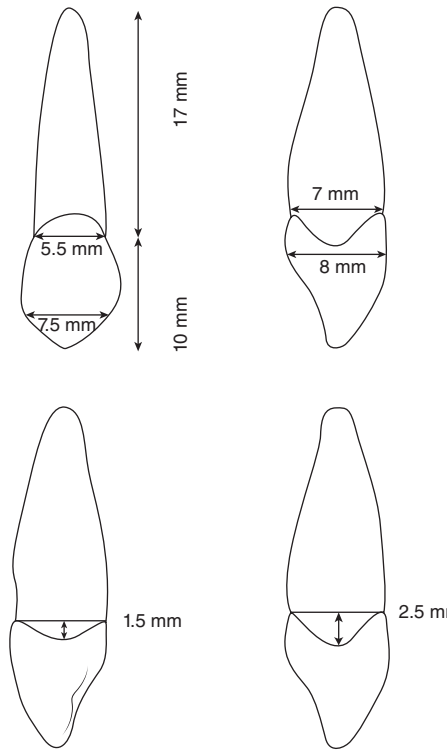


Figure 15.1 Dimensions of the maxillary canine.

Box 15.1 Chronology of the Maxillary Canines

- First evidence of calcification: 4–5 months
- Enamel completion: 6–7 years
- Eruption: 11–12 years
- Root completion: 13–15 years

Box 15.2 Dimensions of the Maxillary Canines

- Length of the crown: 10 mm
- Length of the root: 17 mm
- Mesiodistal width of the crown: 7.5 mm
- Mesiodistal width of the crown at cervix: 5.5 mm
- Labiolingual width of the crown: 8.0 mm
- Labiolingual width of the crown at cervix: 7.0 mm
- Depth of curvature at the mesial aspect: 2.5 mm
- Depth of curvature at the distal aspect: 1.5 mm

aspect. The crown resembles an incisor from this aspect but is smaller than the maxillary central incisors. It also appears asymmetrical from this aspect.

2. **Outlines of the crown** (Fig. 15.3)
   (a) *Mesial outline:* The mesial outline from the cusp tip takes a slope to the contact point and is concave from the contact point to the cervical line.

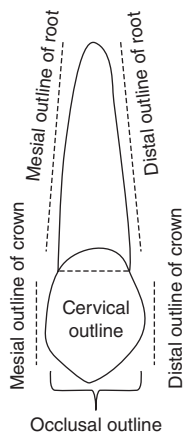


Figure 15.2 Shape of the crown of the maxillary canine in the labial aspect.

   (b) *Distal outline:* The distal outline is S shaped. It is convex towards the contact area and gradually becomes concave towards the cervical line.
   (c) *Incisal outline:* The canine has an incisal edge and is divided into two cuspal slopes, the mesial slope and the distal slope. The slopes meet at right angles but are lost during the wearing away of tooth substance.
   (d) *Cervical outline:* The maxillary canine has a semicircular outline and the curvature is towards the root.

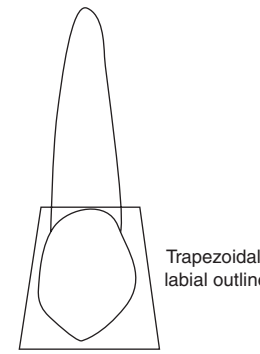


Figure 15.3 Outlines of the crown of the maxillary canine from the labial aspect.

3. **Labial surface** (Fig. 15.4): The labial surface is convex, with a vertical and centrally placed labial ridge extending from the cervical line to the cusp tip. The labial ridge is due to an accentuated development of the middle developmental lobe. Two pronounced grooves

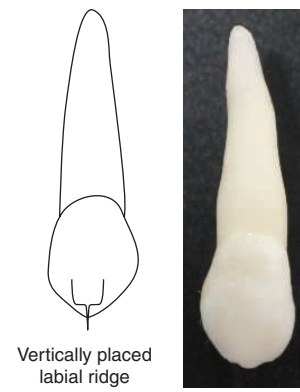


Figure 15.4 Labial surface of the maxillary canine.

separating the mesial, middle and distal developmental lobes are also seen.

4. **Shape of the root:** The root is cone shaped and has a blunt apex. It shows a distal tilt.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third and gradually tapers from the middle third to the apex.
   (b) *Distal outline:* The distal outline is slightly convex from the cervical third to the middle third and gradually tapers from the middle third to the apex. The tip of the root shows a distal inclination.

Lingual Aspect

1. **Shape of the crown:** The shape of the crown is the same as the labial side.
2. **Outlines of the crown:** The outlines of the crown are similar to the labial aspect.
3. **Lingual surface** (Fig. 15.5): The lingual surface has a cingulum and marginal ridges. The cingulum corresponds to the lingual developmental lobe and is larger than that of the incisors. The cingulum adds greatly to the labiopalatal dimensions. There is a lingual ridge extending from the cusp tip to the cingulum dividing the lingual surface into two lingual fossae—the mesiolingual fossa and distolingual fossa. The lingual surface is narrower than the labial surface because of the lingual convergence. The cingulum may exhibit tubercles (round nodule/small eminence). A lingual pit is associated with the tubercles.
4. **Outlines of the root:** The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root leading to decrease in dimension towards the lingual side.

Mesial Aspect

The mesial aspect of maxillary canines is similar to the incisors, but they are more bulky and prominent than the incisors. The mesial surface is more convex except above the contact area and the cervical line where the surface becomes flat.

1. **Shape of the crown** (Fig. 15.6): The mesial aspect of the crown is triangular or wedge shaped with the base towards the root.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline is convex and curves smoothly from the cervical margin to the incisal ridge. Height of convexity is at the cervical third.
   (b) *Lingual outline:* The lingual outline is S shaped. The outline is slightly convex from the cusp tip till the middle third and becomes concave in the middle third. From the middle third, it is convex till the cervical line.
   (c) *Cervical outline:* The cervical curvature is convex towards the incisal edge. The curvature is more than in the distal aspect.
   (d) *Incisal outline:* The incisal ridge forms the apex of the triangular shape of the mesial aspect of the crown. Cusp tip is located labial to the long axis of the tooth.

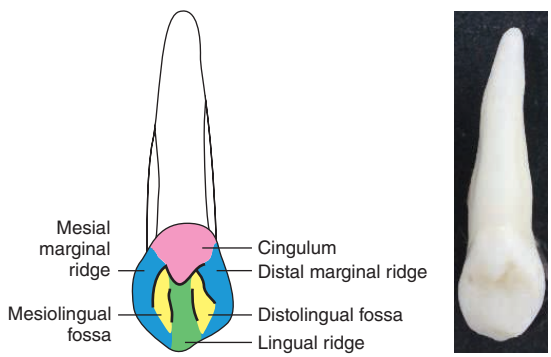


Figure 15.5 Lingual surface of the maxillary canine.

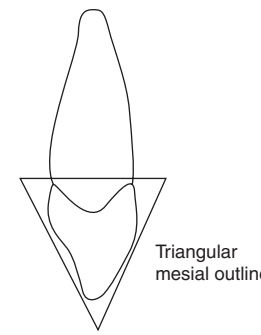


Figure 15.6 Shape of the crown of the maxillary canine in the mesial aspect.

SECTION II

3. **Contact area:** The contact area is at the junction of the middle and incisal third.
4. **Outlines of the root:** The surface of the root on the mesial aspect is broad and has a vertical, shallow depression extending from the cervical line to the apex (**Fig. 15.7**).
   (a) *Labial outline:* The labial outline of the root is slightly convex from the cervical third to the middle third and tapers to the apex.
   (b) *Lingual outline:* The lingual outline is straight from the cervical third to the middle third and there is a gradual taper to the apical third.

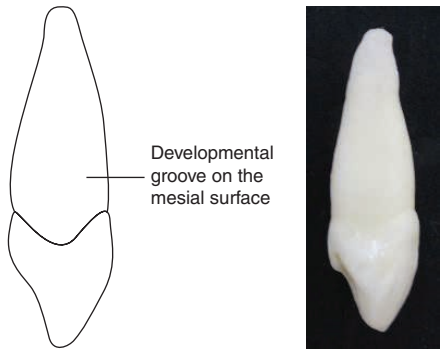


Figure 15.7 Mesial surface of the maxillary canine.

Distal Aspect (Fig. 15.8)

The distal aspect of the crown is bulkier than in the incisors; the distal surface is slightly convex in the incisal third and becomes slightly concave above the contact area.

1. **Shape of the crown:** The distal aspect of the crown is triangular or wedge shaped.
2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect except that they are more convex than in the mesial surface.
3. **Contact area:** The distal contact area is at the centre of the middle third.
4. **Outlines of the root:** The outlines of the root are similar to those of the mesial aspect. The surface of the root from the distal aspect shows a vertical, shallow depression extending from the cervical line to the apex.

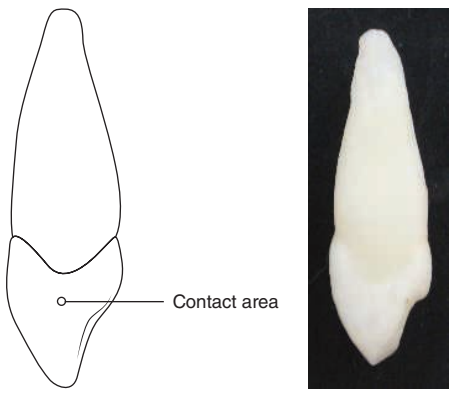


Figure 15.8 Distal aspect of the canine.

Incisal Aspect

1. **Shape of the crown:** The shape of the crown is roughly ovoid in the incisal aspect.
2. **Outlines of the crown** (**Fig. 15.9**): The increased labiolingual dimensions of the canine can be seen from this aspect. The crown outline from this aspect is asymmetrical, with mesial portion of the crown having lesser mesiodistal dimensions.
   (a) *Labial outline:* The labial outline is convex and makes the crown appear bulkier.
   (b) *Lingual outline:* The mesial and distal marginal ridges converge towards the cingulum. The lingual outline is smaller in dimensions than the labial aspect. Two fossae, the mesiolingual fossa and the distolingual fossa, are seen from this aspect.

Variations

1. **Sexual dimorphism:** Maxillary canines exhibit sexual dimorphism (the systematic difference in form between individuals of different sex).
2. **Bushman canine:** It is an extra ridge on the mesial slope of the canine, commonly seen in blacks.
3. **Tuberculum dentale:** It refers to tubercles near the cingulum.
4. **Distal accessory ridge:** It is an extra ridge on the distal marginal ridge.

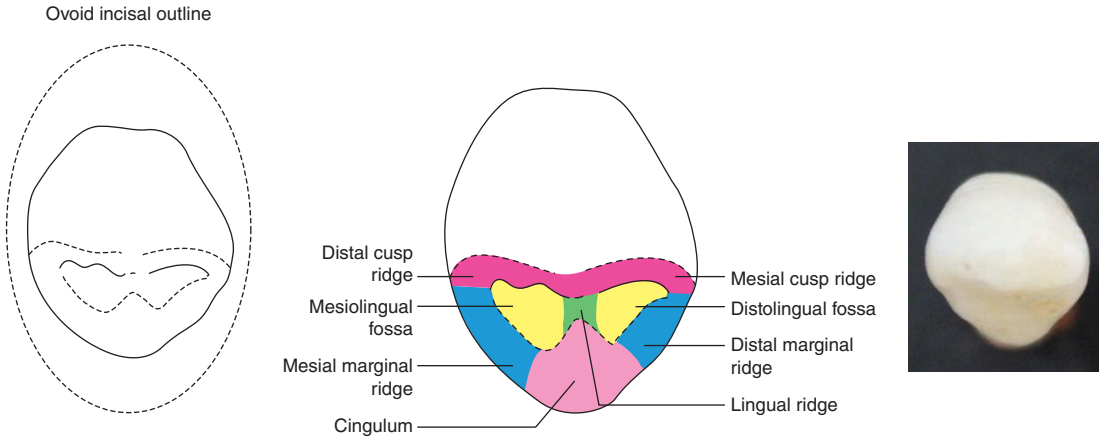


Figure 15.9 Incisal outline of the maxillary canine.

Clinical Considerations: Maxillary Canines

1. The maxillary canines support the lip and the facial muscles. They form the cornerstone of the dental arches. Restorations involving canines should be done keeping this in mind because they have a significant impact on the aesthetics.
2. Maxillary canines are less likely to be affected by dental caries and periodontal problems as their morphology permits self-cleansing activity and increased anchorage.
3. Maxillary canines are impacted frequently due to reduced arch space. Surgical exposure and further orthodontic treatment is required to align them properly.
4. They play a very important role in phonetics (speech).
5. During lateral excursions or movements of the mandible, the upper and lower canines come in contact and prevent the posterior teeth from contacting. This canine guidance is considered the most physiologic of all occlusal relationships because it protects the posterior teeth from wear.
6. Maxillary canines are more prone to ectopic eruption and transposition.
7. The occlusal relationship between the maxillary and mandibular canine is considered for the classification of malocclusion in the absence of first molars.

MANDIBULAR CANINE

The mandibular canines are similar to maxillary canines but narrower mesiodistally and labiolingually. The crown height of the mandibular canine is slightly longer than that of the maxillary canine.

The chronology and dimensions of mandibular canines are stated in **Boxes 15.3** and **15.4**.

Labial Aspect (Fig. 15.10)

1. **Shape of the crown:** The crown of the mandibular canine is trapezoidal.

Box 15.3 Chronology of the Mandibular Canines

- First evidence of calcification: 4 months
- Enamel completion: 7 years
- Eruption: 9–10 years
- Root completion: 13 years

Box 15.4 Dimensions of the Mandibular Canines

- Length of the crown: 11 mm
- Length of the root: 16 mm
- Mesiodistal width of the crown: 7 mm
- Mesiodistal width of the crown at cervix: 5.5 mm
- Labiolingual width of the crown: 7.5 mm
- Labiolingual width of the crown at cervix: 7.0 mm
- Depth of curvature at the mesial aspect: 2.5 mm
- Depth of curvature at the distal aspect: 1 mm

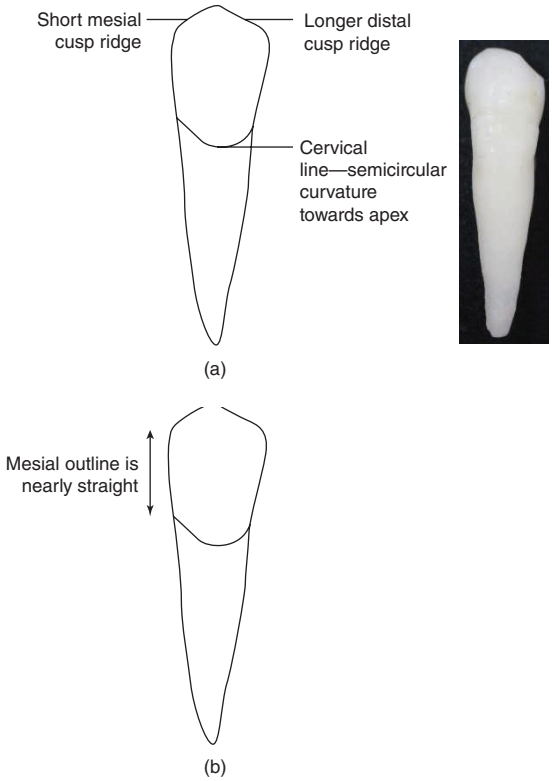


Figure 15.10 Labial aspect of the mandibular canine.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight from the incisal edge to the cervical line and the contact area is located at the incisal third. The outline is straighter than in the maxillary canine.
   (b) *Distal outline:* The distal outline is slightly rounded near the contact area and is straight from the contact area to the cervical line. The contact area is present at the junction of the incisal and middle third.
   (c) *Cervical outline:* The tooth has a semicircular cervical outline and the curvature is towards the root.
   (d) *Incisal outline:* The distal slope is longer and more rounded than the mesial slope. The contact areas on the mesial and distal sides are located at different levels. This feature helps to differentiate between the right and left mandibular canines.
3. **Labial surface:** The labial surface is convex; the convexity is less when compared with maxillary canines.
4. **Shape of the root:** The root is cone shaped and is slightly more pointed than in the maxillary canines.
5. **Outlines of the root:**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third of the root and then gradually tapers from the middle third to the apex. The root has a mild mesial inclination.
   (b) *Distal outline:* The distal outline is very mildly convex from the cervical third to the middle third and gradually tapers from the middle third to the apex.

Lingual Aspect (Fig. 15.11)

1. **Shape of the crown:** The crown is trapezoidal, same as the labial side.
2. **Outlines of the crown:** The outlines are similar to the labial aspect.

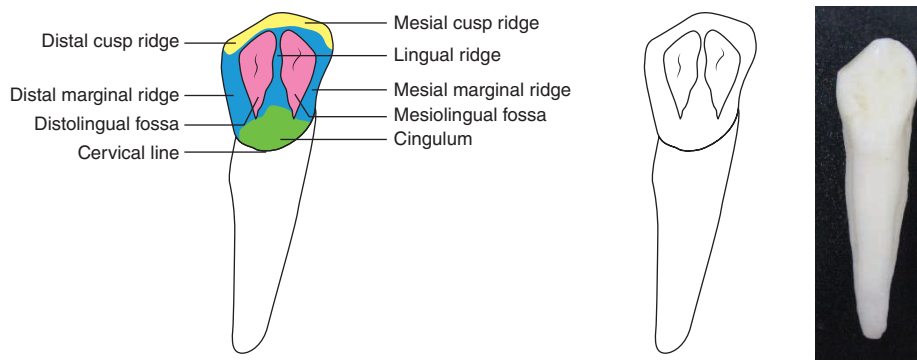


Figure 15.11 Lingual aspect of the mandibular canine.

3. **Lingual surface:** The lingual surface exhibits a cingulum and a lingual fossa bordered by marginal ridges, which are less prominent and smoother than in the maxillary canines.
4. **Outlines of the root:** The outlines are similar to the labial aspect, but there is a lingual taper along the entire length of the root because of the lingual convergence.

Mesial Aspect (Fig. 15.12)

1. **Shape of the crown:** The crown is triangular or wedge shaped from the mesial aspect.
2. **Outlines of the crown**
   (a) *Labial outline:* The labial outline from the crest of curvature shows mild convexity from the incisal edge to the cervical third.
   (b) *Lingual outline:* The lingual outline is S shaped.
   (c) *Cervical outline:* The cervical curvature is convex towards the incisal edge.
   (d) *Incisal outline:* The incisal outline is broader when compared with other mandibular anterior teeth. The cusp tip is either in line with or lingual to the long axis of the tooth.
3. **Contact area:** The contact area in the mesial aspect is present at the incisal third.
4. **Outlines of the root**
   (a) *Labial outline:* The labial outline of the root is straight from the cervical third to the middle third and tapers to the apex.
   (b) *Lingual outline:* The lingual outline is straight from the cervical third to the middle third and there is a gradual taper to the apical third.

Distal Aspect (Fig. 15.13)

1. **Shape of the crown:** The crown is triangular or wedge shaped from the distal aspect.
2. **Outlines of the crown:** The outlines of the crown are similar to those of the mesial aspect.
3. **Contact area:** The contact area is located at the junction of the incisal and middle third.
4. **Outlines of the root:** The outlines of the root are similar to that of the mesial aspect.

Incisal Aspect (Fig. 15.14)

The incisal aspect is asymmetrical with the mesial portion of the crown having greater labiolingual width.

1. **Shape of the crown:** The shape of the crown is roughly ovoid in the incisal aspect.
2. **Outlines of the crown:** The crown shows a lingual tilt.
   (a) *Labial outline:* The labial outline curves towards the distal side as the distal incisal ridge is concave and slants more lingually.
   (b) *Lingual outline:* The lingual outline is convex, with the mesial and distal marginal ridges converging towards the cingulum. The marginal ridges and the lingual fossa are less prominent than in the maxillary canines.

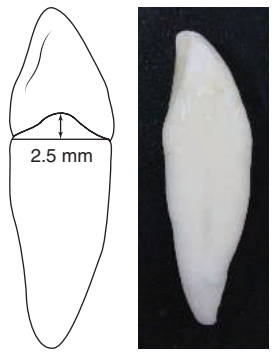


Figure 15.12 Mesial aspect of the mandibular canine.

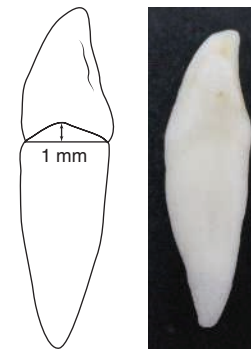


Figure 15.13 Distal aspect of the mandibular canine.

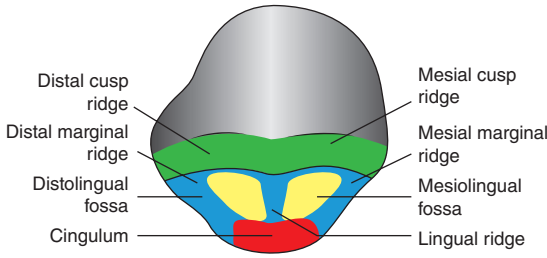


Figure 15.14 Incisal aspect of the mandibular canine.

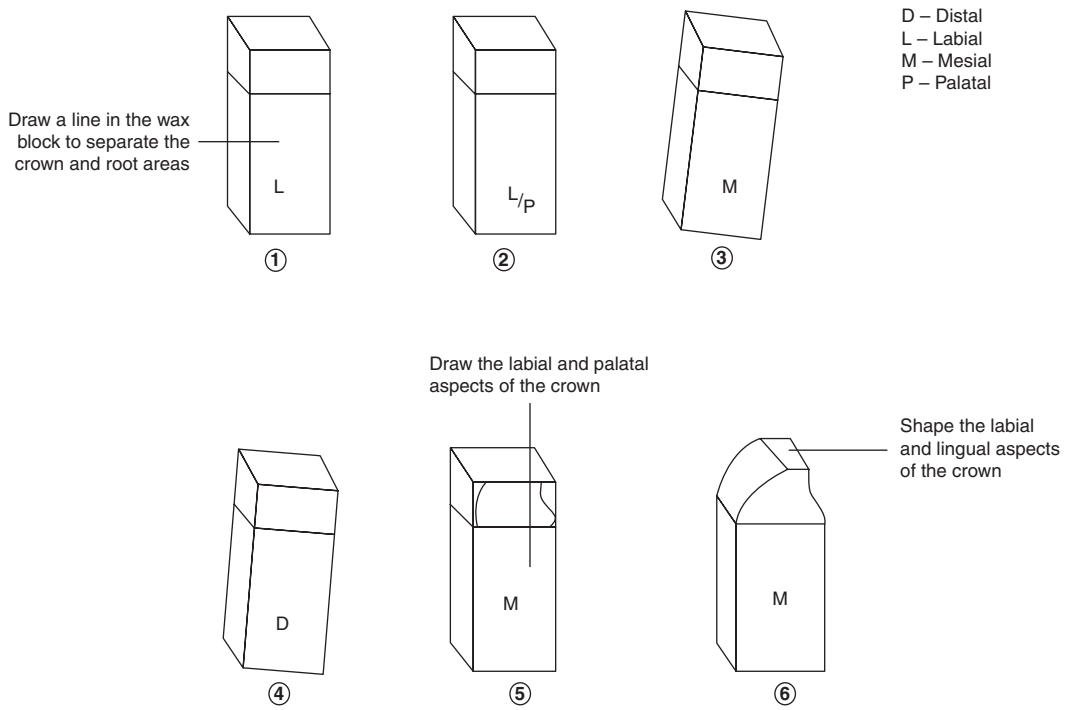
Variation

Although rare, the mandibular canine occasionally presents with two roots, labial and lingual. Among the anterior teeth, the mandibular canine alone presents with this feature.

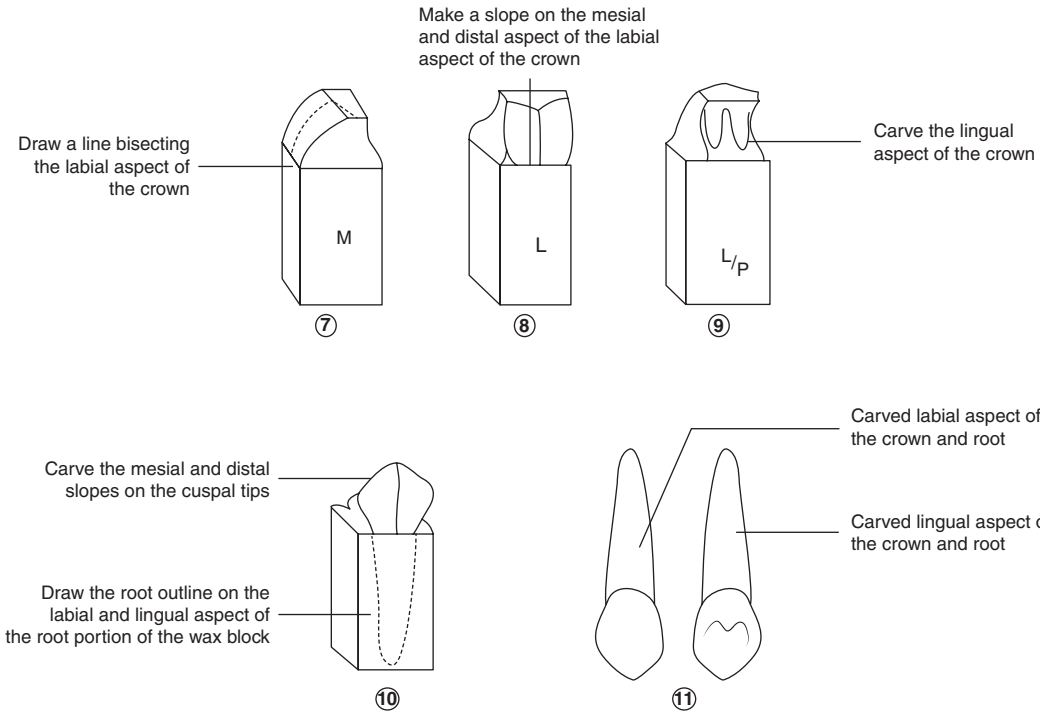
Clinical Considerations: Mandibular Canines

1. The mandibular canines are similar to maxillary canines in that they are also less likely to be affected by periodontal problems and dental caries as their morphology permits self-cleansing activity and anchorage.
2. The mandibular canines assist the maxillary canines during lateral excursions or movements of the mandible and this prevents the posterior teeth from contacting. This canine-guided occlusion is the most physiologic of all occlusal relationships because it protects the posterior teeth from wear.

STEPS FOR CARVING A MAXILLARY CANINE



(*Continued*)



Key Points

Maxillary Canines

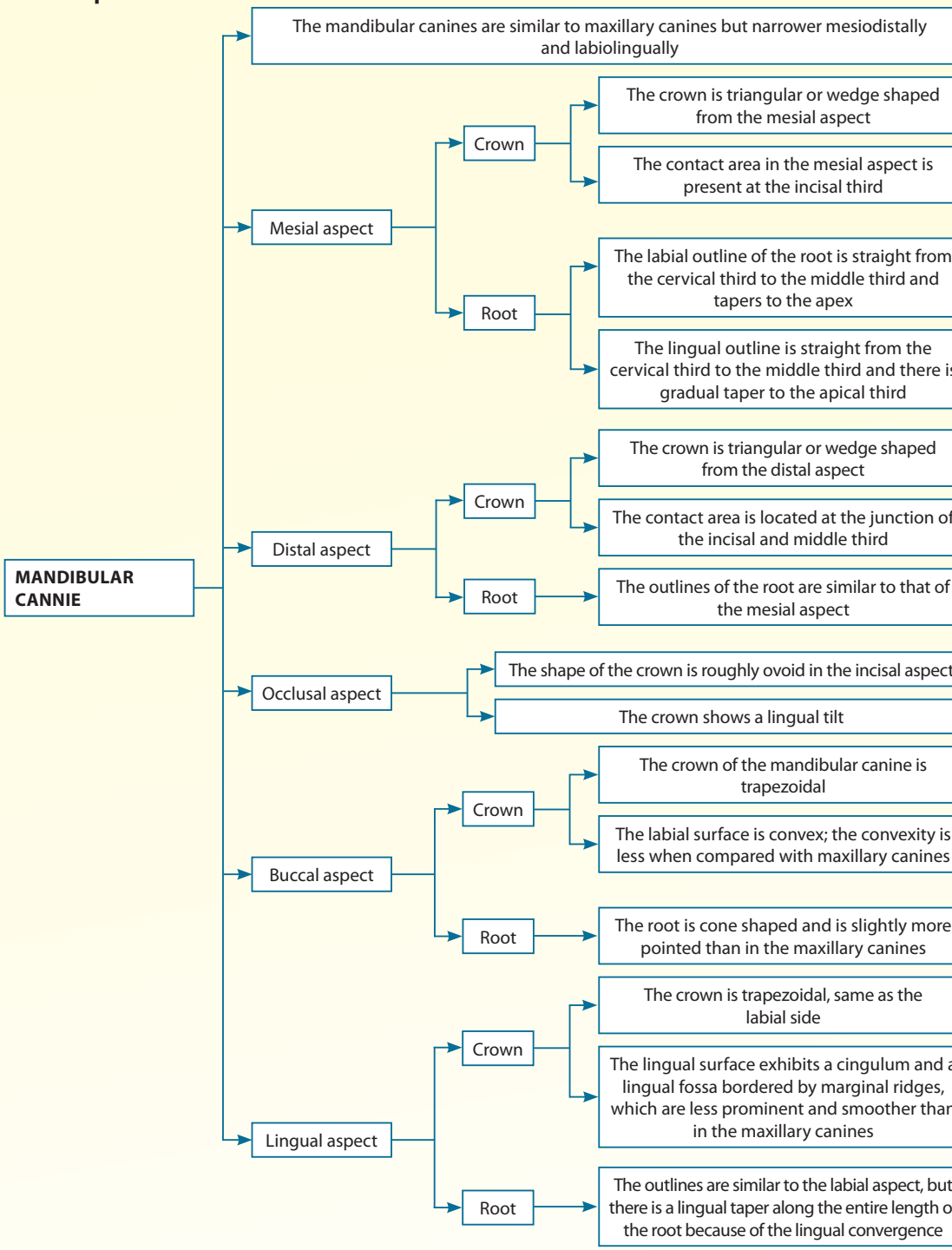
1. The maxillary canines have the longest root when compared with other teeth in the dentition.
2. Canines are referred to as cornerstones of the dental arch.
3. Maxillary canines resemble incisors but are smaller mesiodistally than the incisors.
4. The crown is trapezoidal in the labial and lingual aspects.
5. The crown is triangular/wedge shaped in the mesial and distal aspects.
6. The lingual surface has a prominent lingual ridge which divides the lingual fossa into two: mesial and distal fossae.
7. Canine-guided occlusion protects the posterior teeth from wear and tear.

Mandibular Canines

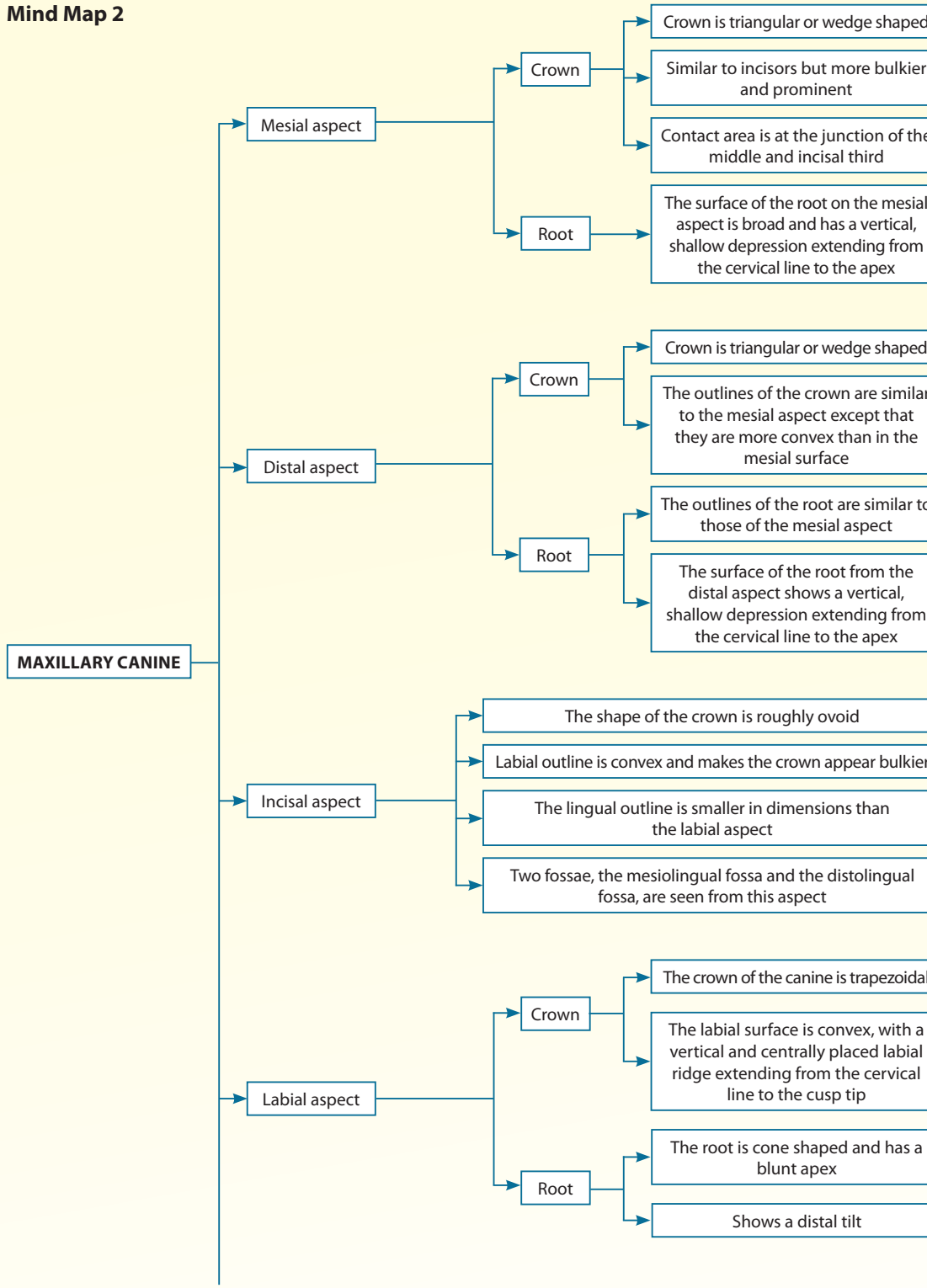
8. The mandibular canines are smaller mesiodistally and labiolingually than the maxillary canines.
9. The crown height of the mandibular canines is slightly longer than that of the maxillary canines.
10. The contact areas in the mesial and distal sides are at different levels, with the mesial contact area at the incisal third and the distal contact area at the junction of the mesial and distal third.
11. The cusp of the mandibular canine has a longer distal than mesial slope.
12. The incisal aspect is asymmetrical with the mesial portion of the crown having greater labiolingual width.

Mind Maps

Mind Map 1

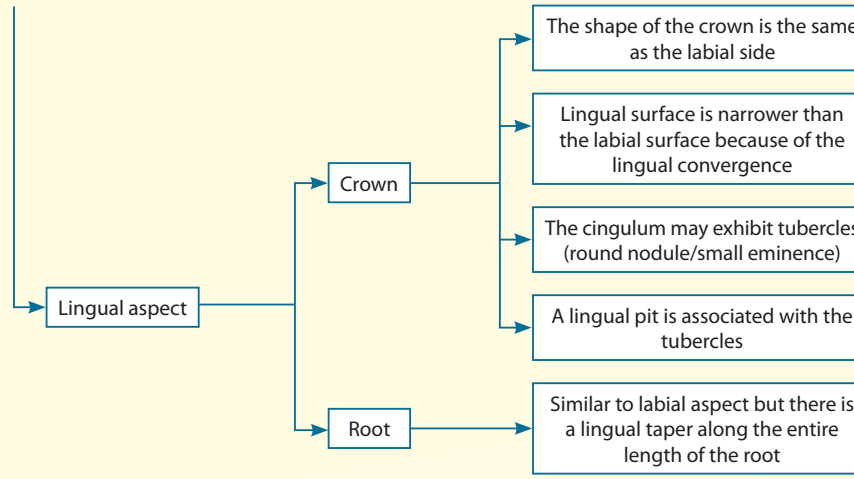


Mind Map 2



(Continued)

(Continued)



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Multiple Choice Questions

1. The longest teeth in oral cavity are the
   (a) Permanent maxillary canines
   (b) Permanent maxillary first premolars
   (c) Permanent maxillary first molars
   (d) Permanent maxillary incisors
2. The cornerstones of the oral cavity are the
   (a) Permanent maxillary canines
   (b) Permanent maxillary premolars
   (c) Permanent maxillary molars
   (d) Permanent mandibular premolars
3. Cingulum shows greater development in the
   (a) Permanent maxillary canines
   (b) Permanent mandibular canines
   (c) Permanent maxillary incisors
   (d) Permanent mandibular incisors
4. Which of the following is not a differentiating feature between the right and left maxillary canines?
   (a) Root curvature is always in distal direction
   (b) Distal half of canine is more convex than mesial half
   (c) Cingulum is more towards distal portion
   (d) Cusp tip is present distal to the line that bisects crown–root
   (e) All of the above

5. The maxillary canine follows which of the following teeth in the eruption sequence of permanent teeth:
   (a) Permanent mandibular canines
   (b) Maxillary lateral incisors
   (c) Mandibular first premolars
   (d) Mandibular second premolars
6. The sharp cusp-like eminence found on cingulum region of the permanent maxillary canine is called the
   (a) Lobe
   (b) Mamelon
   (c) Tubercle
   (d) Cusp tip
7. The permanent anterior teeth with the greatest labiolingual dimensions are the
   (a) Upper laterals
   (b) Lower canines
   (c) Upper canines
   (d) Lower laterals
8. The ridge which divides the lingual fossa into two is called the
   (a) Mesial ridge
   (b) Distal marginal ridge
   (c) Labial ridge
   (d) Lingual ridge
9. The maxillary canine can be distinguished from the mandibular canine by the
   (a) Well-developed cingulum and lingual fossa
   (b) Cusp tips centred over roots
   (c) Short crown and long root
   (d) All of the above
10. The permanent anterior teeth which show sexual dimorphism are the
    (a) Upper laterals
    (b) Lower canines
    (c) Upper canines
    (d) Lower laterals
11. The feature of the mandibular canine that distinguishes it from the maxillary canine is the
    (a) Less prominent facial cusp outline
    (b) Flat lingual fossa
    (c) All of the above
12. The mandibular right and left canines are distinguished by the
    (a) Shorter mesial cusp ridge
    (b) Relatively straight mesial outline
    (c) Long distal cusp ridge
    (d) All of the above
13. The tooth with the longest crown is the
    (a) Maxillary central incisor
    (b) Maxillary canine
    (c) Mandibular central incisor
    (d) Mandibular canine
14. The mesial outline of the labial aspect of the mandibular canine from the contact area to the apex is
    (a) S shaped
    (b) Grooved
    (c) Straight
    (d) Convex
15. The anterior teeth most likely to have bifurcated root are the
    (a) Maxillary canines
    (b) Mandibular canines
    (c) Maxillary central incisors
    (d) Mandibular central incisors
16. The root of permanent mandibular canine is often bifurcated into
    (a) Facial and lingual
    (b) Mesial and distal
    (c) Mesial and lingual
    (d) Facial and distal
17. The mandibular canine differs from the maxillary canine in that
    (a) It has a longer crown and shorter root
    (b) It has less developed cingulum and lingual fossa
    (c) It is less wide mesiodistally
    (d) All of the above
18. Which of the following does the mesial cusp ridge of the permanent mandibular canine oppose in the normal intercuspal position?
    (a) Mesial outline of maxillary canine
    (b) Mesial outline of maxillary lateral incisor
    (c) Distal outline of maxillary canine
    (d) Distal outline of maxillary lateral incisor

CHAPTER 16



Permanent Maxillary and Mandibular Premolars

Overview

The premolar teeth are located between the canine and the molar teeth. Every quadrant has two premolars, with eight premolars in all. Premolars commonly have two cusps and are also therefore referred to as bicuspids. They can be considered as transitional teeth during chewing or mastication. They have properties of both the anterior canines and posterior molars. The buccal surface of the premolars resembles that of a canine tooth.

The maxillary first premolar has two cusps: buccal cusp and lingual cusp. Both the cusps are well developed and well demarcated. The lingual cusp is shorter than the buccal cusp. The mesial marginal groove, which is characteristic of the permanent maxillary first premolar, extends from the mesial marginal ridge and runs from the occlusal third to the middle third of the crown. Buccal root and lingual root are the two roots of the maxillary first premolar. The maxillary first premolar, similar to the anterior teeth, develops from four lobes—the buccal cusp develops from three lobes and the lingual cusp develops from one lobe, but the lingual cusp is better developed than that of the anterior teeth. The maxillary second premolar is similar to the first premolar in form and function. It has two cusps like the first premolar but differs in the root form because it has a single root. Buccal and lingual cusps are of the same height unlike the first premolar. The mesial marginal groove is not evident. Supplementary grooves are commonly seen in the occlusal surface of the second premolar than the first premolar.

The mandibular first premolar has two cusps—buccal cusp and lingual cusp—and a single root. The lingual cusp is shorter than the buccal cusp. A prominent developmental groove called the mesiolingual groove is present over the mesial marginal ridge and found extending in the mesiolingual area of this tooth. The mandibular second premolar resembles the first premolar in the buccal aspect, but lingually this tooth can be of a two-cusp or three-cusp pattern. The three-cusp pattern is composed of mesiolingual, distolingual and buccal cusps while the two-cusp pattern is composed of buccal and lingual cusps. The mesiolingual cusp is not seen in both the premolars, the buccal cusp (more rounded) tip lies in line with the root apex and the lingual cusp extends lingually outside the confines of the root tip. The roots of the mandibular premolars are cone shaped and taper apically. Developmental depressions are commonly seen in the roots of mandibular premolars.

INTRODUCTION

The term *premolar* means *present before the molars*. The premolar teeth are located between the canine and the molar teeth. Every quadrant has two premolars, with eight premolars in all. Premolars commonly have two cusps and are therefore also referred to as *bicuspids*. They can be considered as *transitional teeth* during chewing or mastication. They have properties of both the anterior canines and posterior molars.

MAXILLARY FIRST PREMOLAR

The first maxillary premolar is distal to the permanent canine and mesial to the permanent first molar. The first premolar has two cusps: buccal cusp and lingual cusp. It has two roots: buccal root and lingual root. Similar to the anterior teeth, the maxillary first premolar develops from four lobes—the buccal cusp develops from three lobes

Box 16.1 Chronology of the Maxillary First Premolars

- First evidence of calcification: 1.5–1.75 years
- Enamel completion: 5–6 years
- Eruption: 10–11 years

Box 16.2 Dimensions of the Maxillary First Premolars

- Length of the crown: 8 mm
- Length of the root: 14 mm
- Mesiodistal width of the crown: 7.0 mm
- Mesiodistal width of the crown at cervix: 5.0 mm
- Buccolingual width of the crown: 9.0 mm
- Buccolingual width of the crown at cervix: 8.0 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

and the lingual cusp develops from one lobe, but the lingual cusp is better developed than that of the anterior teeth.

The chronology and dimensions of maxillary first premolars are stated in **Boxes 16.1** and **16.2**.

Buccal Aspect (Fig. 16.1)

The maxillary first premolar resembles a maxillary canine from this aspect. The crown of the maxillary first premolar is wider mesiodistally when compared with other premolars. The crown is wide at the level of the contact areas and narrower at the cementoenamel junction or cervical region.

1. **Shape of the crown:** The crown of the first maxillary premolar is roughly trapezoidal from the buccal aspect.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is slightly concave from the occlusal outline to the contact area. The outline becomes convex near the contact area and is almost straight till the cervical line. The contact area lies in the junction of the occlusal and middle third. The mesial outline is more rounded.
   (b) *Distal outline:* The distal outline is slightly straighter than the mesial outline and converges to the cervical line. The contact area lies at the middle third.
   (c) *Occlusal outline:* The occlusal outline is divided into two cuspal slopes, the mesial slope and the distal slope. The mesial slope is longer than the distal slope. This feature helps in distinguishing right first premolar from the left first premolar.
   (d) *Cervical outline:* The cervical outline is almost straight with a mild convexity towards the root.
3. **Buccal surface:** The buccal surface is convex due to the presence of a *buccal ridge* extending from the cusp tip to the cervical line. The well-developed middle lobe contributes to the formation of the buccal ridge. Imbrication lines and perikymata may be present on the buccal surface; they are present in the cervical third of the crown and extend in the mesiodistal direction.
4. **Root:** Only the buccal root is visible from this aspect. The buccal root is cone shaped and tapers apically.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the buccal root is almost straight to the middle third of the root and gradually tapers from the middle third to the apex.

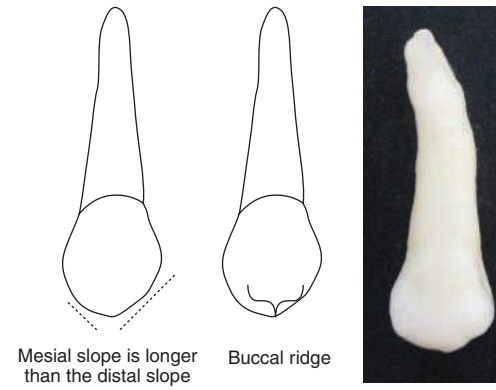


Figure 16.1 Buccal aspect of the maxillary first premolar.

(b) *Distal outline:* The distal outline of the buccal root is slightly convex from the cervical third to the middle third and gradually tapers from the middle third to the apex.

Lingual/Palatal Aspect (Fig. 16.2)

The lingual aspect is rounded in all directions but is smaller than the buccal surface. The lingual cusp is sharp and is narrower mesiodistally than the buccal cusp. The cuspal slopes are not equal in length, and the distal cusp slope, unlike the buccal cusp, is longer than the mesial cusp slope.

1. **Shape of the crown:** The lingual aspect of the crown is the same as the labial side but is more rounded.
2. **Outlines of the crown:** The outlines are similar to the labial aspect.
3. **Lingual surface:** The lingual surface is slightly more convex and has a lingual ridge extending from the cuspal tip to the cervical line. The height of contour is located at the middle third of the crown.
4. **Roots:** The surface of the lingual root is convex. The mesial as well as the distal outlines of the lingual root are almost straight from the cervical line to the apex. There is a lingual taper along the entire length of the root leading to decrease in dimension towards the lingual side. The tip of the buccal root is visible from this aspect as the buccal root is slightly longer than the lingual root.

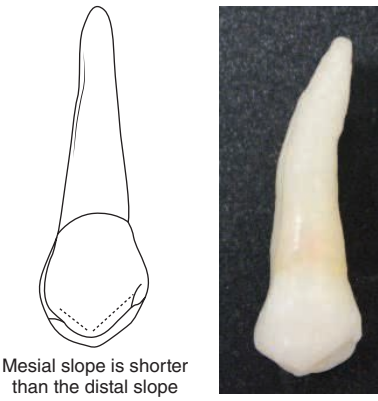


Figure 16.2 Lingual aspect of the maxillary first premolar.

Mesial Aspect (Fig. 16.3)

The mesial surface of the first premolar has a *mesial marginal groove* that extends from the mesial marginal ridge and runs from the occlusal third to the middle third of the crown.

A developmental depression can be seen extending cervically from the mesial contact area. It continues across the cervical line as a deep developmental depression between the roots.

1. **Shape of the crown:** The shape of the crown is trapezoidal, with the longest arm towards the cervical portion and the shortest towards the occlusal portion.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is convex from the cuspal tip to the cervical

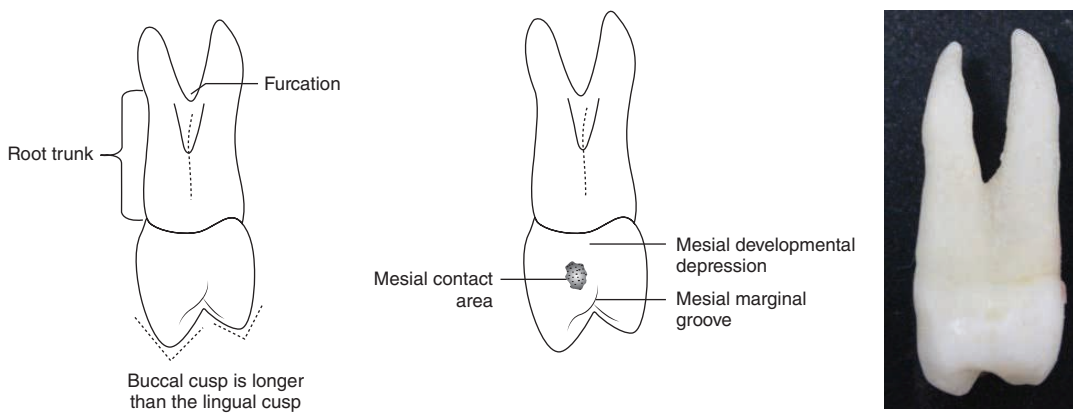


Figure 16.3 Mesial aspect of the maxillary first premolar.

line. The crest of contour is located near the cervical third.

(b) *Lingual outline:* The lingual outline is convex and is more rounded when compared with the buccal aspect. The crest of contour is located within the middle third of the crown.

(c) *Cervical outline:* The cervical curvature is slightly convex towards the occlusal surface. The curvature is more on the mesial aspect with a depth of 1 mm.

(d) *Occlusal outline:* The occlusal outline shows the mesial aspect of the buccal cusp and the lingual cusp. The lingual cusp is shorter than the buccal cusp. Buccal and lingual cusp tips are within the root trunk confines.

3. **Contact area:** Occlusal to the middle third and placed buccally.
4. **Outlines of the root:** The surface of the root on the mesial aspect is broad and has a vertical shallow depression extending from the cervical line to the apex. The root trunk area extending from the cervical line to the furcation can be seen from this aspect.

(a) *Buccal outline:* The buccal outline of the buccal root is convex from the cervical third to the middle third and tapers to the apex. The buccal outline of the lingual root starts from the furcation and slopes straight to the apex.

(b) *Lingual outline:* The lingual outline of the buccal root starts from the furcation area and is slightly convex near the apex. The lingual outline of the lingual root is straight from the cervical line to the apex.

Distal Aspect (Fig. 16.4)

The distal aspect of the crown is similar to the mesial aspect but the developmental depression and the groove is absent on the distal aspect.

1. **Shape of the crown:** The shape of the crown is trapezoidal in the distal aspect.
2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect except that they are more rounded and smooth.
3. **Contact area:** Situated at the same level as the mesial aspect but broader and more buccally placed.
4. **Outlines of the root:** The outlines of the root are similar to the mesial aspect. The surface of the root from the distal aspect shows a vertical shallow depression extending from the cervical line to the apex, but it is not as prominent as in the mesial surface of the root.

Occlusal Aspect

1. **Shape of the crown:** The shape of the crown is roughly hexagonal with six sides. They are the mesiobuccal, mesial, mesiolingual, distolingual, distal and distobuccal sides.
2. **Outlines of the crown:** The crown is wider in the buccal aspect than in the lingual aspect because of the lingual convergence.

(a) *Buccal outline:* The buccal outline is convex and makes the crown appear bulkier from this aspect.

(a) *Lingual outline:* The lingual outline is also convex but its dimensions are smaller than those in the buccal aspect.

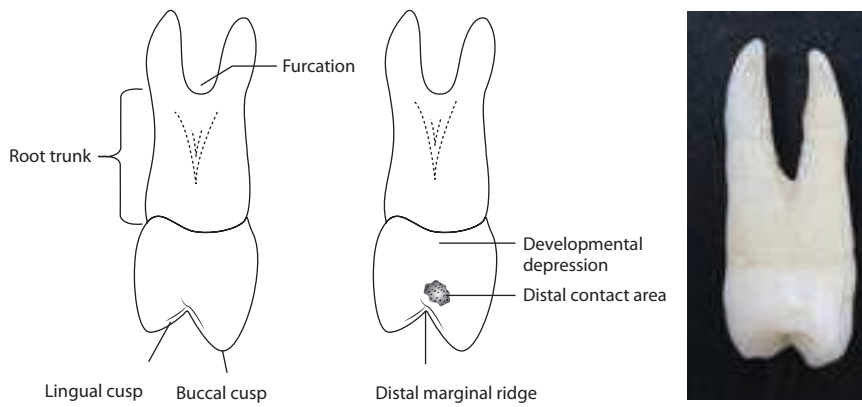


Figure 16.4 Distal aspect of the maxillary first premolar.

(c) *Mesial outline:* The mesial outline is straight and is bordered by the mesial marginal ridge. It is interrupted by a mesial marginal groove.

(d) *Distal outline:* The distal outline is also straight and is bordered by the distal marginal ridge.

3. **Occlusal surface** (**Figs 16.5** and **16.6**): The occlusal surface shows two well-developed cusps, four grooves, two fossae and three ridges.

(a) *Grooves*

- The occlusal surface is divided by a central developmental groove that joins with the mesial marginal groove.
- Two grooves extend from the central groove to the buccal side: mesiobuccal and distobuccal developmental grooves. They form mesial and distal developmental pits in the area of confluence with the central groove.
- Mesial marginal developmental groove extends from the central groove to the mesial marginal ridge and extends to the mesial surface.
- Few supplementary grooves are seen on the occlusal aspect.

(b) *Fossae*

- Mesial triangular fossa is a triangular depression near the mesial marginal ridge.
- Distal triangular fossa is a triangular depression near the distal marginal ridge.

(c) *Ridges*

- Buccal triangular ridge: The mesial and distal cuspal inclines of the buccal cusp join to form a buccal triangular ridge, which extends from the cusp tip to the central groove.
- Lingual triangular ridge: The mesial and distal cuspal inclines of the lingual cusp join to form a lingual triangular ridge, which extends from the cusp tip to the central groove.
- Transverse ridge: The union of the buccal and lingual triangular ridges near the central groove forms this ridge.
  - Distal marginal ridge: It is the ridge which borders the distal triangular fossa.
  - Mesial marginal ridge: It is the ridge which borders the mesial triangular fossa.

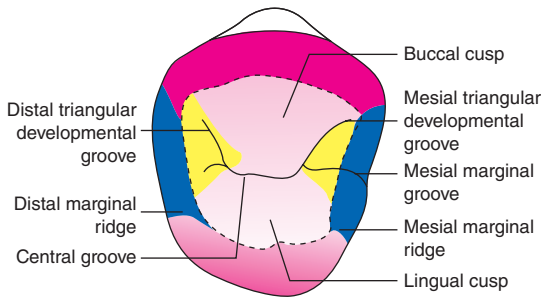


Figure 16.5 Occlusal surface showing the different ridges and grooves of the maxillary first premolar.

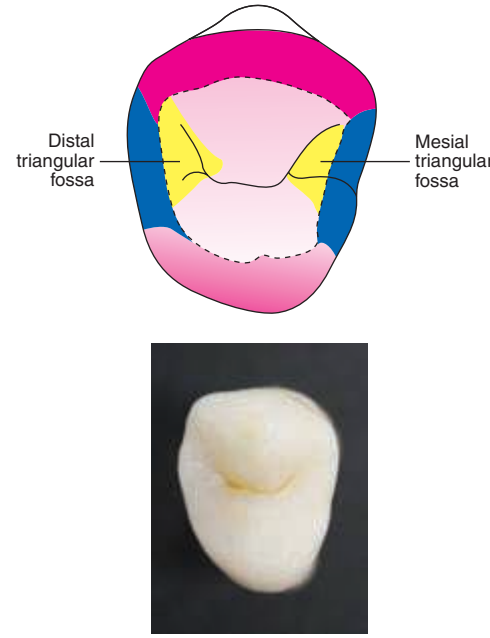


Figure 16.6 Occlusal surface showing the mesial and distal triangular fossae of the maxillary first premolar.

Variations

1. Accessory marginal tubercles may be present on the distal marginal ridge.
2. The *distosaggital ridge*, also called the *UtoAztecan premolar*, is characterized by an exaggerated distobuccal rotation of the buccal

cusp in combination with the presence of a fossa at the intersection of the distal occlusal ridge and distal marginal ridge of upper first premolars. This trait has been found exclusively in native American populations.

3. Rarely, the first premolar may present with a single root or it may be three-rooted.

MAXILLARY SECOND PREMOLAR

The maxillary second premolar is similar to the first premolar in form and function. It has two cusps like the first premolar but differs in the root form because it has a single root.

The chronology and dimensions of maxillary second premolars are stated in **Boxes 16.3** and **16.4**.

Buccal Aspect (Fig. 16.7)

The crown of the maxillary second premolar is smaller mesiodistally and cervico-occlusally when compared with the maxillary first premolar. It looks more rounded than does the crown of the first premolar.

Box 16.3 Chronology of the Maxillary Second Premolars

- First evidence of calcification: 2–2.5 years
- Enamel completion: 6–7 years
- Eruption: 10–12 years
- Root completion: 12–14 years

Box 16.4 Dimensions of the Maxillary Second Premolars

- Length of the crown: 8.5 mm
- Length of the root: 14 mm
- Mesiodistal width of the crown: 7.0 mm
- Mesiodistal width of the crown at cervix: 5.0 mm
- Buccolingual width of the crown: 9.0 mm
- Buccolingual width of the crown at cervix: 8.0 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

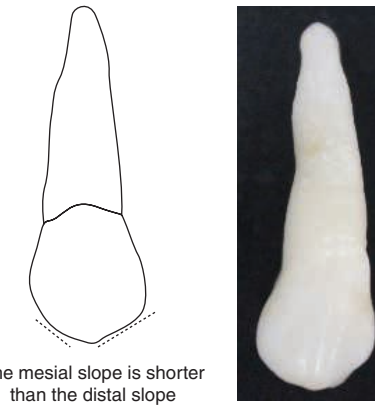


Figure 16.7 Buccal aspect of the maxillary second premolar.

1. **Shape of the crown:** The crown of the second maxillary premolar is roughly trapezoidal from the buccal aspect.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is convex near the contact area and is almost straight till the cervical line.
   (b) *Distal outline:* The distal outline is more rounded than the mesial outline.
   (c) *Occlusal outline:* The occlusal outline is divided into two cuspal slopes, the mesial slope and the distal slope. The mesial slope is shorter than the distal slope unlike that in the maxillary first premolar. The slopes gradually meet at an obtuse angle.
   (d) *Cervical outline:* The cervical outline is almost straight, and there is a mild convexity towards the root.
3. **Buccal surface:** The buccal surface is convex as a result of the buccal ridge extending from the cusp tip to the cervical line. The buccal ridge is less prominent than in the maxillary first premolar.
4. **Shape of the root:** The root is cone shaped and tapers apically.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third of the root and gradually tapers from the middle third to the apex.

(b) *Distal outline:* The distal outline is slightly convex from the cervical third to the middle third and gradually tapers from the middle third to the apex with a distal inclination.

Lingual Aspect (Fig. 16.8)

The lingual aspect is rounded in all directions. The lingual cusp is of the same length as the buccal cusp, unlike the first premolar, where the lingual cusp is smaller than the buccal cusp.

1. **Shape of the crown:** The shape of the crown is the same as in the labial side.
2. **Outlines of the crown:** The outlines are similar to that in the labial aspect.
3. **Lingual surface:** The lingual surface is slightly more convex and has a lingual ridge extending from the cuspal tip to the cervical line. The height of contour is located at the middle third of the crown.
4. **Root:** The root, from this aspect, shows lingual convergence. Distal inclination of the apical third is seen from this aspect.

Mesial Aspect (Fig. 16.9)

The mesial aspect shows the buccal and the lingual cusps. They are of the same length.

1. **Shape of the crown:** The shape of the crown is trapezoidal from the mesial aspect.

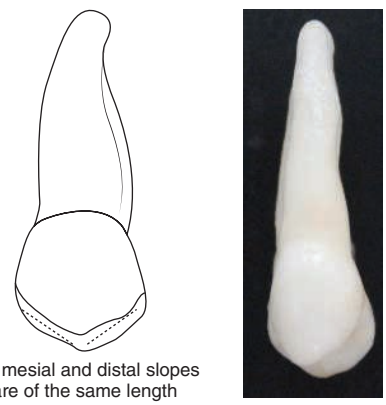


Figure 16.8 Lingual aspect of the maxillary second premolar.

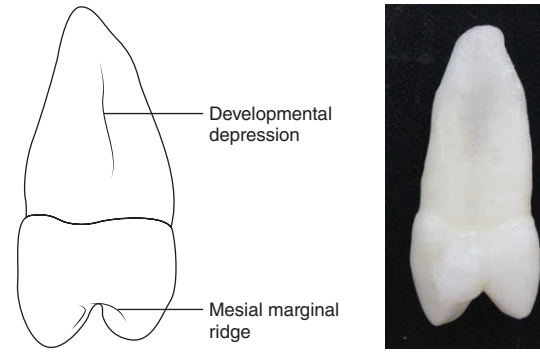


Figure 16.9 Mesial aspect of the maxillary second premolar.

2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is convex, and the height of contour is located within the cervical third of the crown.
   (b) *Lingual outline:* The lingual outline is convex and is more rounded when compared with the buccal aspect. The height of contour is in the middle third of the crown.
   (c) *Cervical outline:* The cervical curvature is convex towards the occlusal edge. The curvature is more on the mesial aspect.
   (d) *Occlusal outline:* The occlusal outline shows the mesial aspect of the buccal cusp and lingual cusp. Both the cusps are of the same height. There is no developmental groove crossing the mesial marginal ridge as in the first premolar.
3. **Contact area:** The contact area in the mesial aspect lies close to the junction of the occlusal and middle third of the crown.
4. **Outline of the root:** The outline of the mesial aspect of the root is convex from the cervical third to the middle third and tapers from the middle third to the apex. The surface of the root on the mesial aspect is broad and has a vertical shallow depression extending from the cervical line to the apex.

Distal Aspect (Fig. 16.10)

The distal aspect of the crown is similar to the mesial aspect, but the developmental depression and the groove are absent on the distal aspect.

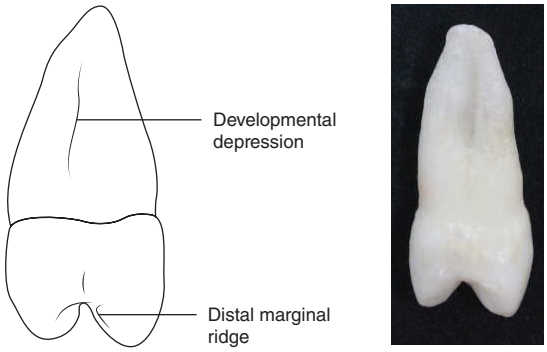


Figure 16.10 Distal aspect of the maxillary second premolar.

1. **Shape of the crown:** The shape of the crown is trapezoidal from the distal aspect.
2. **Outlines of the crown:** The outlines of the crown are similar to that in the mesial aspect except that they are more rounded and smooth.
3. **Contact area:** The contact area is located near the junction of the occlusal and middle third of the crown.
4. **Outline of the root:** The outline of the root is similar to that of the mesial aspect. The surface of the root from the distal aspect shows a vertical shallow depression extending from the cervical line to the apex, but it is not as pronounced as in the mesial surface of the root.

Occlusal Aspect (Fig. 16.11)

The height of the crown is same both buccally and lingually as a result of decreased lingual convergence unlike that of the first premolar. The intercuspal distance is more than that in the maxillary first premolar, thereby making the occlusal aspect wider.

1. **Shape of the crown:** The shape of the crown is ovoid and more rounded when compared with the maxillary first premolar.
2. **Outlines of the crown:** The mesial and distal outlines of the crown are parallel because of lesser lingual convergence, unlike in the maxillary first premolar.
   (a) *Buccal outline:* The labial outline is convex from the occlusal aspect.
   (b) *Lingual outline:* The lingual outline is also convex in this aspect.

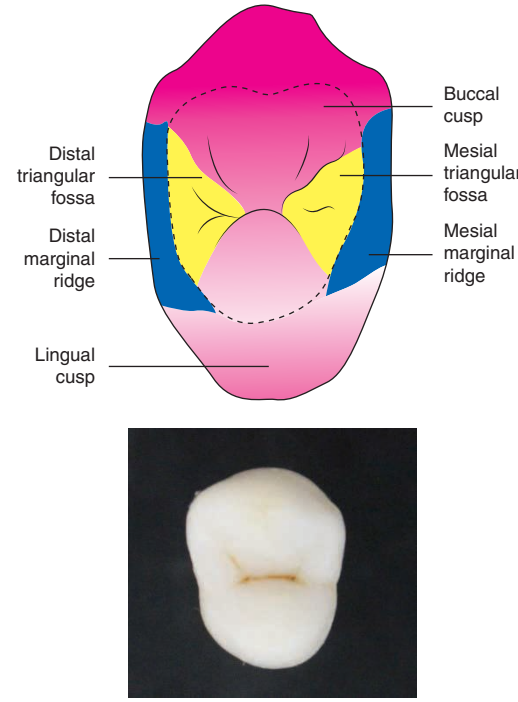


Figure 16.11 Occlusal aspect of the maxillary second premolar.

   (c) *Mesial outline:* The mesial outline is straight and is bordered by the mesial marginal ridge.
   (d) *Distal outline:* The distal outline is also straight and is bordered by the distal marginal ridge.
3. **Occlusal surface:** The occlusal surface shows two well-developed cusps which are of the same height.
   (a) *Grooves*
      - The occlusal surface is divided by a central developmental groove that is shorter and more irregular.
      - More supplementary grooves are present in the second premolar than the first premolar and make its surface appear irregular and wrinkled.
   (b) *Fossae*
      - Mesial triangular fossa is a triangular depression near the mesial marginal ridge.
      - Distal triangular fossa is a triangular depression near the distal marginal ridge.

(c) *Ridges*

- *Buccal triangular ridge*: The mesial and distal cuspal inclines of the buccal cusp join to form a buccal triangular ridge.
- *Lingual triangular ridge*: The mesial and distal cuspal inclines of the lingual cusp join to form a lingual triangular ridge.
- *Transverse ridge*: The union of the buccal and lingual triangular ridges near the central groove forms this ridge.
- *Distal marginal ridge*: It is the ridge which borders the distal triangular fossa.

Clinical Considerations: Maxillary Premolars

1. Maxillary premolars are seen only in permanent dentition.
2. Maxillary first premolars are often extracted for orthodontic treatment in case of space discrepancies.
3. Root canal treatment in maxillary premolars is difficult due to the presence of grooves in the proximal surfaces, and these constrict the root canals.

The differentiating features of maxillary first and second premolars are listed in **Table 16.1**.

MANDIBULAR FIRST PREMOLAR

The mandibular first premolars are present posterior to the mandibular canines and anterior to the mandibular second premolars. They resemble mandibular canines and are smaller in size than the mandibular second premolars.

Box 16.5 Chronology of the Mandibular First Premolars

- First evidence of calcification: 1.5–2 years
- Enamel completion: 5–6 years
- Eruption: 10–12 years
- Root completion: 12–13 years

Box 16.6 Dimensions of the Mandibular First Premolars

- Length of the crown: 8.5 mm
- Length of the root: 14 mm
- Mesiodistal width of the crown: 7 mm
- Mesiodistal width of the crown at cervix: 5 mm
- Labiolingual width of the crown: 7.5 mm
- Labiolingual width of the crown at cervix: 6.5 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

The chronology and dimensions of mandibular first premolars are stated in **Boxes 16.5** and **16.6**.

Buccal Aspect

The crown is bilaterally asymmetrical, and the buccal cusp is large and pointed.

1. **Shape of the crown** (**Fig. 16.12a**): The shape of the crown is trapezoidal in this aspect.

Table 16.1 Differences Between the Maxillary First and Second Premolars

	Maxillary First Premolar	Maxillary Second Premolar
Occlusal aspect	Hexagonal	Ovoid or rectangular
	Supplemental grooves are less in number	Supplementary grooves are more in number making the surface more wrinkled
	Mesial marginal groove is present on the mesial marginal ridge	Mesial marginal groove is absent
	Mesial and distal outlines converge lingually	Mesial and distal outlines are parallel
Buccal aspect	Buccal ridge is prominent	Buccal ridge is less prominent
Cusps	Buccal cusp is larger than the lingual cusp	Both the buccal and lingual cusps are nearly equal in size
Roots	Two roots—buccal and lingual	Single root

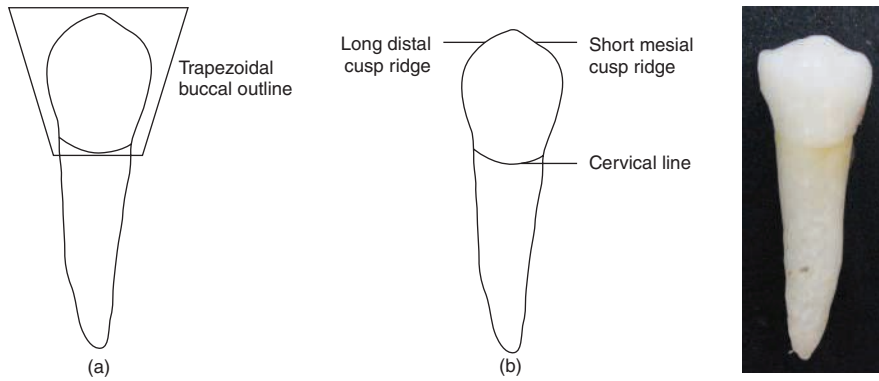


Figure 16.12 Buccal aspect of the mandibular first premolar.

2. **Outlines of the crown** (Fig. 16.12b)
   (a) *Mesial outline:* The mesial outline is straight from the cervical line to the mesial contact area which is located at the junction of the occlusal and middle third. The mesial slope of the buccal cusp shows a mild concavity.
   (b) *Distal outline:* The distal outline is slightly concave from the cervical line to the contact area which is located at the junction of the occlusal and middle third. The distal slope of the buccal cusp also presents with a mild concavity.
   (c) *Cervical outline:* The tooth has a semicircular cervical outline, and the curvature is towards the root. The mesiodistal width at cervix is narrower than at the contact areas.
   (d) *Occlusal outline:* The distal slope is longer than the mesial slope.
3. **Buccal surface:** The buccal surface is more convex when compared with that of the maxillary premolars.
4. **Shape of the root:** The root is cone shaped and is shorter than that of the mandibular canine.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third of the root and then gradually tapers mesially from the middle third to the apex. The root has a mild mesial inclination.
   (b) *Distal outline:* The distal outline is very mildly convex from the cervical third to the middle third and gradually tapers towards the mesial direction from the middle third to the apex.

Lingual Aspect (Fig. 16.13)

1. **Shape of the crown:** The crown is trapezoidal as in the labial side.
2. **Outlines of the crown:** The outlines are similar to the labial aspect.
3. **Lingual surface:** The lingual surface has a lingual cusp which is smaller than the buccal cusp. As the lingual cusp is smaller in size, the occlusal surface can be completely seen from this aspect. The buccal triangular ridge is in line with the lingual cusp. Mesial and distal triangular fossae are seen on either side of the buccal triangular ridge. A prominent developmental

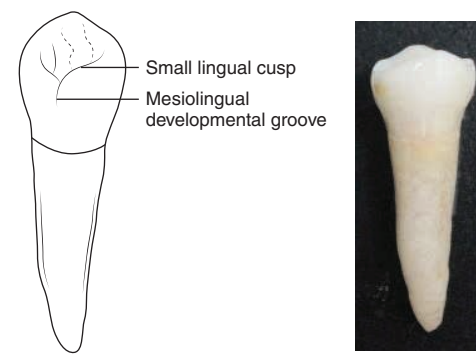


Figure 16.13 Lingual aspect of the mandibular first premolar.

groove called the *mesiolingual groove* is present over the mesial marginal ridge.

4. **Outlines of the root:** The outlines are similar to that in the labial aspect, but there is a lingual taper along the entire length of the root because of the lingual convergence.

Mesial Aspect (Fig. 16.14)

1. **Shape of the crown:** The crown is rhomboidal from this aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline shows prominent convexity, as it curves occlusally from the cervical line to the tip of the buccal cusp. The crest of curvature is present in the cervical third of the crown.
   (b) *Lingual outline:* The lingual outline is less convex when compared with the buccal outline. It is similar to the buccal outline, as the curvature starts at the cervical line and extends to the tip of the lingual cusp. The crest of curvature is present in the middle third of the crown. Mesiolingual developmental groove present over the mesial marginal ridge is evident from this aspect.
   (c) *Cervical outline:* The cervical line is almost straight with a depth of curvature of 1 mm towards the occlusal surface.
   (d) *Occlusal outline:* The buccal cusp and the lingual cusp are seen from this aspect. The buccal cusp tip is in line with the root tip. Lingual cusp is either in line with the root tip or might extend lingually outside the confines of the root tip.
3. **Contact area:** The contact area in the mesial aspect is present at the junction of the occlusal and middle third.
4. **Outlines of the root:** The mesial surface of the root shows a deep developmental groove.
   (a) *Buccal outline:* The buccal outline of the root is slightly convex from the cervical third to the apex.
   (b) *Lingual outline:* The lingual outline is straight from the cervical third to the middle third, and from the middle third there is a gradual taper to the apical third.

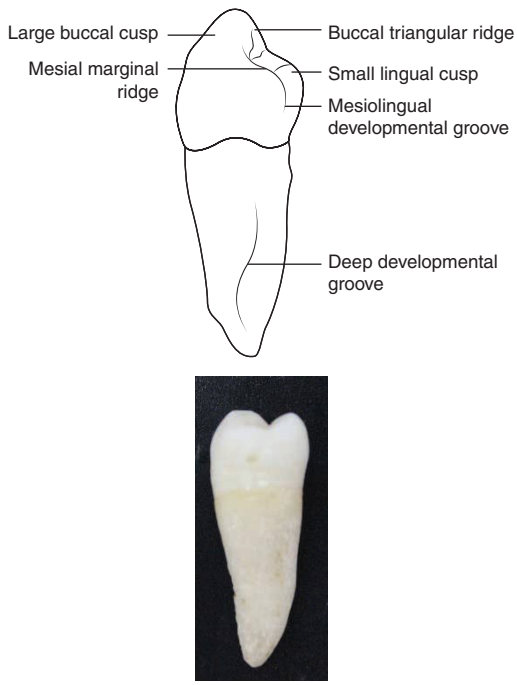


Figure 16.14 Mesial aspect of the mandibular first premolar.

Distal Aspect (Fig. 16.15)

1. **Shape of the crown:** The crown is rhomboidal from this aspect.
2. **Outlines of the crown:** The outlines of the crown are similar to the mesial aspect. The distal marginal ridge is better developed than the mesial marginal ridge. The developmental groove

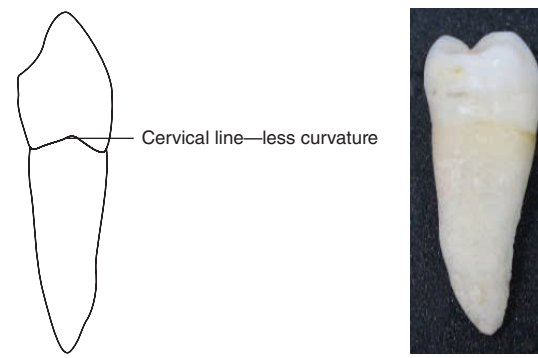


Figure 16.15 Distal aspect of the mandibular first premolar.

present on the mesial marginal ridge in the mesial side is absent on the distal marginal ridge.

3. **Contact area:** The contact area is located at the junction of the occlusal and middle third.
4. **Outlines of the root:** The outlines of the root are similar to those of the mesial aspect, but the developmental groove is shallow and the cervical line shows less curvature.

Occlusal Aspect (Fig. 16.16)

1. **Shape of the crown:** The crown is roughly diamond shaped in the occlusal aspect.
2. **Outlines of the crown:** The crown shows a lingual tilt.
   (a) *Buccal outline:* The buccal outline is convex and is bordered by the mesial and distal slopes of the buccal cusp.
   (b) *Lingual outline:* The lingual outline is convex with the mesial and distal marginal ridges converging towards the lingual cusp.
3. **Occlusal surface**
   (a) *Cusps*
   - *Buccal cusp*: The buccal cusp is larger and more prominent than the lingual cusp. The buccal cusp converges towards the lingual surface.
   - *Lingual cusp*: The lingual cusp is smaller in size when compared with the buccal cusp.

   (b) *Ridges*
   - *Buccal triangular ridge*: This ridge is long and extends from the buccal cusp tip to the central developmental groove.
   - *Lingual triangular ridge*: This ridge is short when compared with the buccal triangular ridge. It extends from the lingual cusp tip to the central developmental groove.
   - *Mesiobuccal cusp ridge*: This ridge is present in the mesial slope of the buccal cusp.
   - *Distobuccal cusp ridge*: This ridge is present in the distal slope of the buccal cusp.
   - *Mesiolingual cusp ridge*: This ridge is present in the mesial slope of the lingual cusp.
   - *Mesial marginal ridge*: This marginal ridge extends from the mesiobuccal cusp ridge to the mesiolingual developmental groove. It is shorter than the distal marginal ridge.
   - *Distal marginal ridge*: This marginal ridge is more prominent than the mesial marginal ridge and extends from the distobuccal ridge to the distal slope of the lingual cusp.

   (c) *Fossae*
   - *Mesial fossa*: It is small and straight/ linear in shape and extends buccolingually. A mesial pit is present in the mesial fossa.
   - *Distal fossa*: This fossa is larger than the mesial fossa. It is crescent shaped/ circular, and a distal pit may be present inside the fossa.

   (d) *Grooves*
   - *Mesiolingual developmental groove*: This is a prominent developmental

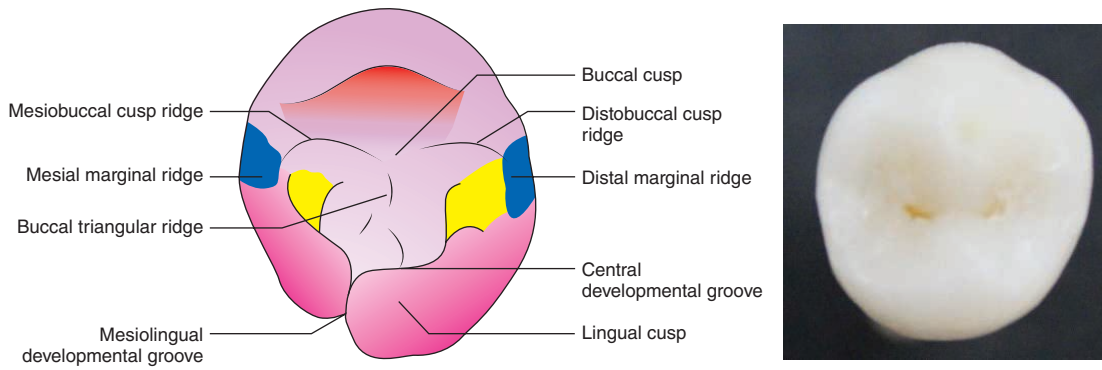


Figure 16.16 Occlusal aspect of the mandibular first premolar.

groove that runs over the mesial marginal ridge.

- *Mesiobuccal triangular groove*: This is present where the buccal triangular ridge slope joins the mesial marginal ridge.
- *Distobuccal triangular groove*: This is present where the buccal triangular ridge slope joins the distal marginal ridge.
- *Central developmental groove*: This groove runs perpendicular to the triangular ridges of the buccal and lingual cusps.

Variation

Although rare, the mandibular first premolar may present with two roots occasionally.

MANDIBULAR SECOND PREMOLAR

The mandibular second premolar is present posterior to the mandibular first premolar and anterior to the molars. The mandibular second premolar is larger than the mandibular first premolar.

The chronology and dimensions of mandibular second premolars are stated in **Boxes 16.7** and **16.8**.

Buccal Aspect

The buccal cusp is smaller than that of the mandibular first premolar but is wider mesiodistally than the first premolar. The buccal aspect is symmetrical. The second premolar resembles the first premolar more in this aspect when compared with other aspects of the first premolar.

1. **Shape of the crown** (**Fig. 16.17a**): The crown is trapezoidal.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is convex from the cervical line to the mesial contact area which is located at the junction of the occlusal and middle third. The mesial slope of the buccal cusp is almost straight.
   (b) *Distal outline:* The distal outline is convex from the cervical line to the contact area which is located at the junction of the occlusal and middle third. The distal slope of the buccal cusp is slightly rounded.
   (c) *Cervical outline* (**Fig. 16.17b**): The buccal aspect of the tooth has a semicircular cervical outline and the curvature is towards the root. The mesiodistal width at cervix is narrower than at the contact areas.
   (d) *Occlusal outline:* The distal slope is longer than the mesial slope.

Box 16.7 Chronology of the Mandibular Second Premolars

- First evidence of calcification: 2–2.5 years
- Enamel completion: 6–7 years
- Eruption: 11–12 years
- Root completion: 13–14 years

Box 16.8 Dimensions of the Mandibular Second Premolars

- Length of the crown: 8.0 mm
- Length of the root: 14.5 mm
- Mesiodistal width of the crown: 7.0 mm
- Mesiodistal width of crown at cervix: 5 mm
- Labiolingual width of the crown: 8.0 mm
- Labiolingual width of the crown at cervix: 7.0 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

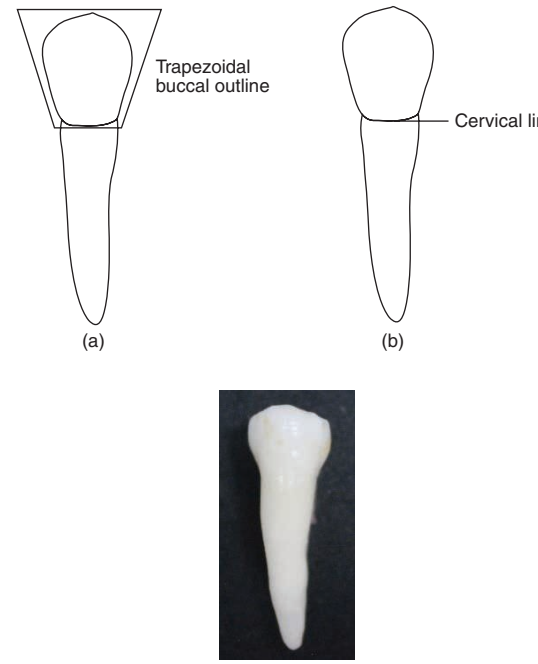


Figure 16.17 Buccal aspect of the mandibular second premolar.

3. **Buccal surface:** The labial surface is more convex when compared with the maxillary premolars.
4. **Shape of the root:** The root is cone shaped and is slightly longer than the root of mandibular first premolar.
5. **Outlines of the root**
   (a) *Mesial outline:* The mesial outline of the root is almost straight to the middle third of the root and then tapers to form a blunt apex.
   (b) *Distal outline:* The distal outline is very mildly concave from the cervical third to the middle third and tapers to form a blunt apex.

Lingual Aspect (Fig. 16.18)

1. **Shape of the crown:** The shape of the crown is trapezoidal as in the labial side.
2. **Outlines of the crown:** The outlines are similar to that in the labial aspect.
3. **Lingual surface:** The lingual surface is more bulbous and spheroidal. The lingual surface has a lingual cusp which is more prominent than that of the mandibular first premolar. This aspect of the mandibular second premolars shows considerable variations as it presents with two types of cuspal patterns—the three-cusp form and the two-cusp form.

   The three-cusp pattern shows the presence of a mesiolingual and distolingual cusp, including the buccal cusp. The mesiolingual cusp is broader than the distolingual cusp. These two lingual cusps are divided by a lingual groove.

   The two-cusp pattern shows one lingual cusp which is more prominent than that of the mandibular first premolar. There is a developmental depression present on the distolingual aspect.
4. **Outlines of the root:** The outlines are similar to those of the labial aspect. The root shows less lingual convergence when compared with the root of mandibular first premolar.

Mesial Aspect (Fig. 16.19)

The crown shows a distinct lingual tilt from this aspect.

1. **Shape of the crown:** The shape of the crown is rhomboidal from this aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline shows prominent convexity, as it curves occlusally from the cervical line to the tip of the buccal cusp. The crest of curvature is present in the middle third of the crown. The cusp is shorter than in the mandibular first premolar.
   (b) *Lingual outline:* The lingual outline is less convex when compared with the buccal outline and the lingual cusp is well-developed when compared with that of the first premolar. The crest of curvature is present in the occlusal third of the crown. The lingual outline is out of the root confines.
   (c) *Cervical outline:* The cervical line is straight with a depth of curvature of 1 mm towards the occlusal surface.

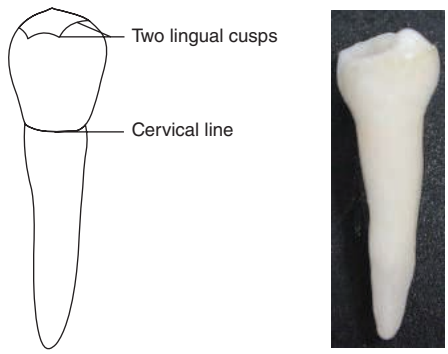


Figure 16.18 Lingual aspect of the mandibular second premolar.

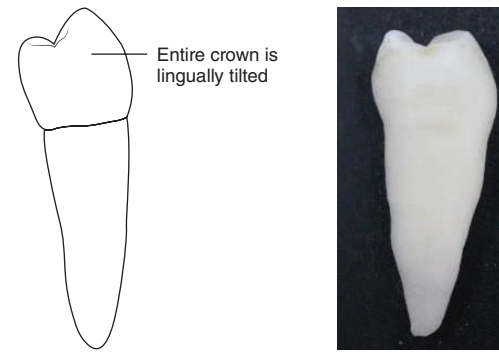


Figure 16.19 Mesial aspect of the mandibular second premolar.

(d) *Occlusal outline:* The buccal cusp and the lingual cusp are seen from this aspect. The buccal cusp tip is not in line to the centre of the root tip because there is a lingual tilt. The marginal ridge is at a right angle to the long axis of the tooth.

3. **Contact area:** The contact area in the mesial aspect is present at the junction of the occlusal and middle third.
4. **Outlines of the root:** The mesial aspect of the root is wider buccolingually.
   (a) *Buccal outline:* The buccal outline of the root is almost straight from the cervical third to the apex.
   (b) *Lingual outline:* The lingual outline is slightly concave from the cervical third to the middle third, and from the middle third there is a gradual taper to form a blunt apex.

Distal Aspect (Fig. 16.20)

1. **Shape of the crown:** The crown is rhomboidal from this aspect.

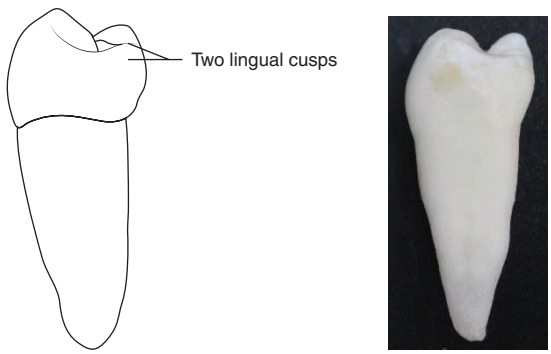


Figure 16.20 Distal aspect of the mandibular second premolar.

2. **Outlines of the crown:** The outlines of the crown are similar to that in the mesial aspect. The distal marginal ridge is at a lower level than the mesial marginal ridge. More of the occlusal surface, that is all the cusps, is seen from this aspect.
3. **Contact area:** The contact area is located at the junction of the occlusal and middle third.
4. **Outlines of the root:** The outlines of the root are similar to that of the mesial aspect, but the developmental groove is shallow.

Occlusal Aspect (Fig. 16.21)

1. **Shape of the crown:** The crown is roughly squarish in the occlusal aspect.
2. **Outlines of the crown:** The crown shows a lingual tilt.
   (a) *Buccal outline:* The buccal outline is convex bordered by the mesial and distal slopes of the buccal cusp.
   (b) *Lingual outline:* The lingual outline varies with the two-cusp pattern and the three-cusp pattern.
3. **Occlusal surface** (Fig. 16.22)
   (a) *Cusps*
   - *Y pattern or the three-cusp pattern*: The shape of the occlusal outline is square. The three cusps are the buccal cusp and the two lingual cusps (the mesiolingual cusp and the distolingual cusp). The mesial developmental groove, distal developmental groove and the lingual groove converge into the central pit.
   - *U pattern/H pattern or the two-cusp pattern*: The shape of the occlusal

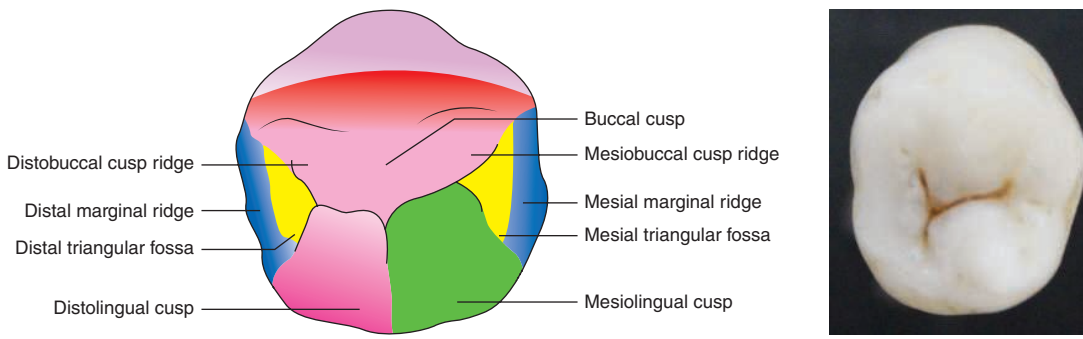


Figure 16.21 Occlusal aspect of the mandibular second premolar.

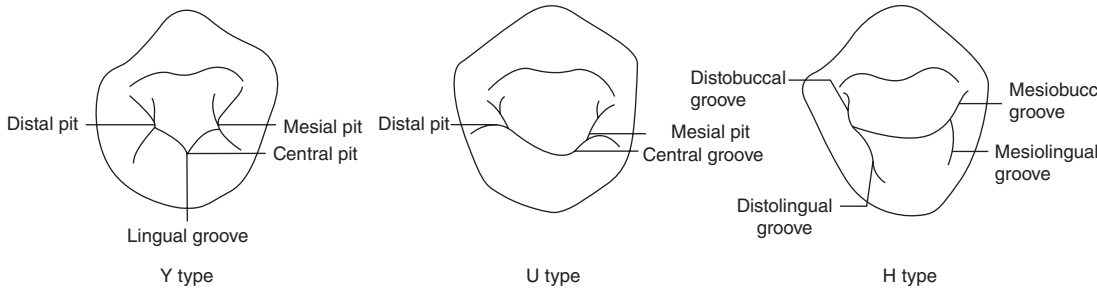


Figure 16.22 Occlusal aspect of the mandibular second premolar showing types of groove pattern.

outline is round to ovoid. The two cusps in this type are the buccal and the lingual cusps.

In the U pattern, the central pit is absent. A central groove runs from the mesial to the distal pit. Two grooves run from the mesial and distal pits towards the buccal aspect.

The H pattern is similar to the U pattern. In addition, two grooves run towards the lingual aspect, giving rise to the H pattern.

(b) *Ridges*
- *Triangular ridges*: All the cusps have well-developed triangular ridges.
- *Mesial marginal ridge*: This ridge is straight and is placed at a more occlusal level than the distal marginal ridge.
- *Distal marginal ridge*: This ridge is slightly concave and is located more cervically when compared with the mesial marginal ridge.

(c) *Fossae*
- *Central fossa*: It is located at the middle of the occlusal surface.
- *Triangular fossae*: Two triangular fossae are present on the inner aspect of the mesial and distal marginal ridges.

(d) *Grooves*: The grooves form Y pattern, U pattern and H pattern depending on the central developmental groove.
- *Central groove*: The central groove is present between the two ridges and extends to the mesial and distal marginal ridges.
- *Mesiobuccal groove*: This groove begins in the mesial pit and runs towards the mesial marginal ridge.
- *Distobuccal groove*: This groove extends from the distal pit to the distal marginal ridge.
- *Lingual groove*: This is present between the two lingual cusps and extends to the lingual surface.
- *Mesiolingual groove*: This groove extends from the mesial pit and runs towards the lingual direction; it is seen in the H-type groove pattern.
- *Distolingual groove*: This groove extends from the distal pit and runs towards the lingual direction; it is seen in the H-type groove pattern.

Variation

The presence of additional lingual cusps is a variation seen in which tooth.

Clinical Considerations: Mandibular Premolars

1. In the mandibular first premolars, the mesial and distal pits in the mesial and distal fossae are prone to dental caries.
2. The lingual inclination of the teeth in the mandibular first premolars causes difficulty in instrumentation.
3. Difficulty in maintaining the lingual aspect leads to periodontal problems in the mandibular first premolars.
4. The mandibular second premolar is frequently impacted because of the premature loss of the

deciduous mandibular second molar. The permanent mandibular first molar which is present adjacent to the deciduous mandibular second molar drifts into the space to be occupied by the mandibular second premolar.

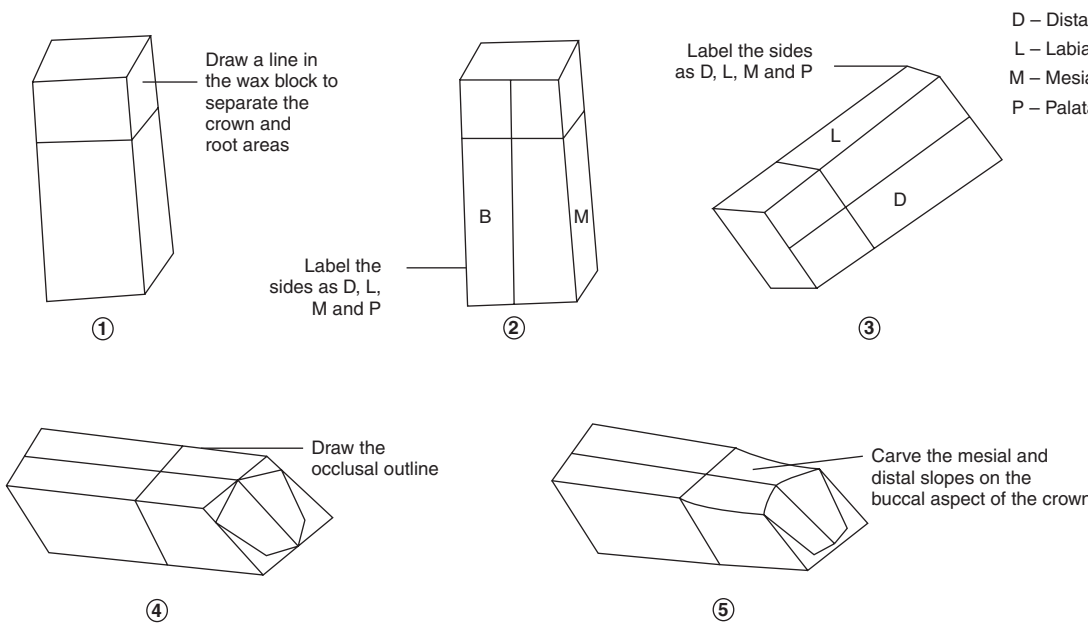
5. A developmental aberration called as Dens evaginatus usually affects the mandibular premolar that presents as an additional cusp in the centre of the occlusal surface. If affected such premolars are called as Leong's premolar.

The differentiating features of mandibular first and second premolars are listed in **Table 16.2**.

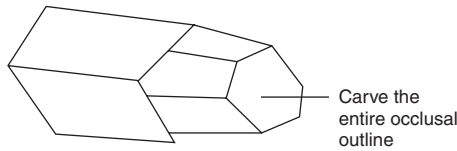
Table 16.2 Differences Between the Mandibular First and Second Premolars

Aspect	Mandibular First Premolar	Mandibular Second Premolar
Occlusal aspect		
Occlusal outline	Diamond shaped	Squarish
Mesial and distal margins	Lingual convergence seen	Parallel to each other
Central pit	Absent	Present
Lingual tilt	Present	Absent
Labial aspect	Asymmetrical buccal cusp	Symmetrical buccal cusp
Lingual aspect	Narrower lingual surface due to lingual convergence	Broader lingual surface when compared with the first premolar

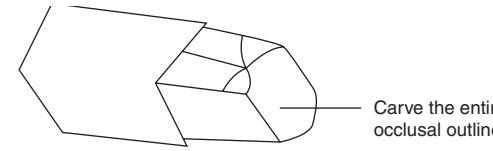
STEPS FOR CARVING A MAXILLARY FIRST PREMOLAR



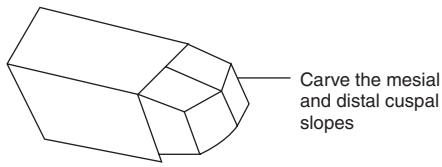
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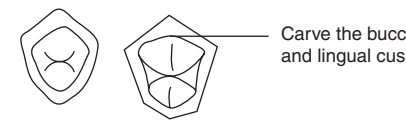
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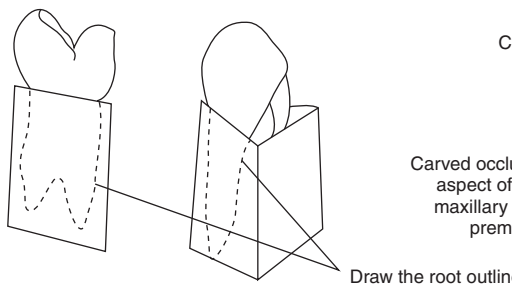
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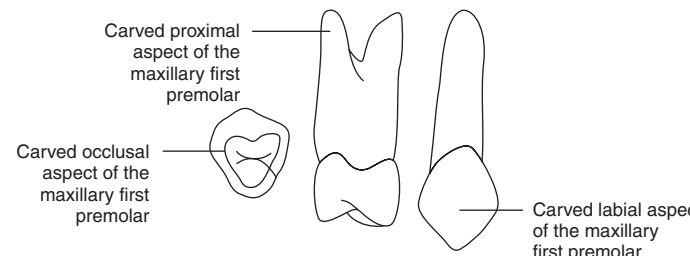
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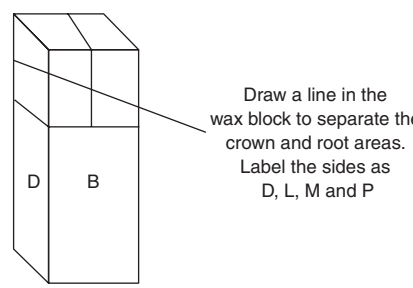


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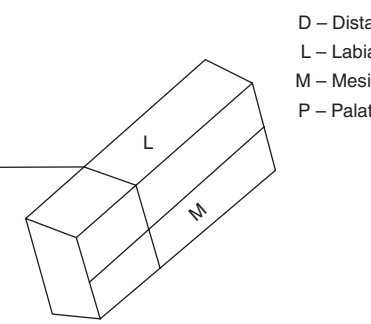


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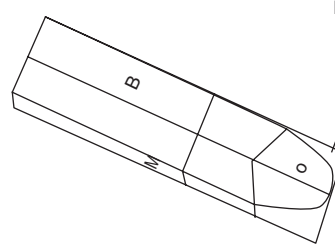
STEPS FOR CARVING A MANDIBULAR FIRST PREMOLAR



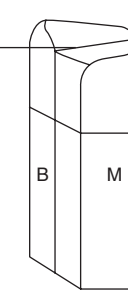
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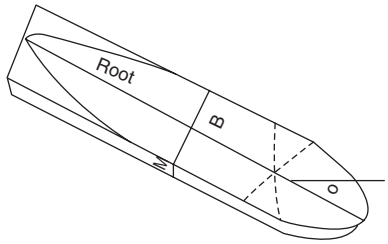


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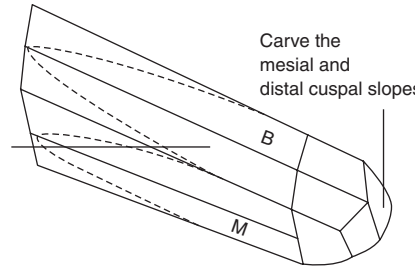


Carve the entire occlusal outline

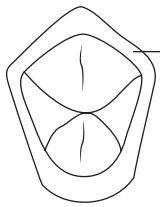
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Draw the root outlines on all sides

Carve the mesial and distal cuspal slopes

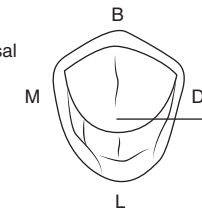


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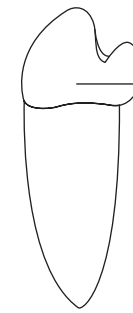


Carve the occlusal aspect of the mandibular first premolar

⑦



Carved occlusal aspect of the mandibular first premolar

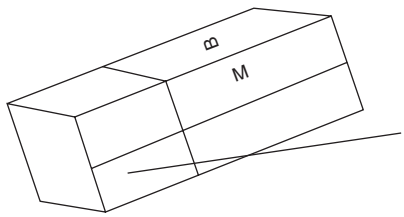


Carved proximal aspect of the crown and root

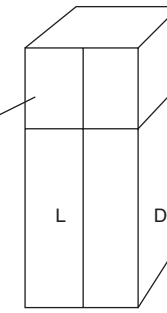
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STEPS FOR CARVING A MANDIBULAR SECOND PREMOLAR

D – Distal
L – Labial
M – Mesial
P – Palatal

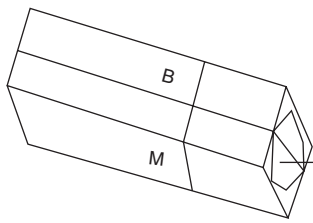


Draw a line in the wax block to separate the crown and root areas. Label the sides as D, L, M and P



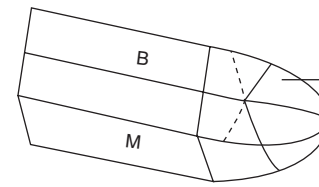
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Draw the occlusal outlines

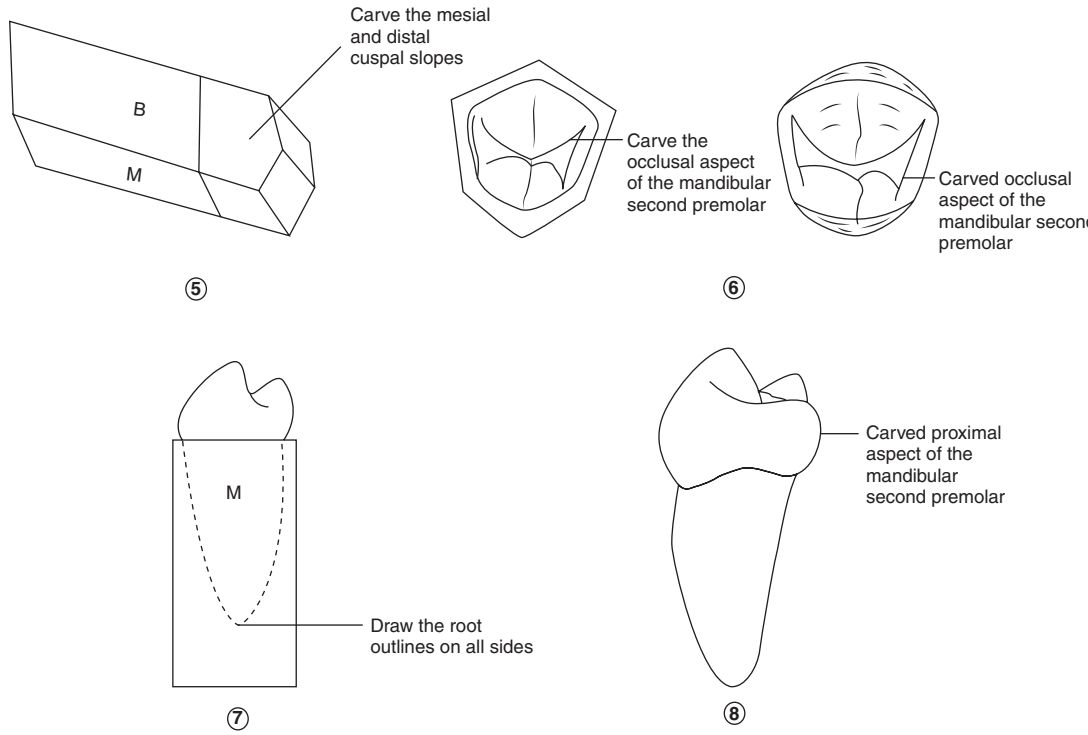
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Carve the occlusal outlines on all sides

④

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Key Points

Maxillary First Premolars

1. The crown of the first premolar is roughly trapezoidal.
2. The lingual cusp is smaller than the buccal cusp.
3. Mesial developmental depression is present on the mesial surface of the root.
4. The occlusal aspect is roughly hexagonal.
5. The mesial contact area lies in the junction of the occlusal and middle third.
6. The distal contact area lies in the middle third.

Maxillary Second Premolars

7. The maxillary second premolar has a single root unlike the first premolar.
8. Both the buccal and the lingual cusps are of the same height.
9. Lingual convergence of the crown is less when compared with that in the first premolar.
10. Mesial developmental groove on the mesial marginal ridge is absent.

Mandibular First Premolars

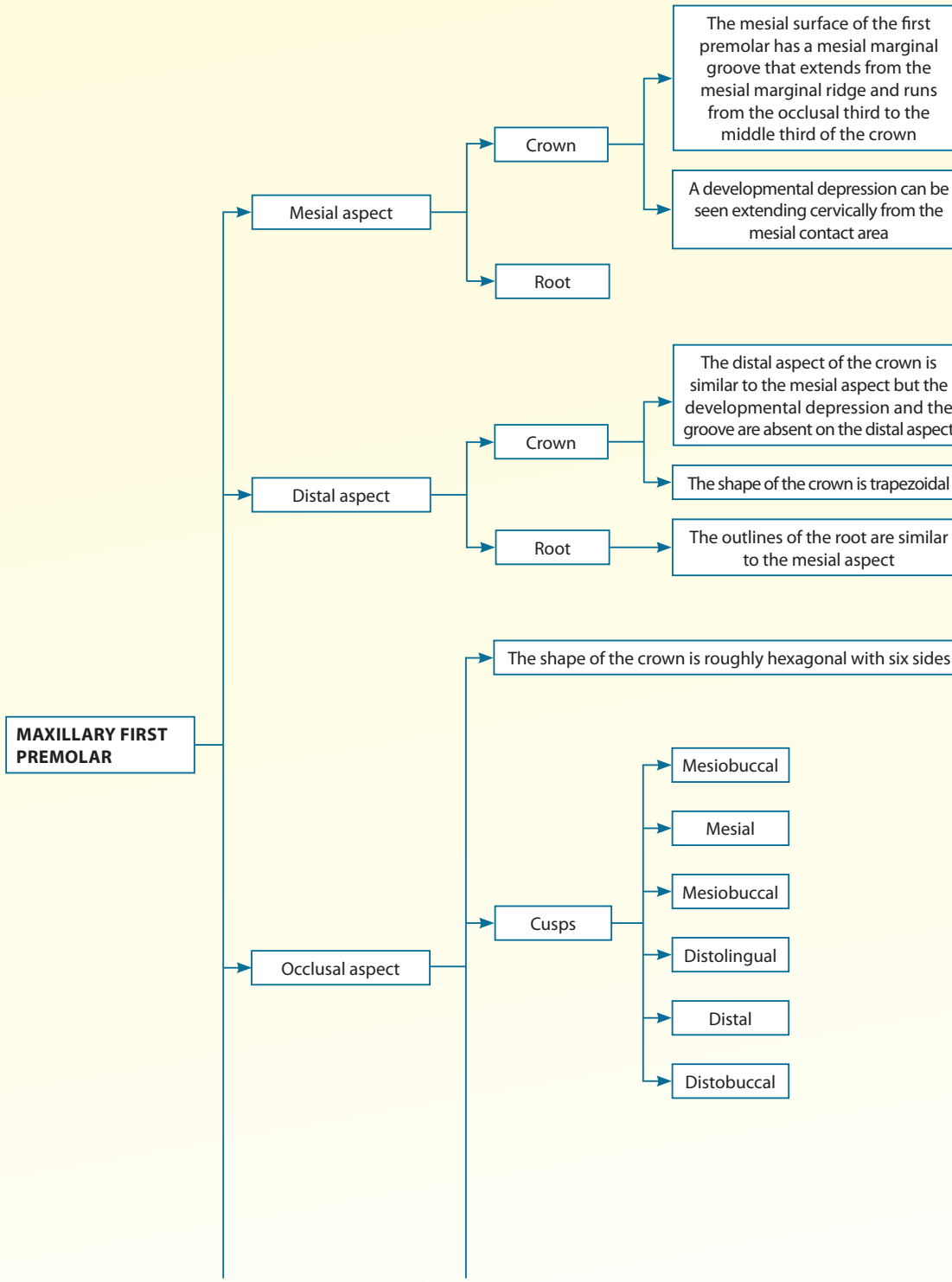
11. The mandibular first premolars resemble mandibular canines.
12. They are smaller in size than the mandibular second premolars.
13. The labial and lingual aspects of the mandibular first premolar are trapezoidal.
14. The mesial and distal aspects of the mandibular first premolar are rhomboidal.
15. The root surfaces, both on the mesial and distal aspects, exhibit developmental depressions.
16. The mesiolingual developmental groove present over the mesial marginal ridge makes the mesial marginal ridge appear shorter.

Mandibular Second Premolars

17. The mandibular second premolar is larger than the mandibular first premolar.
18. The labial and the lingual aspects are trapezoidal, the mesial and the distal are rhomboidal.
19. The lingual cusps exhibit two-cusp or three-cusp patterns and are well developed when compared with that of the mandibular first premolar.
20. The buccal cusps are more rounded when compared with that of the mandibular first premolar.
21. Two types of groove patterns—Y type and U type—are seen in the mandibular second premolar.

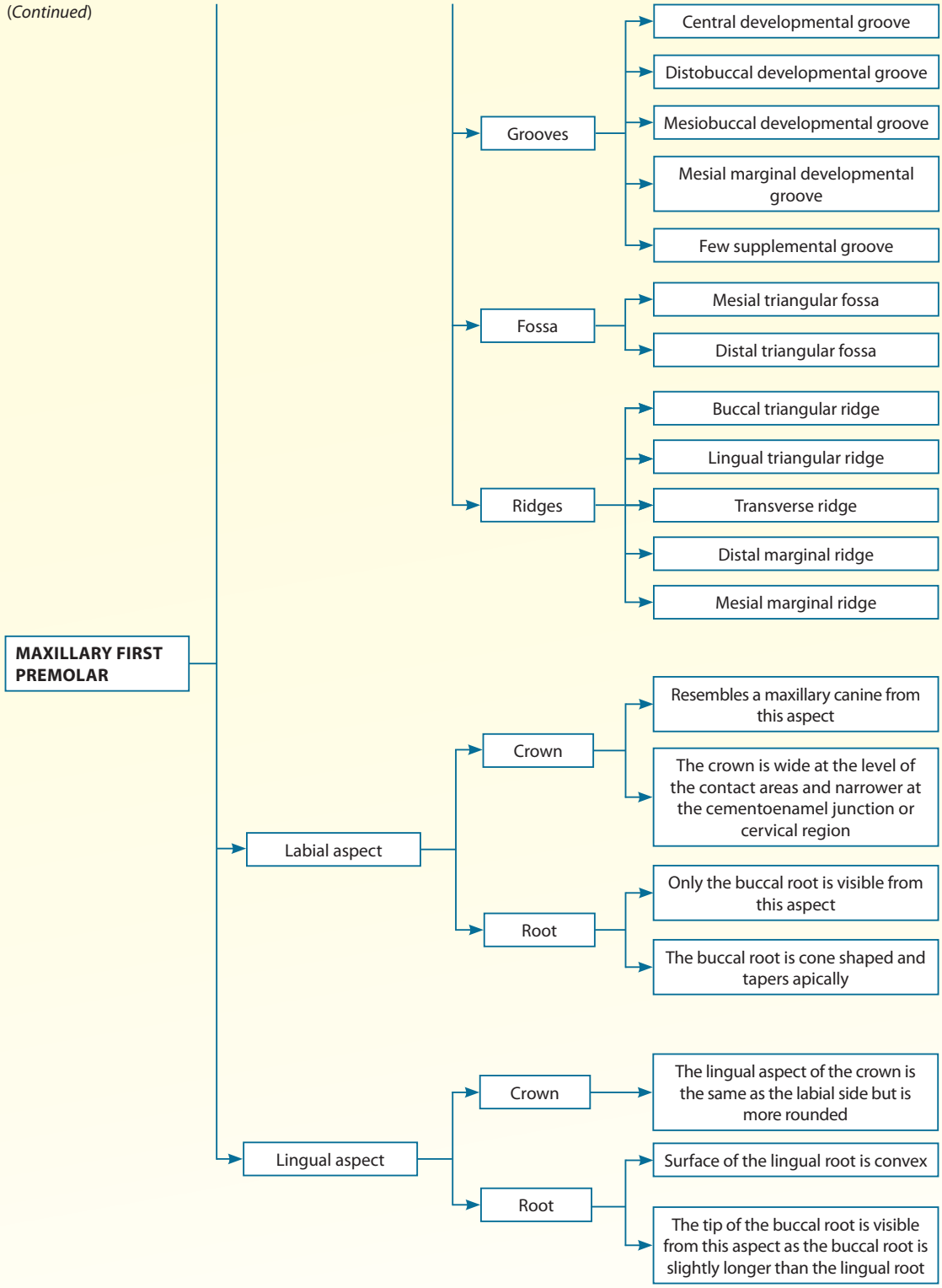
Mind Maps

Mind Map 1

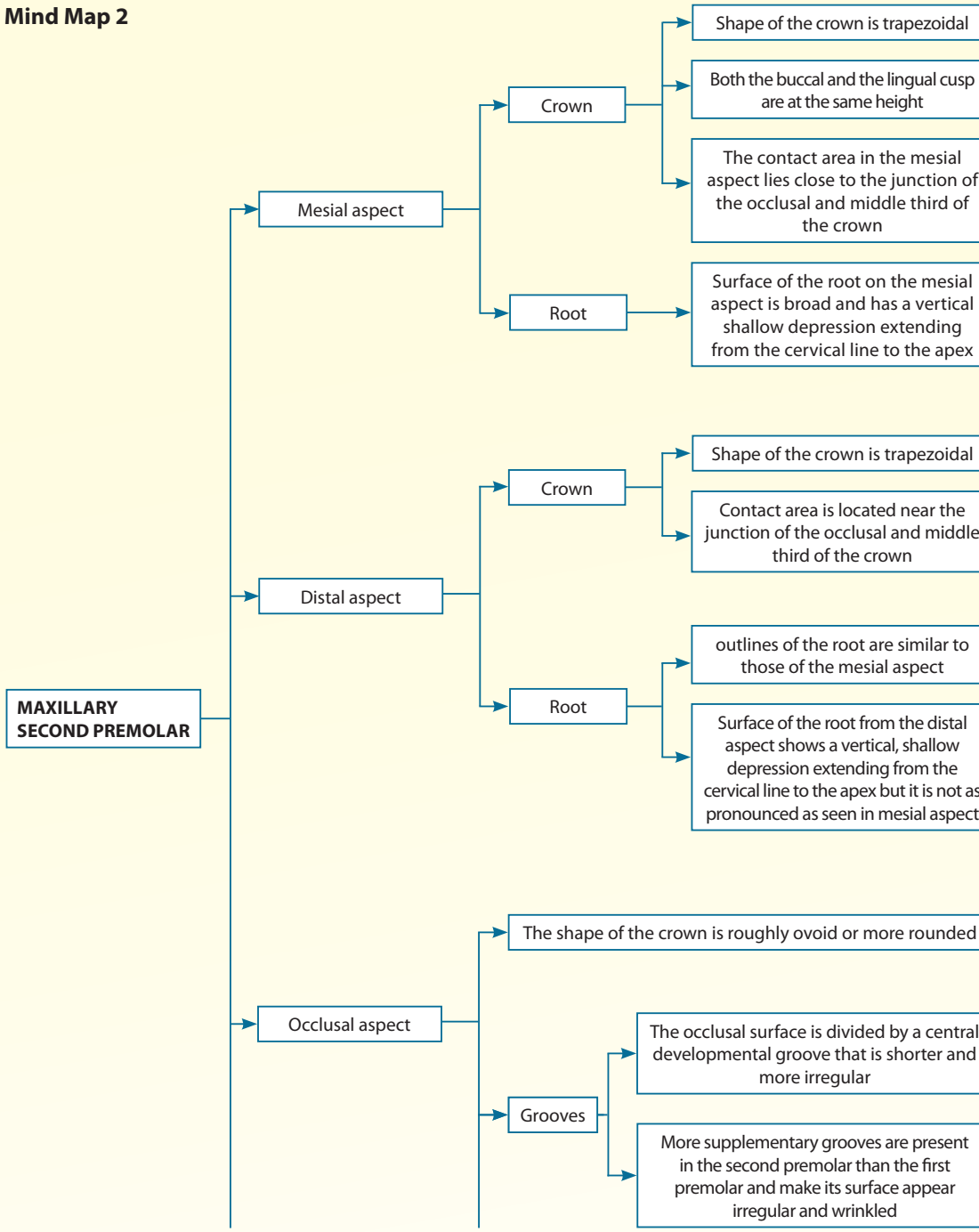


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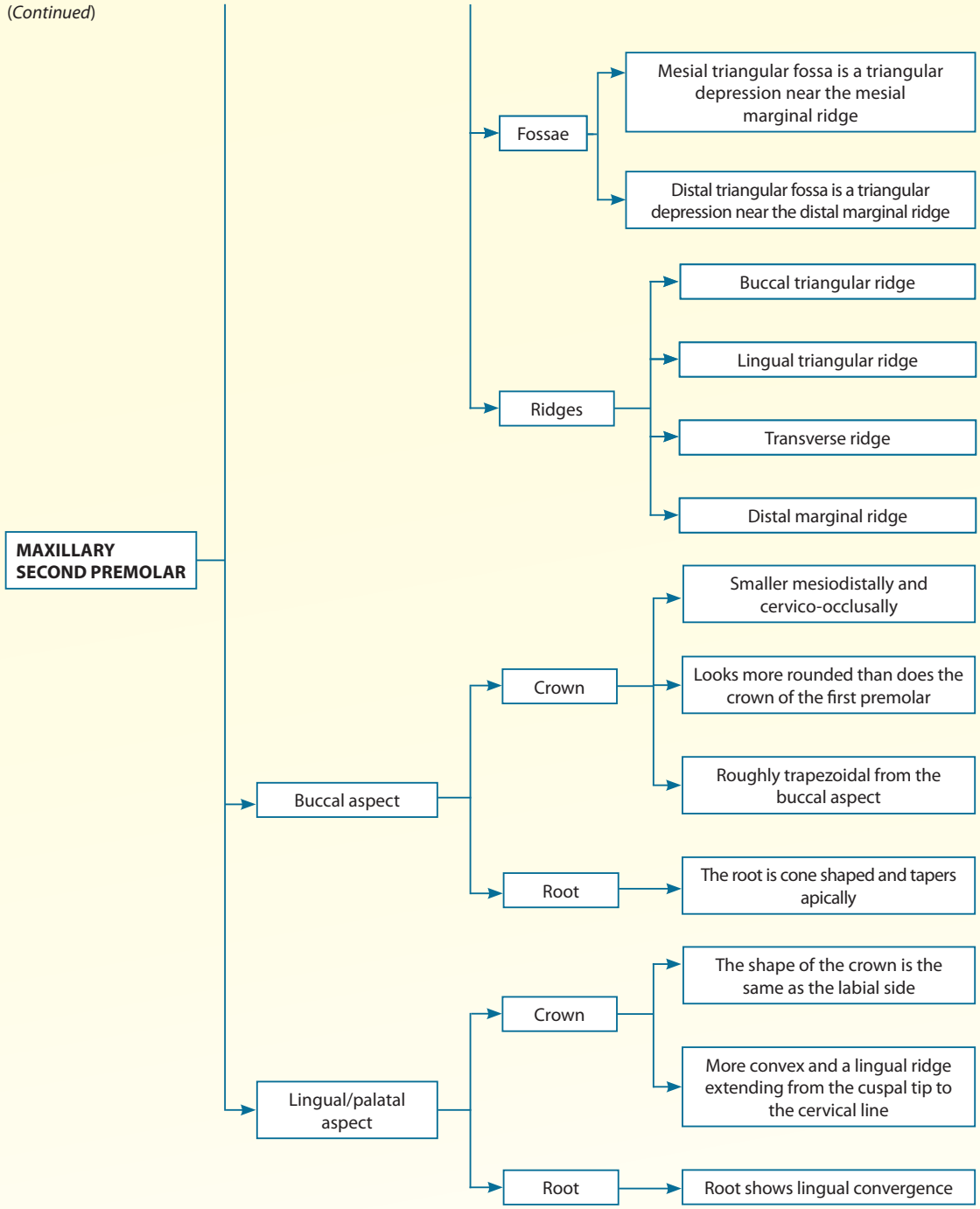

MAXILLARY FIRST PREMOLAR
Labial aspect
Crown
Resembles a maxillary canine from this aspect
The crown is wide at the level of the contact areas and narrower at the cementoenamel junction or cervical region
Root
Only the buccal root is visible from this aspect
The buccal root is cone shaped and tapers apically
Lingual aspect
Crown
The lingual aspect of the crown is the same as the labial side but is more rounded
Root
Surface of the lingual root is convex
The tip of the buccal root is visible from this aspect as the buccal root is slightly longer than the lingual root
Grooves
Central developmental groove
Distobuccal developmental groove
Mesiobuccal developmental groove
Mesial marginal developmental groove
Few supplemental groove
Fossa
Mesial triangular fossa
Distal triangular fossa
Ridges
Buccal triangular ridge
Lingual triangular ridge
Transverse ridge
Distal marginal ridge
Mesial marginal ridge

Mind Map 2

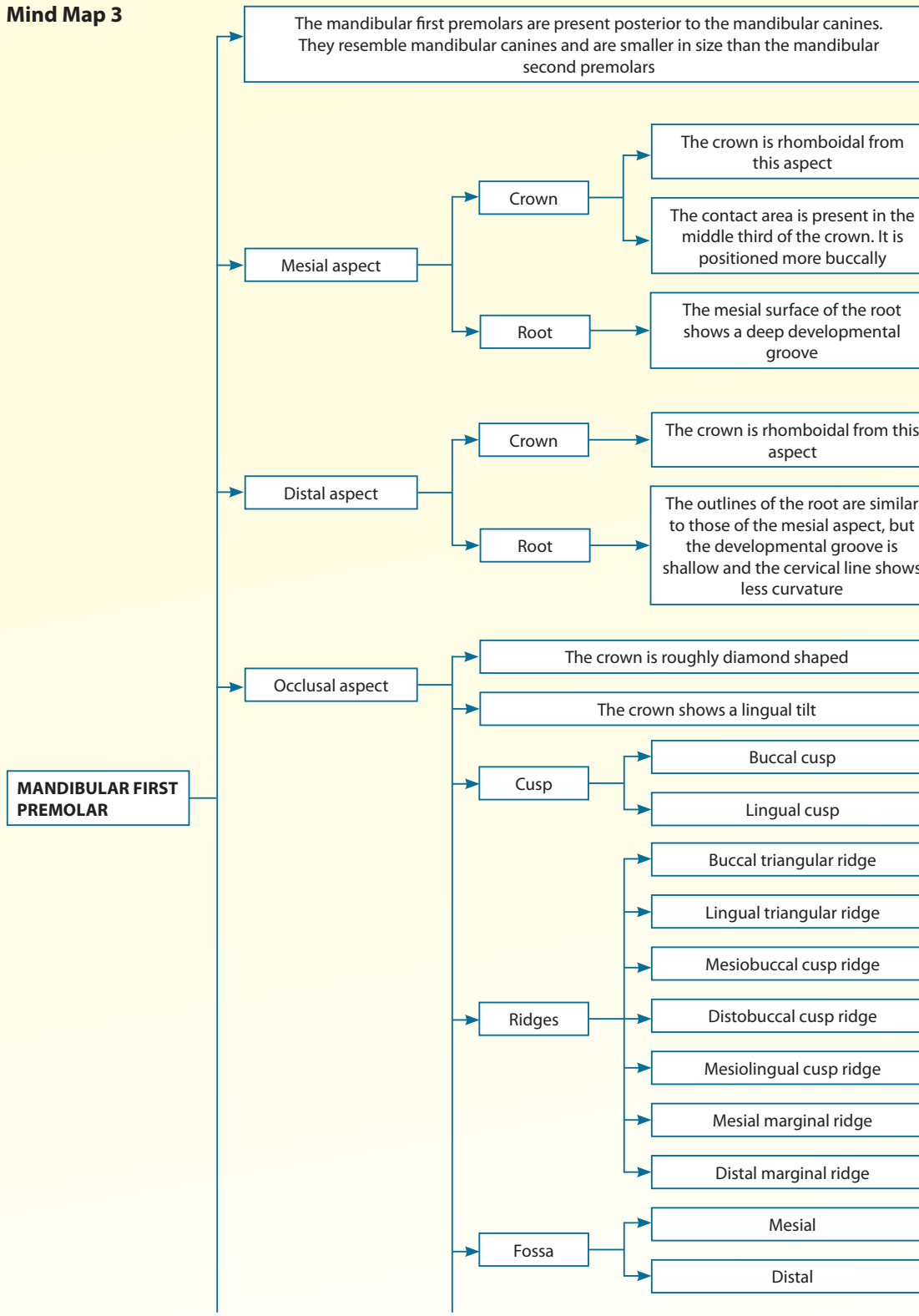


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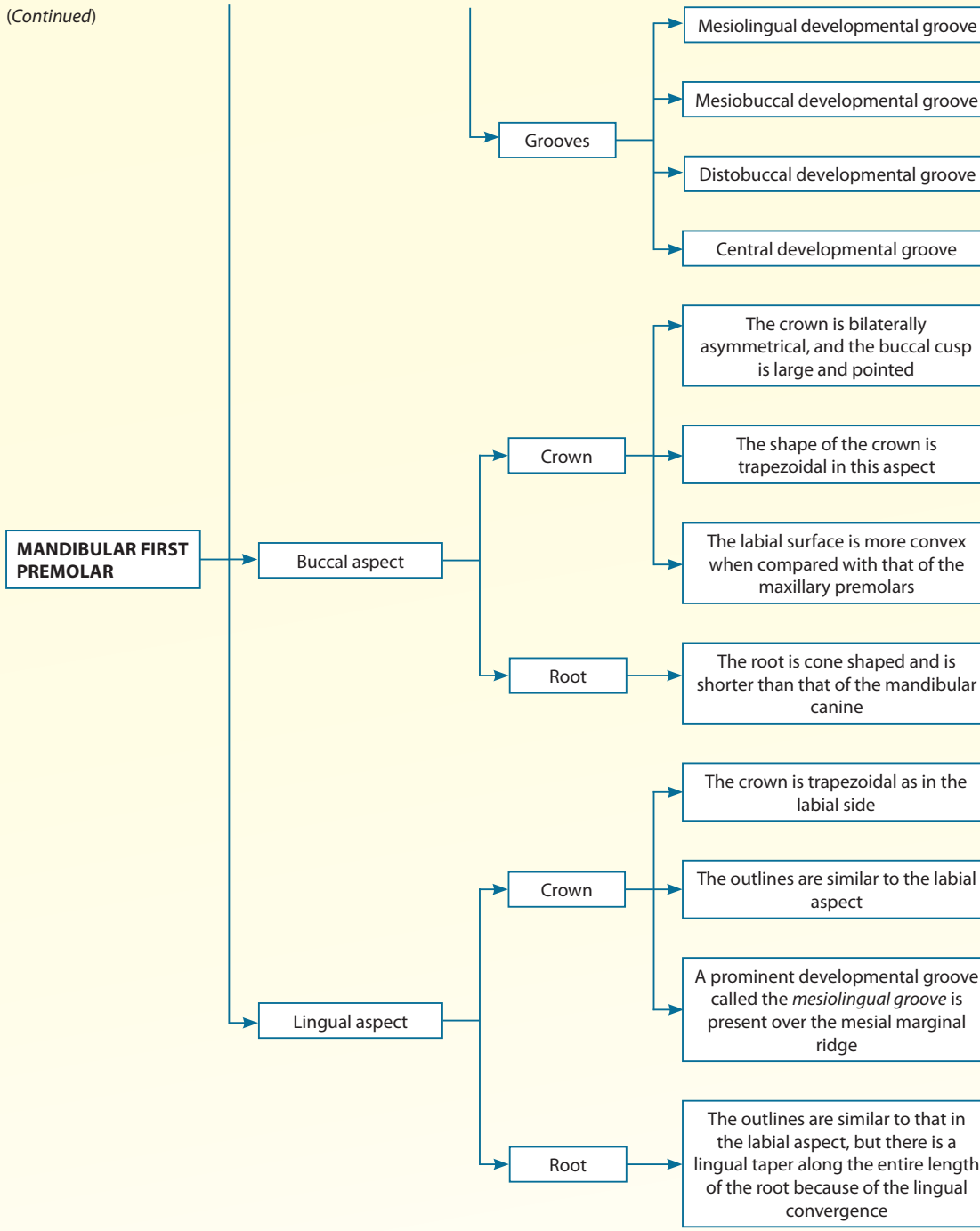

MAXILLARY SECOND PREMOLAR
Buccal aspect
Crown
Smaller mesiodistally and cervico-occlusally
Looks more rounded than does the crown of the first premolar
Roughly trapezoidal from the buccal aspect
Root
The root is cone shaped and tapers apically
Lingual/palatal aspect
Crown
The shape of the crown is the same as the labial side
More convex and a lingual ridge extending from the cuspal tip to the cervical line
Root
Root shows lingual convergence
Fossae
Mesial triangular fossa is a triangular depression near the mesial marginal ridge
Distal triangular fossa is a triangular depression near the distal marginal ridge
Ridges
Buccal triangular ridge
Lingual triangular ridge
Transverse ridge
Distal marginal ridge

Mind Map 3

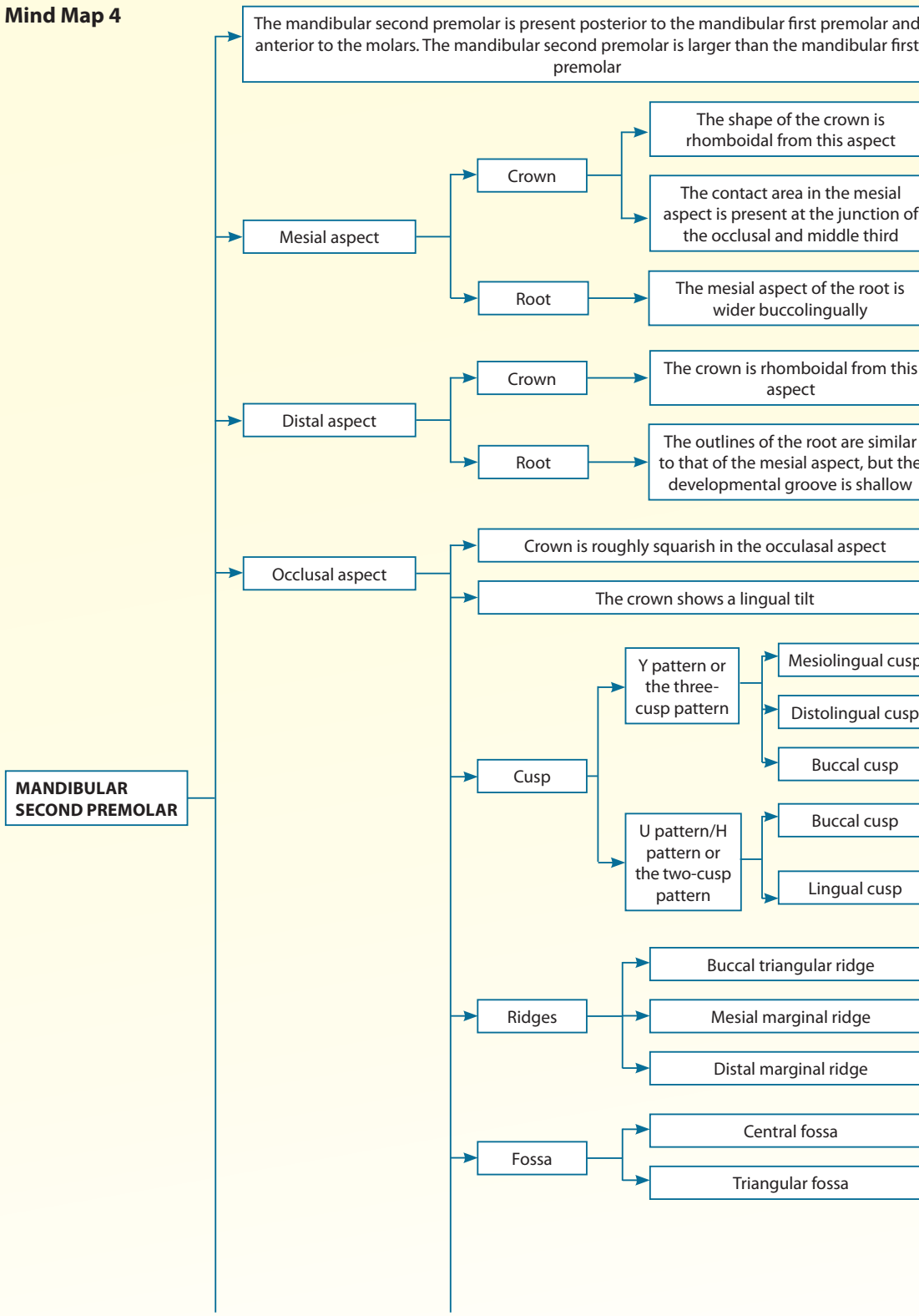


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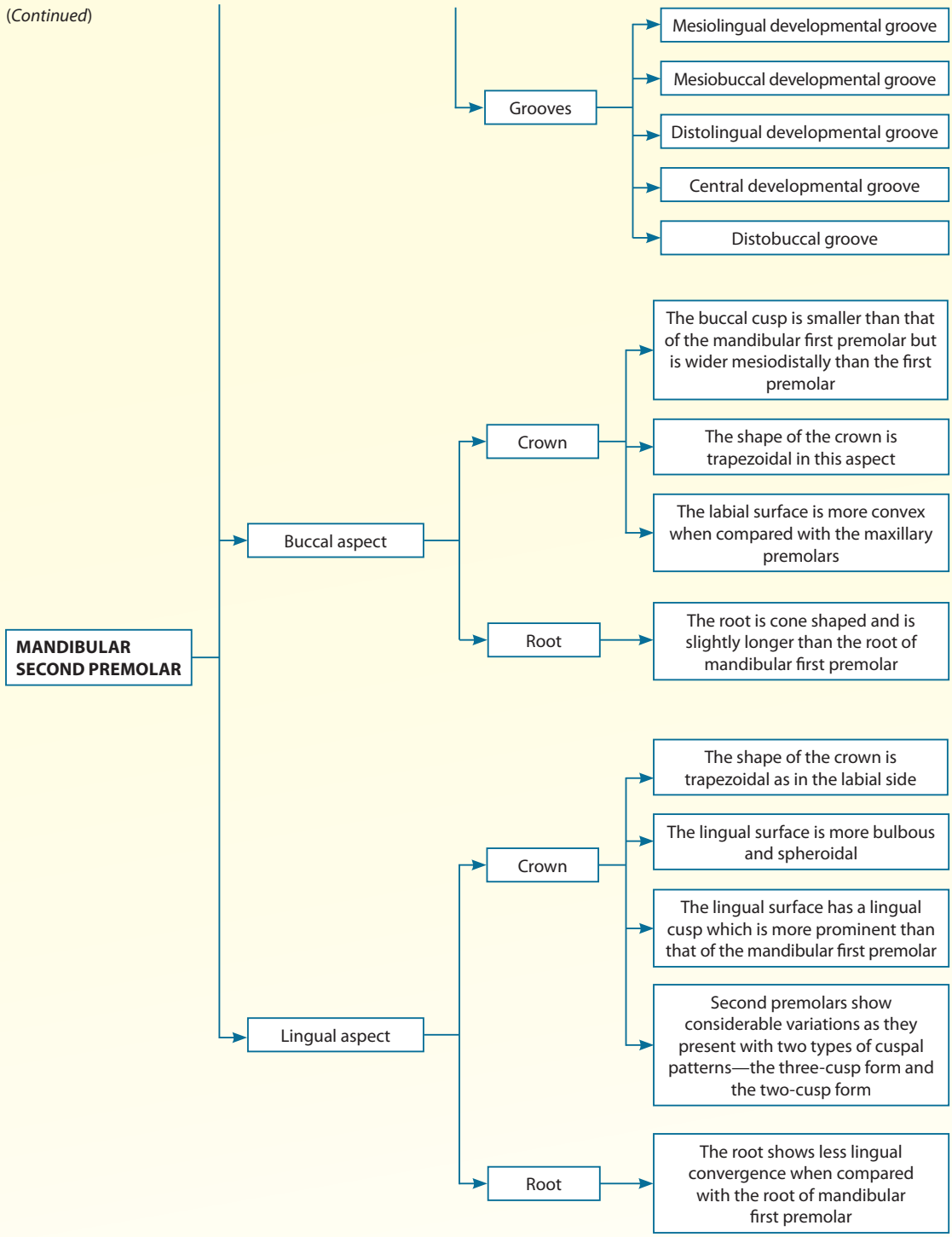

MANDIBULAR FIRST PREMOLAR
Buccal aspect
Crown
The crown is bilaterally asymmetrical, and the buccal cusp is large and pointed
The shape of the crown is trapezoidal in this aspect
The labial surface is more convex when compared with that of the maxillary premolars
Root
The root is cone shaped and is shorter than that of the mandibular canine
Grooves
Mesiolingual developmental groove
Mesiobuccal developmental groove
Distobuccal developmental groove
Central developmental groove
Lingual aspect
Crown
The crown is trapezoidal as in the labial side
The outlines are similar to the labial aspect
A prominent developmental groove called the mesiolingual groove is present over the mesial marginal ridge
Root
The outlines are similar to that in the labial aspect, but there is a lingual taper along the entire length of the root because of the lingual convergence

Mind Map 4



(*Continued*)

(*Continued*)


MANDIBULAR SECOND PREMOLAR
Buccal aspect
Crown
The buccal cusp is smaller than that of the mandibular first premolar but is wider mesiodistally than the first premolar
The shape of the crown is trapezoidal in this aspect
The labial surface is more convex when compared with the maxillary premolars
Root
The root is cone shaped and is slightly longer than the root of mandibular first premolar
Grooves
Mesiolingual developmental groove
Mesiobuccal developmental groove
Distolingual developmental groove
Central developmental groove
Distobuccal groove
Lingual aspect
Crown
The shape of the crown is trapezoidal as in the labial side
The lingual surface is more bulbous and spheroidal
The lingual surface has a lingual cusp which is more prominent than that of the mandibular first premolar
Second premolars show considerable variations as they present with two types of cuspal patterns—the three-cusp form and the two-cusp form
Root
The root shows less lingual convergence when compared with the root of mandibular first premolar

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3. Scheid RC. Woelfel's Dental Anatomy: Its Relevance to Dentistry. 7th ed. Baltimore: Lippincott Williams & Wilkins; 2007.

Multiple Choice Questions

1. Premolars are commonly called
   (a) Bicuspids
   (b) Tricuspids
   (c) Cusp tips
   (d) Cornerstones
2. Which premolars have bifurcated roots?
   (a) Maxillary second premolars
   (b) Maxillary first premolars
   (c) Mandibular first premolars
   (d) Mandibular second premolars
3. Maxillary premolars more commonly resemble which primary tooth?
   (a) Primary maxillary first molar
   (b) Primary maxillary canine
   (c) Primary mandibular first molar
   (d) Primary mandibular canine
4. Among the maxillary premolars, which has a longer mesial cusp ridge and a shorter distal cusp ridge from the facial aspect?
   (a) Maxillary second premolars
   (b) Maxillary first premolars
   (c) Both a and b
   (d) None of the above
5. Pronounced concavity on the mesial surface of the crown is found in the
   (a) Maxillary second premolars
   (b) Maxillary first premolars
   (c) Mandibular second premolars
   (d) Mandibular first premolars
6. The occlusal form of the maxillary first premolar is
   (a) Hexagonal
   (b) Round
   (c) Rhomboidal
   (d) Trapezoidal
7. The mesial marginal developmental groove is a characteristic feature of they
   (a) Maxillary second premolars
   (b) Maxillary first premolars
   (c) Mandibular first molars
   (d) Maxillary canines
8. Uto-Aztecan premolar trait is seen in which population group?
   (a) Indians
   (b) Mongoloids
   (c) Native Americans
   (d) Caucasoids
9. Among the following, which is true?
   (a) Maxillary first premolars have well-developed buccal cusp when compared with the lingual cusp
   (b) Maxillary second premolars have equal development of both cusps
   (c) Maxillary first premolars have two roots
   (d) All of the above
10. Supplemental grooves are more commonly seen in the
    (a) Maxillary second premolars
    (b) Maxillary first premolars
    (c) Mandibular second premolars
    (d) Mandibular canines
11. The smallest of premolars is the
    (a) Maxillary first premolar
    (b) Maxillary second premolar
    (c) Mandibular first premolar
    (d) Mandibular second premolar

12. The mesiolingual groove is found on which of the following permanent teeth?
    (a) Mandibular second premolars
    (b) Mandibular first premolars
    (c) Maxillary first molars
    (d) Maxillary canines
13. During intercuspation, the lingual cusp of the mandibular first premolar usually
    (a) Contacts the lingual fossa of the maxillary first premolar
    (b) Contacts the embrasure between maxillary canines and premolars
    (c) Contacts the mesial marginal ridge of the maxillary second premolar
    (d) Does not occlude with any tooth
14. The mandibular second premolar is similar to the mandibular first premolar in which aspect?
    (a) Buccal view
    (b) Lingual view
    (c) Occlusal view
    (d) All of the above
15. The three-cusp pattern is most commonly seen in the
    (a) Mandibular second premolar
    (b) Maxillary first premolar
    (c) Maxillary second premolar
    (d) Mandibular molar
16. The distolingual cusp may not always be present in the
    (a) Maxillary first molar
    (b) Mandibular first molar
    (c) Mandibular second molar
    (d) Mandibular second premolar
17. In the three-cusp pattern of the mandibular second premolar, the order of the cusps from the smallest to largest is
    (a) Distolingual, mesiolingual, facial
    (b) Facial, mesiolingual, distolingual
    (c) Mesiolingual, facial, distolingual
    (d) Distolingual, facial, mesiolingual
18. In which premolar can all the three cusps be seen from the distal view?
    (a) Maxillary first premolar
    (b) Maxillary second premolar
    (c) Mandibular first premolar
    (d) Mandibular second premolar
19. The mandibular premolar differs from the maxillary premolar in the
    (a) Mesiodistally flattened roots
    (b) Lingually tilted crowns
    (c) Less-developed lingual cusp
    (d) All of the above
20. The mandibular second premolar has a characteristic occlusal pattern of the letter
    (a) Y
    (b) Z
    (c) M
    (d) S



CHAPTER 17

Permanent Maxillary and Mandibular Molars

Overview

The rearmost and the most complicated teeth are the permanent molars. They are used to grind food. Adult humans have 12 molars, 3 in each quadrant. The buccal and lingual surfaces of permanent maxillary and mandibular molar teeth demonstrate developmental grooves separating the well-developed cusps. In mandibular molars, these grooves usually end in buccal and lingual pits which are more susceptible to dental caries. Maxillary molars are composed of three roots while mandibular molars are composed of two roots.

INTRODUCTION

Molar (Latin *mola*) means *millstone*. Molars are the rearmost and the most complicated teeth. They are used to grind food. Adult humans have 12 molars, 3 in each quadrant.

MAXILLARY FIRST MOLAR

The maxillary first molars are the largest maxillary teeth. They are lateral to the second premolars. They play a major role in the mastication of food and are vital in maintaining the vertical dimension of the face.

The maxillary first molars have three roots: two buccal and one palatal. The area below the cervical line is the root trunk. The furcation is where the roots bifurcate or trifurcate. The spaces between the roots are called furcation crotches.

Box 17.1 Chronology of the Maxillary First Molars

- First evidence of calcification: At birth
- Enamel completion: 3–4 years
- Eruption: 6–7 years
- Root completion: 9–10 years

Box 17.2 Dimensions of the Maxillary First Molars

- Length of the crown: 7.5 mm
- Length of the root
  - Mesiobuccal: 12.9 mm
  - Distobuccal: 12.2 mm
  - Palatal: 13.7 mm
- Mesiodistal width of the crown: 10.0 mm
- Mesiodistal width of the crown at cervix: 8.0 mm
- Buccolingual width of the crown: 11.0 mm
- Buccolingual width of the crown at cervix: 10.0 mm
- Depth of curvature at the mesial aspect: 0.7 mm
- Depth of curvature at the distal aspect: 0.3 mm

The chronology and dimensions of the maxillary first molars are stated in **Boxes 17.1** and **17.2**.

Buccal Aspect (Fig. 17.1)

1. **Shape of the crown:** The crown of the first maxillary molar is trapezoidal from the buccal aspect.
2. **Outlines of the crown:** All the four major cusps are seen from this view; the crown is divided symmetrically by the buccal groove.
   (a) *Mesial outline:* The mesial outline is convex from the occlusal surface to the mesial contact area; from the contact area, the outline extends straight to the cervical line. The contact area is at the junction of the occlusal and middle third of the crown.
   (b) *Distal outline:* The distal outline is convex from the occlusal surface to the cervical line. The contact area lies in the middle third.
   (c) *Occlusal outline:* The occlusal outline is bordered by the mesiobuccal and distobuccal cusps. The mesiobuccal cusp is wider mesiodistally. The mesial slope of

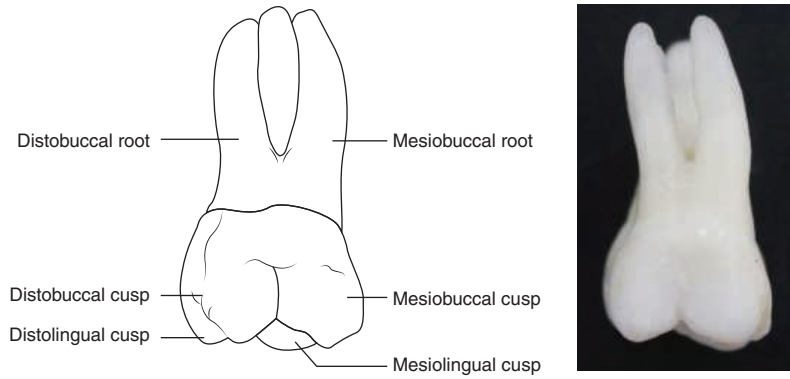


Figure 17.1 Buccal aspect of the maxillary first molar.

the mesiobuccal cusp is longer than the distal slope of the mesiobuccal cusp and they meet at an obtuse angle.

(d) *Cervical outline:* The cervical outline is almost straight.

3. **Buccal surface:** The buccal surface is convex and is larger than in the premolars. There is a buccal groove between the buccal cusps, and it extends cervically on the buccal surface to the middle third of the crown. The buccal groove ends in a pit in some cases.
4. **Shape of the roots**
   (a) *Mesiobuccal root:* The root is cone shaped, and there is a gradual taper to the apex. It is inclined distally.
   (b) *Distobuccal root:* The shape of the root is conical, and it tapers towards the apex. It is inclined mesially.
5. **Outlines of the roots**
   (a) *Mesiobuccal root:* The mesial outline of the mesiobuccal root is concave from the cervical line to the middle third and then it becomes convex till the apex. This curvature gives a distal inclination to the apical third.
   (b) *Distobuccal root:* The mesial outline of the distobuccal root is concave from the furcation till the apex. The distal outline of the distobuccal cusp is concave from the cervical line till the middle third and then it becomes convex till the apex, giving a mesial inclination to the root.

Lingual/Palatal Aspect (Fig. 17.2)

The lingual/palatal aspect is more convex and rounded than the buccal aspect, and the mesiodistal width is the same as the buccal aspect.

1. **Shape of the crown:** The shape of the crown is trapezoidal, similar to the buccal side.
2. **Outlines of the crown:** The outlines are similar to the labial aspect. Only two cusps are

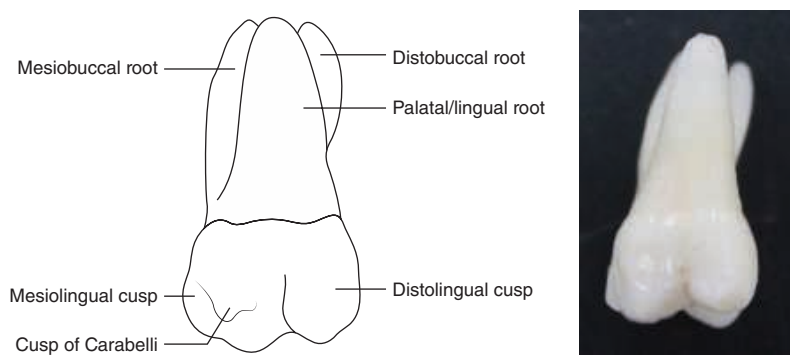


Figure 17.2 Lingual aspect of the maxillary first molar.

visible from the lingual aspect—the mesiolingual and the distolingual cusps. The mesiolingual cusp is longer than the other cusps, hence masking the view of the buccal cusps. The distolingual cusp is small and rounded. A fifth (accessory) cusp, called the cusp of Carabelli, is commonly present on the mesiolingual aspect of the tooth.

3. **Lingual surface:** The lingual surface is slightly more convex and has a lingual developmental groove extending from the occlusal aspect to the lingual surface.
4. **Root:** The palatal root (lingual root) is present on the lingual aspect. It is conical.
5. **Outlines of the root:** The lingual root is broader mesiodistally and narrow buccolingually.
   (a) *Mesial outline:* The mesial outline of the lingual root starts from the root trunk area and is slightly convex till the apex.
   (b) *Distal outline:* The distal outline extends from the cervical line to the apex and is almost straight till the apex.

Mesial Aspect (Fig. 17.3)

1. **Shape of the crown:** The shape of the crown is trapezoidal. The crown is broad faciolingually.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is convex from the cusp tip to the cervical line; the crest of curvature is located at the cervical third of the crown.
   (b) *Lingual outline:* The lingual outline is convex. The presence of the cusp of Carabelli makes the outline more prominent. The crest of curvature is at the middle third of the crown.
   (c) *Cervical outline:* The cervical curvature is almost straight and the depth of the curvature is 0.7 mm on the mesial aspect.
   (d) *Occlusal outline:* The occlusal outline shows the mesial aspect of the mesiobuccal cusp and the mesiolingual cusp with the cusp of Carabelli. The buccal slope and the lingual slope of the cusps meet at right angles. The lingual cusp is longer than the buccal cusp.
3. **Contact area:** The contact area is at the junction of occlusal and middle third of the crown.
4. **Mesial surface:** The mesial surface is convex and a shallow concavity is present above the contact area extending to the root surface.
5. **Roots:** The mesiobuccal and the lingual/palatal roots are seen from this aspect. The root trunk length on the mesial aspect is 4 mm.
6. **Outlines of the roots**
   (a) *Mesiobuccal root:* The mesiobuccal root is broad buccolingually. The buccal outline of the mesiobuccal root is straight from the cervical line to the middle third. From the middle third, there is mild convexity, and the root is slightly tilted buccally with the apex in line with the tip of the mesiobuccal cusp. The lingual outline of the mesiobuccal root is convex from the furcation area to the apex.
   (b) *Palatal/lingual root:* The palatal or lingual root is narrow buccolingually, and

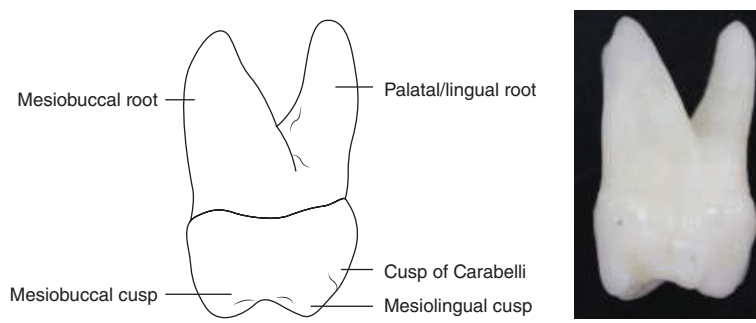


Figure 17.3 Mesial aspect of the maxillary first molar.

the buccal outline is concave from the furcation area to the apex. The lingual outline is convex from the cervical line to the apex.

Distal Aspect (Fig. 17.4)

The distal aspect of the crown is similar to the mesial aspect; the distobuccal and the distolingual cusps as well as the mesial cusp tips are seen from this aspect.

1. **Shape of the crown:** The shape of the crown is trapezoidal from the distal aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is slightly convex from the cusp tip to the cervical line.
   (b) *Lingual outline:* The lingual outline is convex and is more prominent in the contact area.
   (c) *Cervical outline:* The cervical outline is almost straight with a depth of 0.3 mm.
   (d) *Occlusal outline:* The distobuccal cusp is larger than the distolingual cusp. The buccal and the lingual slopes of the distobuccal cusp and the distolingual cusp meet at right angles.
3. **Contact area:** The contact area is located at the middle third.
4. **Outlines of the roots**
   (a) *Distobuccal root:* The distobuccal root starts from the root trunk area. The buccal outline of the distobuccal root is straight till the middle third and convex from the middle third to the apex. The lingual outline of the distobuccal root is slightly concave from the furcation area to the apex.
   (b) *Lingual root:* The lingual root is narrow buccolingually. The buccal outline is concave and the lingual outline is convex from the cervical line to the apex.

Occlusal Aspect

1. **Shape of the crown:** The shape of the crown is rhomboidal with four sides and the opposite sides are parallel to each other.
2. **Outlines of the crown:** The crown is wider buccolingually than mesiodistally. Crown shows convergence on the buccal aspect and the distal aspect. The lingual aspect is wider mesiodistally than the buccal aspect.
   (a) *Buccal outline:* The buccal outline is convex.
   (b) *Lingual outline:* The lingual outline is more convex and rounded.
   (c) *Mesial outline:* The mesial outline is straight and longer than the distal outline.
   (d) *Distal outline:* The distal outline is slightly convex.
3. **Occlusal surface**
   (a) *Cusps* (**Fig. 17.5a**): Following are the four major cusps:
   - *Mesiobuccal:* This is the second largest among the major cusps.

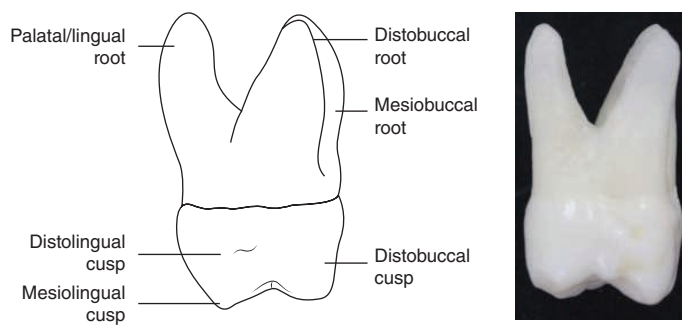


Figure 17.4 Distal aspect of the maxillary first molar.

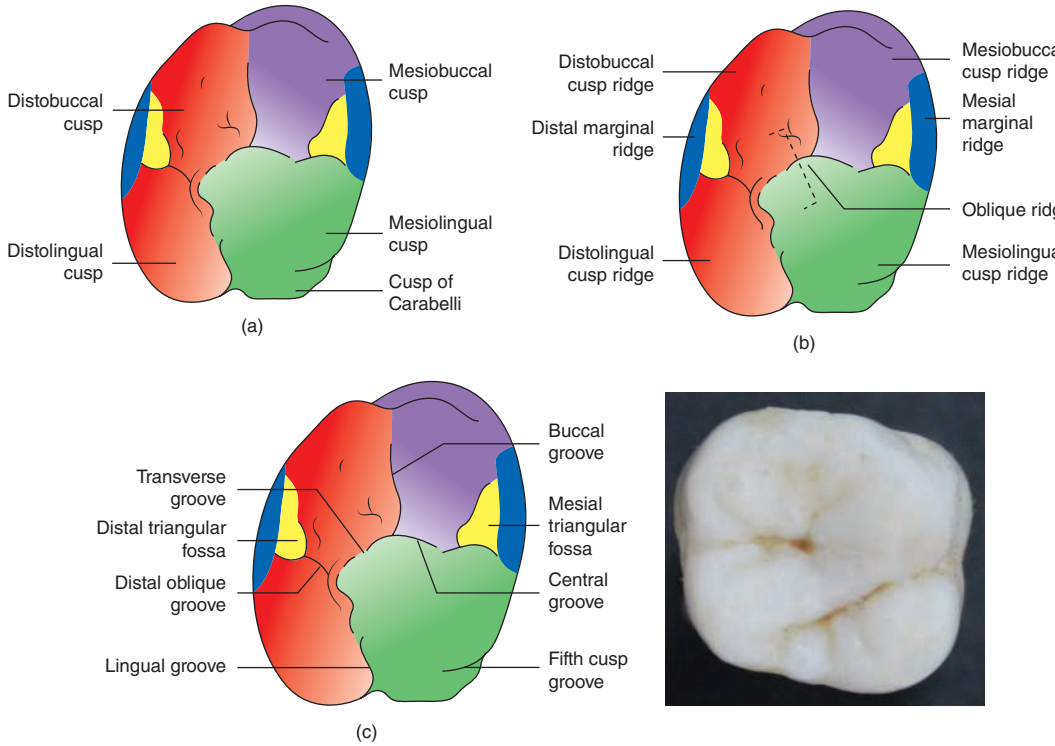


Figure 17.5 Occlusal aspect showing (a) cusps, (b) ridges and (c) grooves and fossae.

- *Distobuccal:* This cusp is the third largest among the major cusps.
- *Mesiolingual:* This is the largest cusp in the maxillary molar.
- *Distolingual:* It is the smallest major cusp.

In addition, these is another cusp, the cusp of Carabelli, which is a supplementary cusp.

(b) *Ridges* (**Fig. 17.5b**)

- *Mesial and distal marginal ridges:* The distal marginal ridge is shorter than the mesial marginal ridge.
- *Cuspal ridges:* The buccal and lingual sides of each cusp have a cuspal ridge.
- *Triangular ridge:* This is present on all the four cusps.
- Oblique *ridge:* This extends from the mesiolingual to the distobuccal cusp.
- *Transverse ridge:* The triangular ridge of the mesiolingual cusp and triangular ridge of the mesiobuccal cusp form the transverse ridge.

(c) *Fossa* (**Fig. 17.5c**)

- *Central fossa:* It is large and is bounded by the oblique, the transverse and the buccal cusp ridges.
- *Distal fossa:* It is elongated and appears as a cigar-shaped fossa from the mesiolingual and the distolingual cusps.
- *Mesial triangular fossa:* This is present within the mesial marginal ridge.
- *Distal triangular fossa:* This is present within the distal marginal ridge.

(d) *Grooves* (**Fig. 17.5c**)

- *Buccal* groove: This starts from the central fossa and extends between the mesiobuccal and the distobuccal cusps.
- *Distal oblique groove:* The distal oblique groove extends from the distal triangular fossa lingually between the distolingual cusp and the mesiolingual cusp to continue as the lingual groove.

- *Central groove:* This extends mesially from the central fossa to the transverse ridge and ends in the mesial triangular fossa.
- *Transverse groove:* This extends from the central groove and runs distally across the oblique ridge to the distal triangular fossa.
- *Fifth cusp groove:* This groove separates the fifth cusp from the mesiolingual cusp.
- *Lingual groove:* This is present between the lingual cusps and extends onto the lingual surface.

Applied Morphology

1. The maxillary first molar is considered vital for proper occlusion. Classification of malocclusion is based on the occlusal relationship between the maxillary and the mandibular first molars.
2. The maxillary first molars are commonly affected by dental caries because of their complex occlusal surface.
3. Periodontal problems occur more commonly with the maxillary first molars because of their proximity to the parotid salivary duct. The plaque formed on the tooth surface hardens faster to form calculus because of the increased mineral content of saliva.
4. Loss of the maxillary first molar causes drifting of adjacent teeth and a compromised occlusion.
5. The oblique ridge is usually preserved during cavity preparations as it offers significant strength to the occlusal table. It is involved in cavity preparation only when it is deeply undermined by caries.
6. The maxillary first molar presents difficulty in extraction because of its flaring roots.

MAXILLARY SECOND MOLAR

The maxillary second molars are located distal to the first molars and mesial to the third molars in the maxillary arch. They have four cusps and three roots but exhibit considerable variation in morphology when compared to the first molars.

The chronology and dimensions of the maxillary second molars are stated in **Boxes 17.3** and **17.4**.

Box 17.3 Chronology of the Maxillary Second Molars

- First evidence of calcification: 2½–3 years
- Enamel completion: 7–8 years
- Eruption: 12–13 years
- Root completion: 14–16 years

Box 17.4 Dimensions of the Maxillary Second Molars

- Length of the crown: 7.0 mm
- Length of the root
  - Mesiobuccal: 11 mm
  - Distobuccal: 11 mm
  - Palatal: 12 mm
- Mesiodistal width of the crown: 9.0 mm
- Mesiodistal width of the crown at cervix: 7.0 mm
- Buccolingual width of the crown: 11.0 mm
- Buccolingual width of the crown at cervix: 10.0 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0.0 mm

Buccal Aspect (Fig. 17.6)

1. **Shape of the crown:** The crown of the second maxillary molar is trapezoidal from the buccal aspect.
2. **Outlines of the crown:** The crown is shorter in the occlusocervical aspect and narrower mesiodistally than in the first molars. It is more rounded than in the first molars.
   (a) *Mesial outline:* The mesial outline is slightly convex from the occlusal surface to the cervical line. The contact area is at the middle third of the crown.
   (b) *Distal outline:* The distal outline is more convex than the mesial outline and the contact area lies at the middle third.
   (c) *Occlusal outline:* The occlusal outline is bordered by mesiobuccal and distobuccal cusps. The mesiobuccal cusp is longer and wider mesiodistally than the distobuccal cusp. The mesial and distal cuspal slopes of the mesiobuccal cusp and the distobuccal cusp meet at an obtuse angle.
   (d) *Cervical outline:* The cervical outline is almost straight. There is a slight convexity towards the root at the centre.

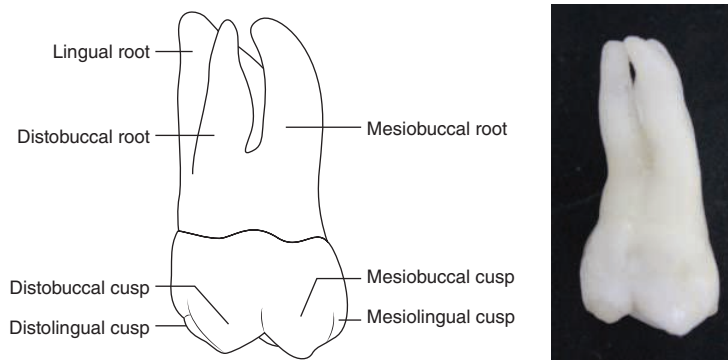


Figure 17.6 Buccal aspect of the maxillary second molar.

3. **Buccal surface:** The buccal surface is convex and is smaller than that of the first molar. A buccal groove separates the two buccal cusps, and it extends cervically on the buccal surface to the middle third of the crown.
4. **Shape of the roots:** The two buccal roots (mesial and distal) and the lingual/palatal root are seen from this aspect.
   (a) *Mesiobuccal root:* The root is cone shaped and more bulbous than the distobuccal root. The apex shows a slight distal tilt.
   (b) *Distobuccal root:* The shape of the root is conical and is smaller than the mesiobuccal root. It shows a mild mesial inclination.
5. **Outlines of the roots**
   (a) *Mesiobuccal root:* The mesial outline of the mesiobuccal root is concave from the cervical line to the middle third and then it becomes convex till the apex; hence, it gives the apical third the distal inclination. The distal outline of the mesiobuccal root is concave from the furcation area to the apex.
   (b) *Distobuccal root:* The mesial outline of the distobuccal root is convex from the furcation till the middle third and becomes concave towards the apex. The distal outline of the distobuccal cusp is convex from the root trunk to the apex. The apex shows a mild mesial inclination.

Lingual Aspect (Fig. 17.7)

The fifth cusp or cusp of Carabelli is absent in the second molars. The mesiodistal width of the lingual aspect is lesser than that of the first molars. The outlines are similar to the buccal aspect. Two cusps are visible from the lingual aspect: mesiolingual and distolingual cusps. The mesiolingual cusp is longer than the distolingual cusp. The distolingual cusp is small and less developed when compared with that in the first molars.

1. **Shape of the crown:** The shape of the crown is trapezoidal, the same as in the labial side.

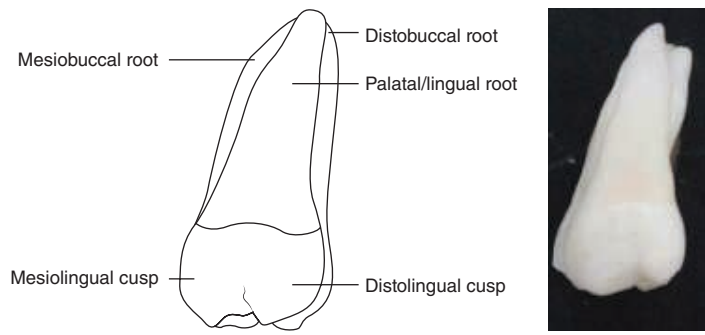


Figure 17.7 Lingual aspect of the maxillary second molar.

2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is convex from the cervical line to the contact area.
   (b) *Distal outline:* The distal outline is almost straight from the cervical line to the contact area.
   (c) *Cervical outline:* The cervical outline curves slightly towards the root.
   (d) *Occlusal outline:* The occlusal outline is bordered by the mesiolingual and the distolingual cusps. The mesiolingual cusp is at a higher level than the distolingual cusp. The mesial and distal cusp inclines of the mesiolingual and the distolingual cusps, respectively, are at an obtuse angle.
3. **Lingual surface:** The lingual surface is narrower than the buccal surface and has a lingual developmental groove extending from the occlusal aspect to the middle third of the lingual surface.
4. **Shape of the root:** The palatal root (lingual root) is present on the lingual aspect. It is conical.
5. **Outlines of the root:** The lingual root is broader mesiodistally and narrow buccolingually.
   (a) *Mesial outline:* The mesial outline of the lingual root starts from the cervical line and is convex till the apex.
   (b) *Distal outline:* The distal outline extends from the cervical line to the apex and is slightly convex till the apex.

Mesial Aspect (Fig. 17.8)

1. **Shape of the crown:** The shape of the crown is trapezoidal. The crown is broad faciolingually but is smaller when compared with that in the first molars.

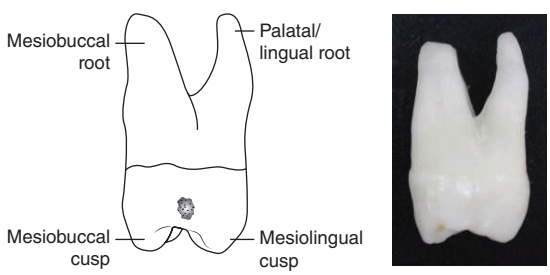


Figure 17.8 Mesial aspect of the maxillary second molar.

2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is convex from the cusp tip to the cervical line. The crest of curvature is at the cervical third.
   (b) *Lingual outline:* The lingual outline is more convex than in the buccal aspect. The crest of curvature is at the middle third.
   (c) *Cervical outline:* The cervical curvature is almost straight and the depth of the curvature is 1.0 mm on the mesial aspect.
   (d) *Occlusal outline:* The occlusal outline shows the mesial aspect of the mesiobuccal cusp and the mesiolingual cusp. The buccal slope and the lingual slopes of the cusps meet at right angles. The lingual cusp and the buccal cusp are equal in length.
3. **Contact area:** The contact area is at the middle third of the crown.
4. **Mesial surface:** The mesial surface is convex and a shallow concavity is present above the contact area extending to the root surface.
5. **Roots:** The mesiobuccal and the lingual/palatal roots are seen from this aspect. The roots are closer to each other when compared with the flaring roots of the first molars, and they are confined with the crown outline.
6. **Outlines of the roots**
   (a) *Mesiobuccal root:* The mesiobuccal root is broad buccolingually. The buccal outline of the mesiobuccal root is straight from the cervical line to the middle third.
   (b) *Palatal/lingual root:* The palatal/lingual root is narrow buccolingually and the buccal outline is concave from the furcation area to the apex. The lingual outline is convex from the cervical line to the apex.

Distal Aspect (Fig. 17.9)

The distal aspect of the crown is similar to the mesial aspect. The distobuccal and distolingual cusps are seen from this aspect.

1. **Shape of the crown:** The shape of the crown is trapezoidal in the distal aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is slightly convex from the cusp tip to the cervical line.

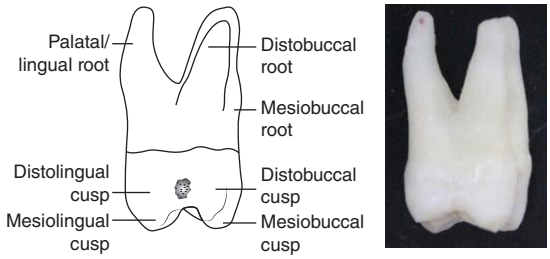


Figure 17.9 Distal aspect of the maxillary second molar.

(b) *Lingual outline:* The lingual outline is convex and more prominent in the contact area.

(c) *Cervical outline:* The cervical outline is almost straight.

(d) *Occlusal outline:* The distobuccal and distolingual cusps are seen and both the cusps are of the same height.

3. **Contact area:** The contact area is located at the middle third of the crown.
4. **Outlines of the roots**

(a) *Distobuccal root:* The distobuccal root starts from the root trunk area. The buccal and lingual outlines of the distobuccal root are straight. The root is tilted buccally.

(b) *Lingual root:* The lingual root is narrow buccolingually. The buccal outline is concave, and the lingual outline is convex from the cervical line to the apex. The apex of the lingual root lies in line with the distolingual cusp tip.

Occlusal Aspect

1. **Shape of the crown:** The shape of the crown is rhomboidal from the occlusal aspect.
2. **Outlines of the crown:** The crown is wider buccolingually than mesiodistally. The buccolingual dimensions are the same as that of the first molars. The crown shows a lingual convergence, which is more prominent when compared to that in the first molars.

(a) *Buccal outline:* The buccal outline is convex.

(b) *Lingual outline:* The lingual outline is more convex and rounded.

(c) *Mesial outline:* The mesial outline is concave because of the tilt of the crown distally.

(d) *Distal outline:* The distal outline is convex.

3. **Occlusal surface (Fig. 17.10):** The four visible cusps are the mesiobuccal, distobuccal,

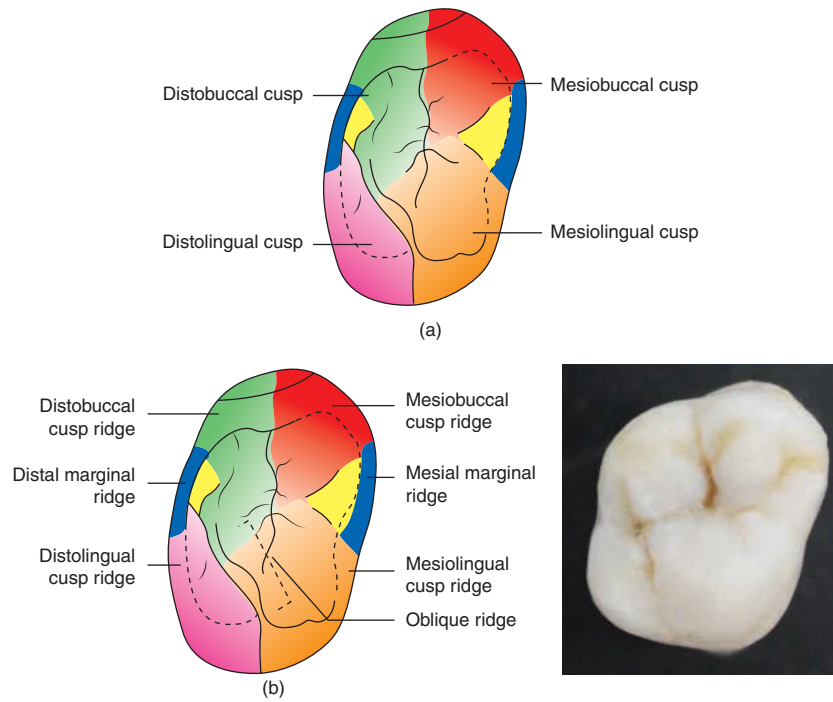


Figure 17.10 Occlusal aspect showing (a) cusps and (b) ridges.

mesiolingual and distolingual cusps. The mesiobuccal cusp and the mesiolingual cusp are bigger than the distal cusp. Supplementary grooves and pits are seen. The oblique ridge is less prominent than that of the first molars.

MAXILLARY THIRD MOLAR

The maxillary third molar exhibits significant variations in size and shape. It is the last tooth in the maxillary arch.

The chronology and dimensions of the maxillary third molars are stated in **Boxes 17.5** and **17.6**.

Buccal Aspect (Fig. 17.11)

1. **Shape of the crown:** The shape of the crown is trapezoidal.
2. **Outlines of the crown:** The crown is shorter in the occlusocervical aspect and narrower mesiodistally than in the second molars.
   (a) *Mesial outline:* The mesial outline is slightly convex from the occlusal surface to the cervical line. The contact area is at the middle third of the crown.
   (b) *Distal outline:* The distal outline is more convex than the mesial outline, and the contact area lies at the middle third.

Box 17.5 Chronology of the Maxillary Third Molars

- First evidence of calcification: 7–9 years
- Enamel completion: 12–16 years
- Eruption: 17–21 years
- Root completion: 18–25 years

Box 17.6 Dimensions of the Maxillary Third Molars

- Length of the crown: 6.5 mm
- Length of the root: 11.0 mm
- Mesiodistal width of the crown: 8.5 mm
- Mesiodistal width of the crown at cervix: 6.5 mm
- Buccolingual width of the crown: 10.0 mm
- Buccolingual width of the crown at cervix: 9.5 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0.0 mm

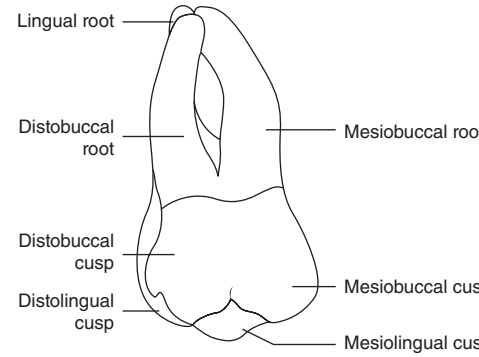


Figure 17.11 Buccal aspect of the maxillary right third molar.

   (c) *Occlusal outline:* The occlusal outline is bordered by the mesiobuccal and distobuccal cusps. The mesiobuccal cusp is longer and wider mesiodistally than the distobuccal cusp. The mesiolingual cusp is also seen from this aspect.
   (d) *Cervical outline:* The cervical outline is almost straight.
3. **Buccal surface:** The buccal surface is convex and is smaller than that of the second molars. A buccal groove separates the two buccal cusps and it extends only for a short distance when compared with the first and second molars.
4. **Roots:** The third molar roots are usually fused to form a single root. They have a distal tilt.

Lingual Aspect (Fig. 17.12)

The distolingual cusp is absent in most of the cases. One large lingual cusp is present.

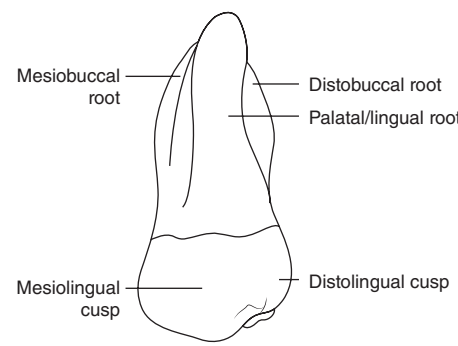


Figure 17.12 Lingual/palatal aspect of the maxillary right third molar.

Mesial Aspect (Fig. 17.13)

1. **Shape of the crown:** The crown is trapezoidal from this aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is convex from the cusp tip to the cervical line.
   (b) *Lingual outline:* The lingual outline is slightly convex.
   (c) *Cervical outline:* The cervical curvature is almost straight.
   (d) *Occlusal outline:* The occlusal outline shows the mesiobuccal and mesiolingual cusps.
3. **Contact area:** The contact area is at the middle third of the crown.
4. **Root:** The roots are fused and the root trunk is longer with a small bifurcation in the apical region.

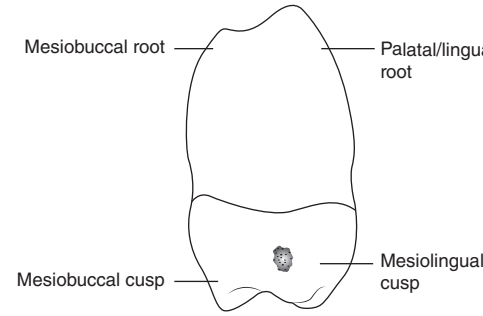


Figure 17.13 Mesial aspect of the maxillary right third molar.

Distal Aspect (Fig. 17.14)

The distal aspect of the crown is similar to the mesial aspect. The distobuccal and distolingual cusps are seen from this aspect.

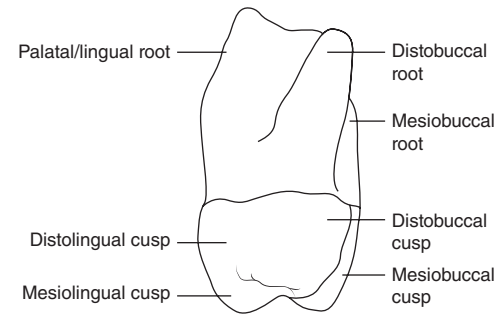


Figure 17.14 Distal aspect of the maxillary right third molar.

Occlusal Aspect (Fig. 17.15)

Shape of the crown: The crown is heart shaped. The distolingual cusp is absent or poorly developed. The lingual convergence is more pronounced than in the first and second molars. Supplemental grooves are numerous, making it appear more wrinkled. The oblique ridge is poorly developed or even absent in some cases.

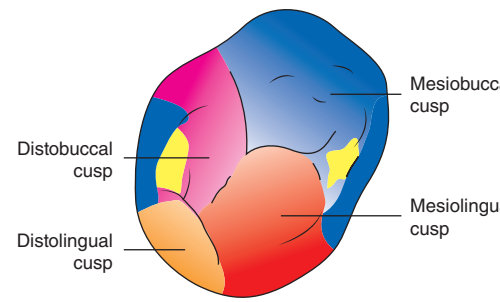


Figure 17.15 Occlusal aspect of the maxillary right third molar.

Applied Morphology

1. The maxillary third molars are frequently impacted when there is less arch space in the maxilla.
2. The maxillary third molars are prone to dental caries because of the difficulty in maintaining oral hygiene in that region.
3. The position of the maxillary third molars makes restorative procedures difficult.

VARIATIONS IN MAXILLARY MOLARS

1. **Cusp of Carabelli:** It is a small cusp situated on the palatal surface of the mesiopalatal cusp and is seen in 60% of maxillary first molars.
2. **Paramolar tubercle:** A tubercle is present on the buccal side of the mesiobuccal cusp. It is also known as parastyle.

The differentiating features of the maxillary first, second and third molars are listed in **Table 17.1**.

SECTION II

Table 17.1 Differences Between the Maxillary Molars

Aspect	Maxillary First Molar	Maxillary Second Molar	Maxillary Third Molar
Occlusal aspect			
Shape	Rhomboidal	Rhomboidal	Heart shaped
Oblique ridge	Very prominent	Small	Poorly developed or absent
Supplementary grooves	Minimal	More than the first molar	More number of supplementary grooves than the first and second molars, making the occlusal surface appear wrinkled
Cusp of Carabelli	Seen on the mesiolingual cusp	Absent	Absent
Cusps	Buccal cusps are equal in height	The distobuccal cusp is smaller than the first molar	The distobuccal cusp is smallest amongst these molars
	The mesiolingual cusp is larger than the distolingual cusp	The mesiolingual cusp is larger than the distolingual cusp. The distolingual cusp is smaller than in the first molars	The distolingual cusp is mostly absent
Roots	The roots flare beyond the crown	Roots are closer together	Roots are fused
	The lingual root is wide mesiodistally	Lingual root is slightly narrower than in the first molar	Lingual root is slender

MANDIBULAR FIRST MOLAR

The mandibular first molar is present posterior to the mandibular second premolar. The mandibular first molar is the largest of all the mandibular teeth.

The chronology and dimensions of the mandibular first molars are stated in **Boxes 17.7** and **17.8**.

Box 17.7 Chronology of the Mandibular First Molars

- First evidence of calcification: At birth
- Enamel completion: 2½–3 years
- Eruption: 6–7 years
- Root completion: 9–10 years

Box 17.8 Dimensions of the Mandibular First Molars (Fig. 17.16)

- Length of the crown: 7.5 mm
- Length of the root: 14 mm
- Mesiodistal width of the crown: 11 mm
- Mesiodistal width of the crown at cervix: 9 mm
- Labiolingual width of the crown: 10.5 mm
- Labiolingual width of the crown at cervix: 9 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

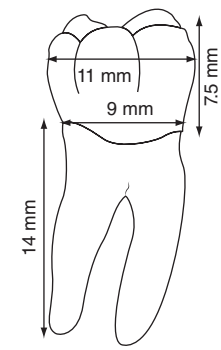


Figure 17.16 Dimensions of the mandibular first molar.

Buccal Aspect

1. **Shape of the crown (Fig. 17.17a):** The shape of the crown is roughly trapezoidal.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is almost straight from the cervical line to the contact area. The contact area is located at the junction of the occlusal and middle third. The mesial cusp slope of the mesiobuccal cusp extends from the

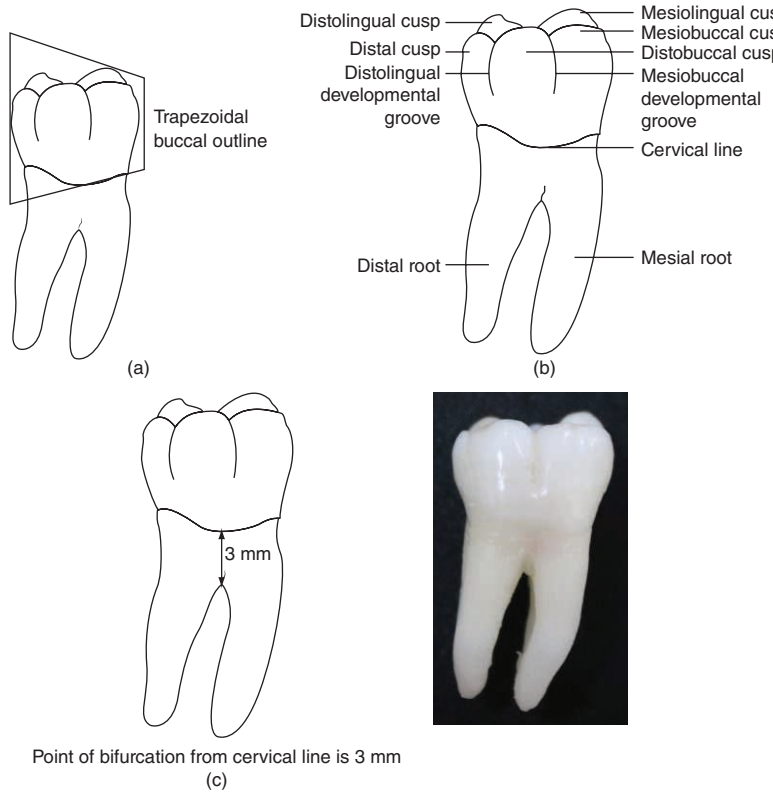


Figure 17.17 Buccal aspect of the mandibular first molar.

contact area to the mesiobuccal cusp tip and is slightly convex.

(b) *Distal outline:* The distal outline is almost straight from the cervical line to the contact area which is located at the junction of the occlusal and middle third. The distal slope of the distal cusp is slightly convex and extends from the contact area to the distal cusp tip.

(c) *Cervical outline:* The cervical line is almost straight with a slight curvature towards the root.

(d) *Occlusal outline:* The occlusal outline shows three buccal cusps: mesiobuccal, distobuccal and distal cusps. The mesiobuccal cusp is the largest and the distal cusp is the smallest. The mesiolingual and distolingual cusps are also seen from this aspect.

3. **Buccal surface (Fig. 17.17b):** The buccal surface is convex and shows the presence of two developmental grooves: mesiobuccal developmental groove and distobuccal developmental groove. The mesiobuccal developmental groove separates the mesiobuccal and distobuccal cusps and extends onto the middle third of the buccal surface. The distobuccal developmental groove separates the distobuccal and the distal cusps and extends onto the middle third of the buccal surface. The cervical third of the buccal surface has the buccocervical ridge extending mesiodistally. The mesiobuccal groove usually ends in formation of a buccal pit.

4. **Outlines of the roots (Fig. 17.17c):** Two roots—mesial and distal—are seen from this aspect. The buccal surface of the root trunk is seen. The root trunk is short when compared with the maxillary first molar and measures about 3 mm. The bifurcation begins at a closer level to the root trunk than in the maxillary first molars.

   (a) *Mesial root:* The mesial outline of the root is convex and the apical third is inclined distally. The distal outline of the mesial root is concave.

(b) *Distal root:* The mesial outline of the root is concave and the distal outline is convex. The apical third of the distal root is inclined distally.

Lingual Aspect

1. **Shape of the crown:** The shape of the crown is trapezoidal, same as in the labial side.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight from the cervical line to the contact area which is located at the middle third till the mesiolingual cusp tip. The mesial contact area is located slightly higher than on the distal side.
   (b) *Distal outline:* The distal outline is convex from the cervical line to the cusp tip.
   (c) *Cervical outline:* The cervical line is almost straight.
   (d) *Occlusal outline* (**Fig. 17.18a**)**:** The mesiolingual and distolingual cusps are seen from this aspect and they are higher than the buccal cusps. In addition to these lingual cusps, a part of the distal cusp is also seen.

   The mesiolingual cusp is larger than the distolingual cusp. The cuspal slopes of the mesiolingual and distolingual cusps meet at an obtuse angle.
3. **Lingual surface:** The lingual surface is convex. A lingual developmental groove runs between the two lingual cusps and extends for a shorter distance than the grooves seen in the buccal surface.
4. **Roots** (**Fig. 17.18b**)**:** The two roots are seen from this aspect. The root trunk is longer in this aspect and measures about 4 mm from the cervical line to the bifurcation. A developmental depression is seen extending from the cervical line to the bifurcation. The mesial and distal roots are longer in this aspect, though their mesiodistal width is lesser than the buccal aspect.

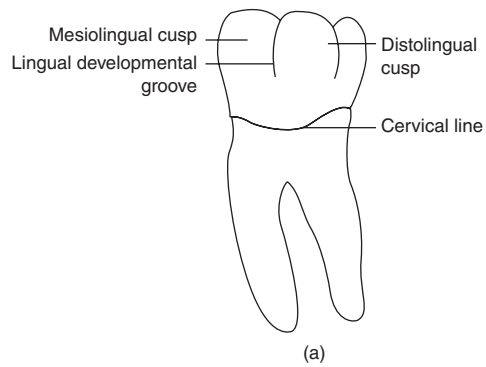


Figure 17.18 Lingual aspect of the mandibular first molar.

(a) *Mesial root:* The mesial outline of the mesial root is convex and the distal outline is concave. The apical third is inclined distally.

(b) *Distal root:* The mesial outline of the distal root is almost straight from the bifurcation to the apex. The distal outline of the distal root is convex from the bifurcation till the middle third and is concave in the apical third.

Mesial Aspect

1. **Shape of the crown (Fig. 17.19a):** The shape of the crown is rhomboidal in the mesial aspect.
2. **Outlines of the crown:** The crown shows a lingual inclination from this aspect.
   (a) *Buccal outline:* The buccal outline of the crown is convex from the cervical line to the middle third due to the cervical ridge and is slightly concave from the middle third. The crest of curvature is at the cervical third of crown.
   (b) *Lingual outline:* The lingual outline is almost straight from the cervical line to the middle third. From the middle third till the mesiolingual cusp tip, the outline is slightly convex. The crest of curvature is at the middle third of crown.
   (c) *Cervical outline:* The cervical outline is almost a straight line with depth of curvature of 1 mm towards the occlusal surface.
   (d) *Occlusal outline* (**Fig. 17.19b**)*:* The mesiobuccal cusp and the mesiolingual cusp are seen from this aspect. The mesiolingual cusp is higher than the mesiobuccal cusp. The mesial marginal ridge is higher than the distal marginal ridge. The ridge has a mesial marginal groove positioned lingual to the centre of the crown.
3. **Contact area:** The contact area is present at the junction of the occlusal and middle third of the crown.
4. **Root:** The mesial root is seen from this aspect. The buccal outline of the mesial root is convex from the cervical line to the apex. The lingual outline is convex from the cervical line to the apex. There is a broad, concave developmental depression in the mesial surface of the mesial root extending from the cervical line to the apex.

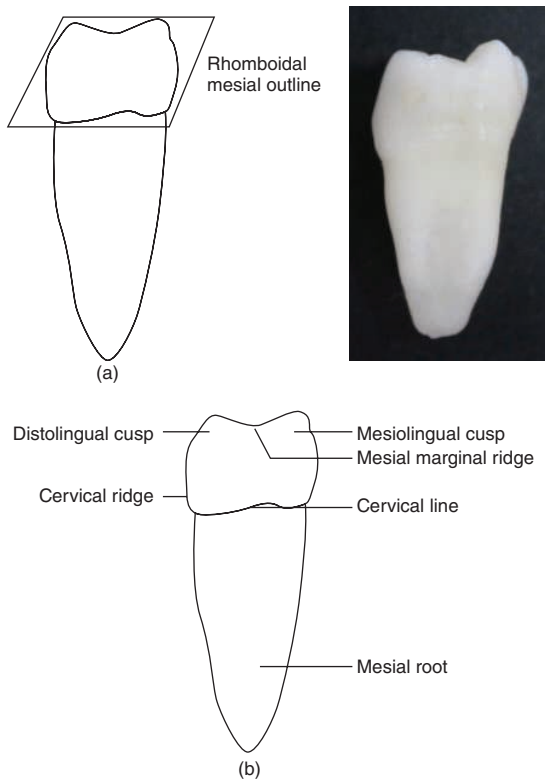


Figure 17.19 Mesial aspect of the mandibular first molar.

Distal Aspect (Fig. 17.20)

1. **Shape of the crown:** The crown is rhomboidal from this aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is slightly convex from the cervical line to the distal cusp tip.
   (b) *Lingual outline:* The lingual outline is almost straight from the cervical line till the middle third and slightly convex from the middle third to the tip of the distolingual cusp.
   (c) *Cervical outline:* The cervical outline is almost straight.
   (d) *Occlusal outline:* All the five cusps are seen from this aspect because of the distal convergence of the crown and shorter

SECTION II

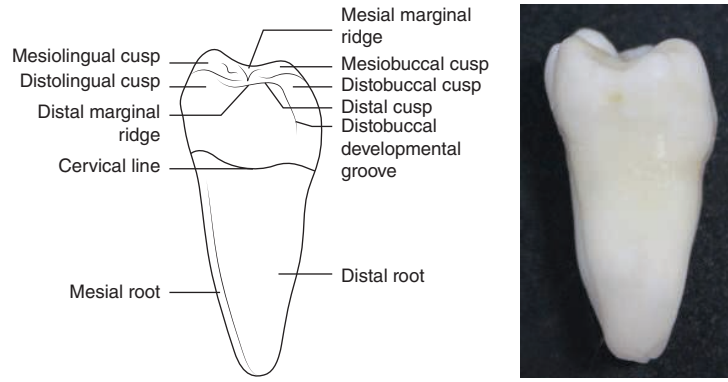


Figure 17.20 Distal aspect of the mandibular first molar.

distal marginal ridge. The distal marginal ridge has a distal marginal groove which is placed lingually.

3. **Contact area:** The contact area is located at the junction of the occlusal and middle third.
4. **Root:** The distal root is seen from this aspect. The buccal outline is convex from the cervical line to the apex. The lingual outline is almost straight from the cervical third to the apical third. The distal surface of the distal root is smooth but sometimes presents with a developmental depression.

   The lingual outline of the mesial root is also seen from this aspect.

Occlusal Aspect

1. **Shape of the crown:** The occlusal aspect of the mandibular first molar is pentagonal.
2. **Outlines of the crown:** The outline of the crown is roughly five-sided with five cusps. The outline shows convergence towards the distal side making it smaller than the mesial side. The mesiodistal width of the crown is more than the buccolingual measurement. The grooves with a five-cusp mandibular first molar show a Y pattern.
   (a) *Buccal outline:* The buccal outline is convex, bordered by the mesial and distal slopes of the mesiobuccal, distobuccal and distal cusps. The buccal cusps are divided by mesiobuccal developmental and distobuccal developmental grooves.
   (b) *Lingual outline:* The lingual outline is convex, bordered by the mesial and distal slopes of the mesiolingual and distolingual cusps. The lingual cusps are divided by the lingual groove.
3. **Occlusal surface**
   (a) *Cusps* (**Fig. 17.21a**)**:** There are five cusps in the mandibular molar with four major cusps and one minor cusp. The distal cusp is the minor cusp, whereas the mesiobuccal, distobuccal, mesiolingual and distolingual cusps are all major cusps.
   (b) *Buccal cusps*
   - *Mesiobuccal cusp:* This is the largest of the buccal cusps and is also wider than the lingual cusps. The cusp ridges are flat with less curvature.
   - *Distobuccal cusp:* It is smallest among the major cusps. The cusp ridges are more rounded than the mesiobuccal cusp.
   - *Distal cusp:* It is the smallest of all the cusps in the mandibular molar. The cusp ridges are sharper than the mesiobuccal and distobuccal cusps.

   (c) *Lingual cusps*
   - *Mesiolingual cusp:* This cusp is widest mesiolingually and is slightly higher than the distolingual cusp. The cusp ridges form an obtuse angle at the cusp tips.

- *Distolingual cusp:* The cusp is almost similar to mesiolingual cusp except that it is slightly smaller. The cusp ridges form an obtuse angle at the cusp tips.

(d) *Ridges* (**Fig. 17.21a**)

- *Mesial marginal ridge:* The ridge is present on the occlusal outline of the mesial aspect.
- *Distal marginal ridge:* The ridge is present on the occlusal outline of the distal aspect.
- *Triangular ridges:* These ridges extend from the five cuspal tips to the central groove.
- *Cuspal ridges:* These ridges form the occlusal outline on the buccal surface and the lingual surface.

(e) *Fossae:* Three fossae are present, one being a major fossa and two minor fossae.

- *Central fossa:* This is a major fossa and is a circular depression seen at the centre of the occlusal surface between the buccal and lingual cusp ridges.
- *Mesial triangular fossa:* This is a minor fossa and is a smaller depression adjacent to the mesial marginal ridge.
- *Distal triangular fossa:* This is also a minor fossa and is a smaller depression adjacent to the distal marginal ridge.

(f) *Pits* (**Fig. 17.21b**)

- *Central pit:* It is a narrow depression seen in the central fossa.
- *Mesial pit:* It is seen in the mesial triangular fossa.
- *Distal pit:* It is seen in the distal triangular fossa.

SECTION II

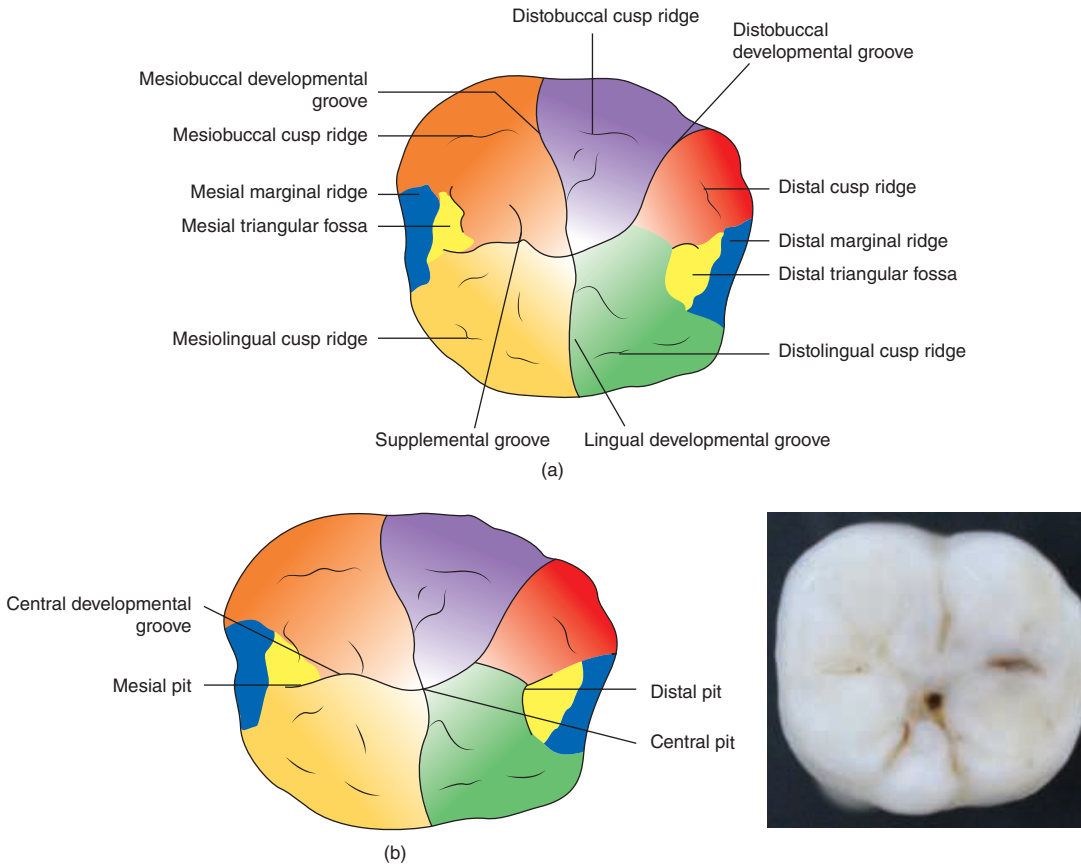


Figure 17.21 Occlusal aspect of the mandibular first molar.

(g) *Grooves*

- *Central developmental groove:* The groove radiates from the central pit to the mesial and the distal sides. It ends in the mesial and distal pits.
- *Mesiobuccal developmental groove:* The groove begins at the central pit and extends between the mesiobuccal and distobuccal cusps. It further traverses over the buccal surface.
- *Distobuccal developmental groove:* The groove begins at the central pit and extends between the distobuccal and the distal cusps. It further traverses over the buccal surface.
- *Lingual developmental groove:* The groove begins at the central pit and extends between the mesiolingual and distolingual cusps and further traverses over the lingual surface.

MANDIBULAR SECOND MOLAR

The mandibular second molar is present posterior to the mandibular first molar.

The chronology and dimensions of the mandibular second molars are stated in **Boxes 17.9** and **17.10**.

Box 17.9 Chronology of the Mandibular Second Molars

- First evidence of calcification: 2½–3 years
- Enamel completion: 7–8 years
- Eruption: 11–13 years
- Root completion: 14–15 years

Box 17.10 Dimensions of the Mandibular Second Molars (Fig. 17.22)

- Length of the crown: 7.0 mm
- Length of the root: 13 mm
- Mesiodistal width of the crown: 10.5 mm
- Mesiodistal width of the crown at cervix: 8.0 mm
- Labiolingual width of the crown: 10.0 mm
- Labiolingual width of the crown at cervix: 9.0 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

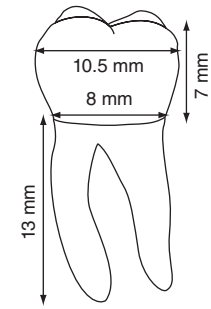


Figure 17.22 Dimensions of the mandibular second molar.

Buccal Aspect (Fig. 17.23)

1. **Shape of the crown:** The shape of the crown is roughly trapezoidal or rectangular.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is almost straight from the cervical line to the contact area and is slightly convex till the mesiobuccal cusp tip. The contact area is located at the junction of the occlusal and middle third.
   (b) *Distal outline:* The distal outline is almost straight from the cervical line to the contact area and convex till the distobuccal cusp tip. The contact area is located at the middle third.
   (c) *Cervical outline:* The cervical line is almost straight.
   (d) *Occlusal outline:* The occlusal outline shows two buccal cusps—mesiobuccal and distobuccal. The mesiobuccal cusp is larger than the distobuccal cusp. The mesiolingual and distolingual cusps are also seen from this aspect.
3. **Buccal surface:** The buccal surface is convex and shows the presence of a single buccal developmental groove separating the mesiobuccal and distobuccal cusps. The buccal groove usually ends in the formation of a buccal pit.
4. **Roots:** The mesial and distal roots are seen from this aspect. The roots are shorter and are placed closer to each other. The root trunk is short when compared with the first mandibular molar.

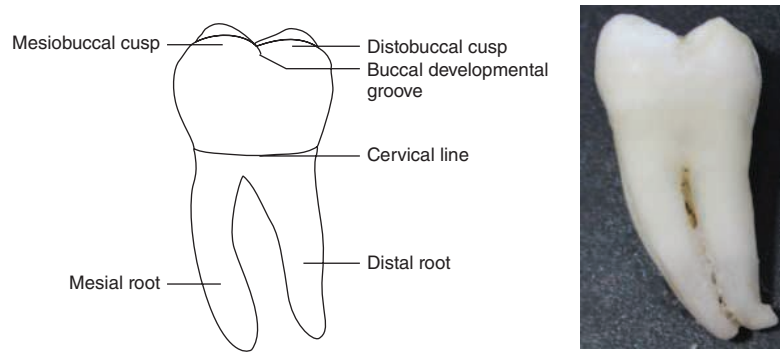


Figure 17.23 Buccal aspect of the mandibular second molar.

5. **Outlines of the root**
   (a) *Mesial root:* The mesial outline of the root is convex and the apical third is inclined distally. The distal outline of the mesial root is concave.
   (b) *Distal root:* The mesial outline of the root is concave and the distal outline is convex. The apical third of the distal root is inclined mesially unlike the first molar which shows a distal inclination.

Lingual Aspect (Fig. 17.24)

1. **Shape of the crown:** The shape of the crown is trapezoidal, same as in the labial side.
2. **Outlines of the crown**
   (a) *Mesial outline:* The mesial outline is straight from the cervical line to the contact area and convex till the mesiolingual cusp tip.
   (b) *Distal outline:* The distal outline is convex from the cervical line to the distolingual cusp tip.

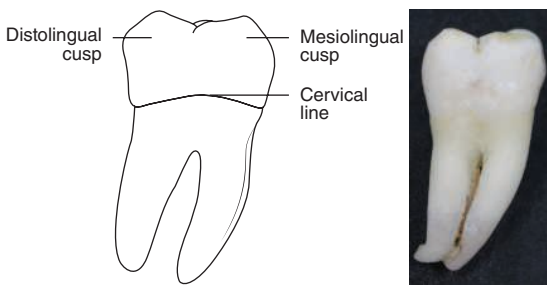


Figure 17.24 Lingual aspect of the mandibular second molar.

   (c) *Cervical outline:* The cervical line is almost straight.
   (d) *Occlusal outline:* The mesiolingual and distolingual cusps are seen from this aspect as they are higher than the buccal cusps. The mesiolingual cusp is almost similar in dimensions to the distolingual cusp. The cuspal slopes of the mesiolingual and distolingual cusps meet at an obtuse angle.
3. **Lingual surface:** The lingual surface is convex. A lingual developmental groove runs between the two lingual cusps.
4. **Roots:** The two roots are seen from this aspect. The root trunk is longer in this aspect when compared with the buccal aspect.
5. **Outlines of the root**
   (a) *Mesial root:* The mesial outline of the mesial root is convex and the distal outline is concave. The apical third is inclined distally.
   (b) *Distal root:* The mesial outline of the distal root is concave and the distal outline is convex. The apical third is tilted mesially.

Mesial Aspect (Fig. 17.25)

1. **Shape of the crown:** The shape of the crown is rhomboidal from this aspect.
2. **Outlines of the crown:** The crown shows a lingual inclination from this aspect.
   (a) *Buccal outline:* The buccal outline of the crown is convex from the cervical line to the middle third due to the presence of the cervical ridge, but it is less prominent than the first molar.

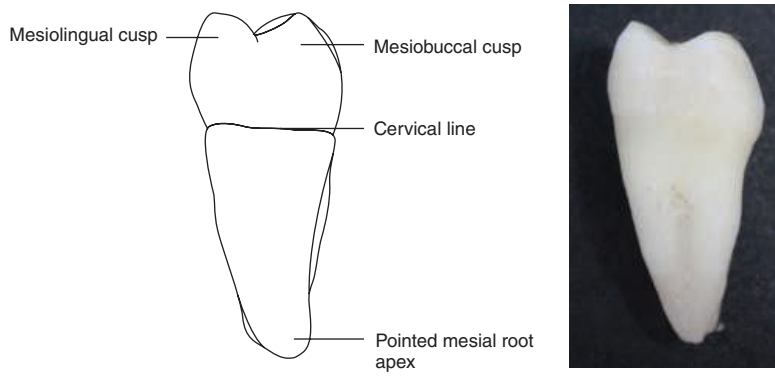


Figure 17.25 Mesial aspect of the mandibular second molar.

(b) *Lingual outline:* The lingual outline is almost straight from the cervical line to the middle third. From the middle third till the mesiolingual cusp tip, the outline is slightly convex.

(c) *Cervical outline:* The cervical line is almost a straight line with a depth of curvature of 1 mm towards the occlusal surface.

(d) *Occlusal outline:* The mesiobuccal cusp and the mesiolingual cusp are seen from this aspect. The mesial marginal ridge is not divided by the mesial marginal groove.

3. **Contact area:** The contact area is present at the junction of the occlusal and middle third of the crown.
4. **Root:** The mesial root is seen from this aspect. The buccal outline of the mesial root is straight from the cervical line to the apex. The lingual outline is convex from the cervical line to the apex. There is a shallow developmental depression in the mesial surface of the mesial root extending from the cervical line to the apex. The buccal outline of the distal root is also seen.

Distal Aspect (Fig. 17.26)

1. **Shape of the crown:** The shape of the crown is rhomboidal from this aspect.
2. **Outlines of the crown**

(a) *Buccal outline:* The buccal outline is slightly convex from the cervical line to the distal cusp tip.

(b) *Lingual outline:* The lingual outline is straight from the cervical line till the middle third and slightly convex near the distolingual cusp.

(c) *Cervical outline:* The cervical outline is straight without curvature from this aspect.

(d) *Occlusal outline:* All the four cusps are seen from this aspect because of the short distal marginal ridge. The distal marginal ridge does not have a distal marginal groove.

3. **Contact area:** The contact area is located at the middle third. It is broad and extends buccolingually.
4. **Root:** The distal root is seen from this aspect. The buccal outline of the distal root is convex from the cervical line to the apex. The lingual outline is convex from the cervical third to the middle third.
5. The lingual outline of the mesial root is also seen from this aspect.

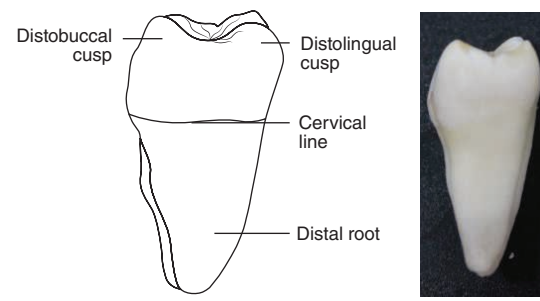


Figure 17.26 Distal aspect of the mandibular second molar.

Occlusal Aspect

1. **Shape of the crown:** The shape of the crown is rectangular in this aspect (**Fig. 17.27a**).
2. **Outlines of the crown:** The outline of the crown is rectangular with four cusps. The groove pattern in the second molar is a '+' type.
   (a) *Buccal outline:* The buccal outline is convex, bordered by the mesial and distal slopes of the mesiobuccal and distobuccal

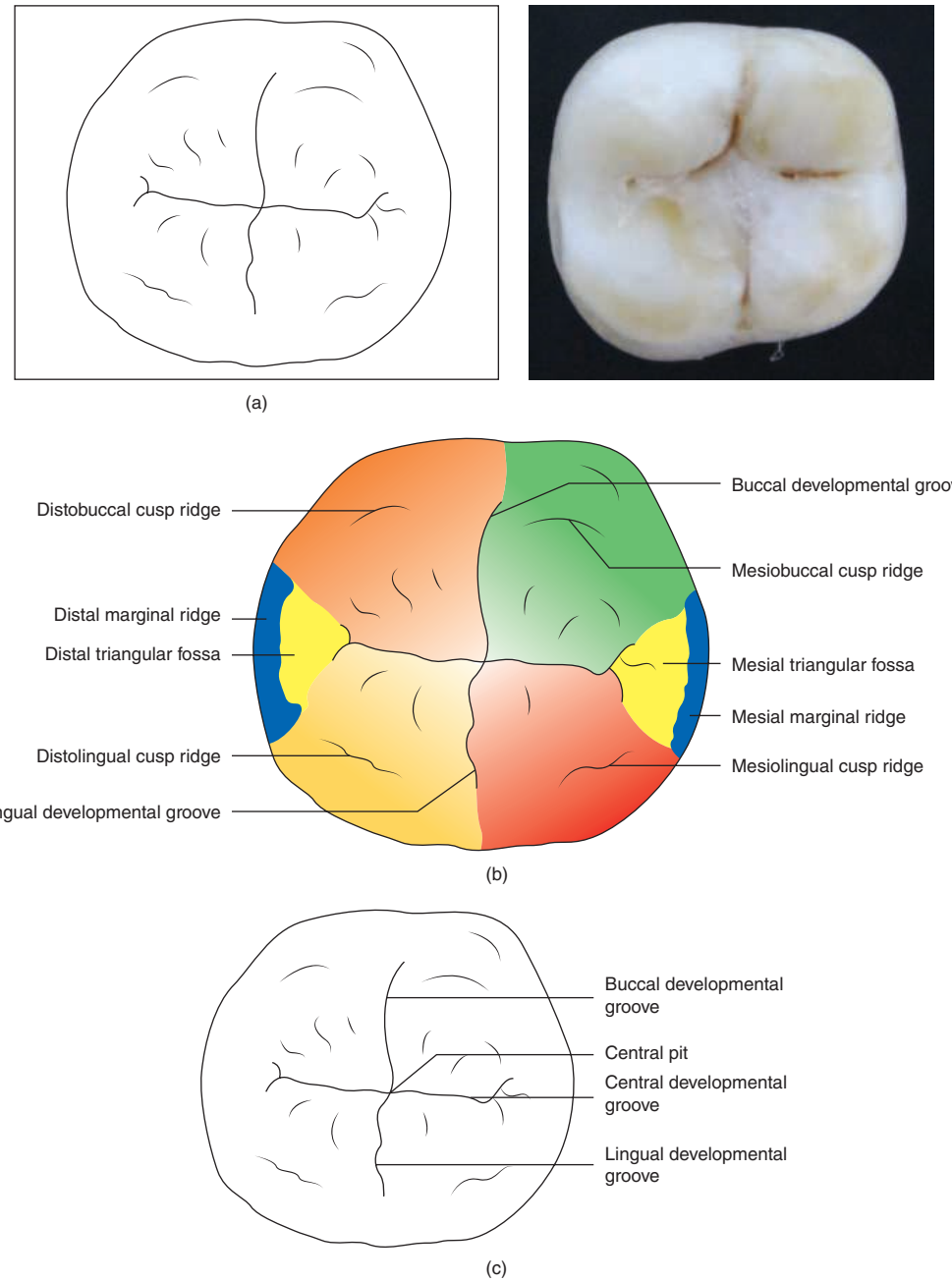


Figure 17.27 Occlusal aspect of the mandibular second molar.

cusps. The buccal cusps are divided by the buccal developmental groove.

(b) *Lingual outline:* The lingual outline is convex, bordered by the mesial and distal slopes of the mesiolingual and distolingual cusps. The lingual cusps are divided by the lingual groove.

3. **Occlusal surface**

(a) *Cusps* (**Fig. 17.27b**)**:** There are four cusps in the mandibular second molar—the mesiobuccal, distobuccal, mesiolingual and distolingual cusps. Both the buccal and lingual mesial cusps are larger than their distal counterparts. The distal cusp is absent in this tooth.

(b) *Ridges* (**Fig. 17.27b**)

- *Mesial marginal ridge:* The ridge is present on the occlusal outline of the mesial aspect.
- *Distal marginal ridge:* The ridge is present on the occlusal outline of the distal aspect.
- *Triangular ridges:* These ridges extend from the four cuspal tips to the central groove.
- *Cuspal ridges:* These ridges form the occlusal outline on the buccal surface and the lingual surface.

(c) *Fossae* (**Fig. 17.27b**)

- Three fossae are present.
- *Central fossa:* It is a circular depression seen at the centre of the occlusal surface between the buccal and lingual cusp ridges.
- *Mesial triangular fossa:* It is a smaller depression adjacent to the mesial marginal ridge.
- *Distal triangular fossa:* It is a smaller depression adjacent to the distal marginal ridge.

(d) *Grooves* (**Fig. 17.27c**)

- *Central developmental groove:* The groove radiates from the central pit to the mesial and the distal sides and ends in the mesial and distal pit.
- *Buccal developmental groove:* The groove begins at the central pit and extends between the mesiobuccal and distobuccal cusps and further traverses over the buccal surface.
- *Lingual developmental groove:* The groove begins at the central pit and extends between the mesiolingual and distolingual cusp and further traverses over the lingual surface.

MANDIBULAR THIRD MOLAR

The mandibular third molar is present posterior to the mandibular second molar. The morphology of mandibular third molars is considerably variable.

The chronology and dimensions of the mandibular third molars are stated in **Boxes 17.11** and **17.12**.

Box 17.11 Chronology of the Mandibular Third Molars

- First evidence of calcification: 8–10 years
- Enamel completion: 12–16 years
- Eruption: 17–21 years
- Root completion: 18–25 years

Box 17.12 Dimensions of the Mandibular Third Molars (Fig. 17.28)

- Length of the crown: 7.0 mm
- Length of the root: 11 mm
- Mesiodistal width of the crown: 10.0 mm
- Mesiodistal width of the crown at cervix: 7.5 mm
- Labiolingual width of the crown: 9.5 mm
- Labiolingual width of the crown at cervix: 9.0 mm
- Depth of curvature at the mesial aspect: 1.0 mm
- Depth of curvature at the distal aspect: 0 mm

Buccal Aspect (Fig. 17.29)

1. **Shape of the crown:** The shape of the crown is roughly ovoid.
2. **Outlines of the crown**

(a) *Mesial outline:* The mesial outline is convex from the cervical line to the

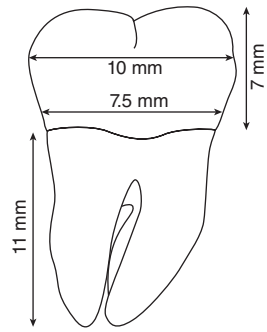


Figure 17.28 Dimensions of the mandibular third molar.

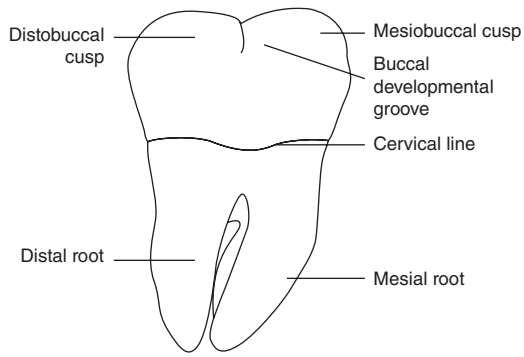


Figure 17.29 Buccal aspect of the mandibular third molar.

mesiobuccal cusp tip. The contact area is located at the middle third.

(b) *Distal outline:* The distal outline is also convex from the cervical line to the distobuccal cusp tip.

(c) *Cervical outline:* The cervical line is slightly curved near the bifurcation area.

(d) *Occlusal outline:* The occlusal outline shows two buccal cusps: mesiobuccal and distobuccal. The mesiobuccal cusp is almost the same size as the distobuccal cusp.

3. **Buccal surface:** The buccal surface is convex and shows the presence of a single buccal developmental groove separating the mesiobuccal and distobuccal cusps.
4. **Roots:** Two roots—mesial and distal—are seen from this aspect. The roots are short and are placed close to each other. The root trunk is short when compared with the other mandibular molars.

(a) *Mesial root:* The mesial outline of the root is convex and the apical third is inclined distally. The distal outline of the mesial root is concave.

(b) *Distal root:* The mesial outline of the root is concave and the distal outline is convex. The apical third of the distal root is inclined mesially unlike the first molar which shows a distal inclination.

Lingual Aspect (Fig. 17.30)

1. **Shape of the crown:** The shape of the crown is trapezoidal, same as in the labial side.
2. **Outlines of the crown**

(a) *Mesial outline:* The mesial outline is convex from the cervical line to the mesiolingual cusp tip.

(b) *Distal outline:* The distal outline is convex from the cervical line to the distolingual cusp tip.

(c) *Cervical outline:* The cervical line is almost straight.

(d) *Occlusal outline:* The mesiolingual and the distolingual cusps are seen from this aspect. The mesiolingual cusp is larger than the distolingual cusp.

3. **Lingual surface:** The lingual surface is convex. A lingual developmental groove runs between

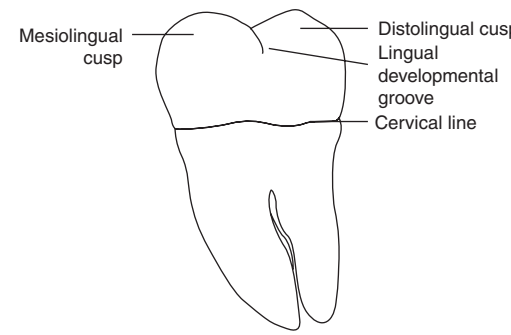


Figure 17.30 Lingual aspect of the mandibular third molar.

the two lingual cusps and extends to a short distance on the lingual surface.

4. **Roots:** The two roots are seen from this aspect. The root trunk is longer in this aspect when compared with the buccal aspect.
   (a) *Mesial root:* The mesial outline of the mesial root is convex and the distal outline is concave. The apical third is inclined distally.
   (b) *Distal root:* The mesial outline of the distal root is concave, and the distal outline is convex. The apical third is tilted distally.

Mesial Aspect (Fig. 17.31)

1. **Shape of the crown:** The crown is rhomboidal in this aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline of the crown is convex from the cervical line to the mesiobuccal cusp tip.
   (b) *Lingual outline:* The lingual outline is also convex from the cervical line to the tip of the mesiolingual cusp.
   (c) *Cervical outline:* The cervical line is almost a straight line with 1 mm depth of curvature towards the occlusal surface.
   (d) *Occlusal outline:* The mesiobuccal and mesiolingual cusps are seen from this aspect. The mesial marginal ridge is not divided by the mesial marginal groove.
3. **Contact area:** The contact area is present in the middle third of the crown. It is positioned more buccally.
4. **Root:** The mesial root is seen from this aspect. The buccal outline of the mesial root is slightly convex from the cervical line to the apex. The lingual outline is straight from the cervical line to the apex. There is a shallow developmental depression in the mesial surface of the mesial root extending from the cervical line to the apex.
5. The buccal outline of the distal root is also seen.

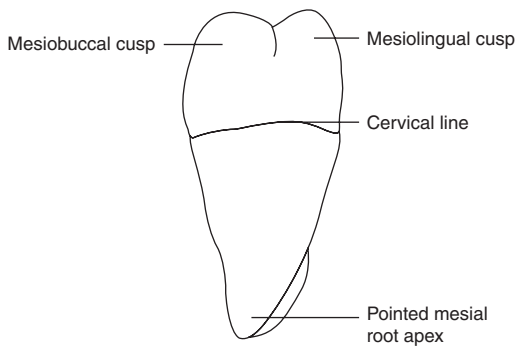


Figure 17.31 Mesial aspect of the mandibular third molar.

Distal Aspect (Fig. 17.32)

1. **Shape of the crown:** The shape of the crown is rhomboidal in the distal aspect.
2. **Outlines of the crown**
   (a) *Buccal outline:* The buccal outline is slightly convex from the cervical line to the tip of the distal cusp.
   (b) *Lingual outline:* The lingual outline is convex from the cervical line to the distolingual cusp tip.
   (c) *Cervical outline:* The cervical line is almost a straight line without any curvature.
   (d) *Occlusal outline:* All the four cusps are seen from this aspect because of the short distal marginal ridge. The distal marginal ridge does not have a distal marginal groove.

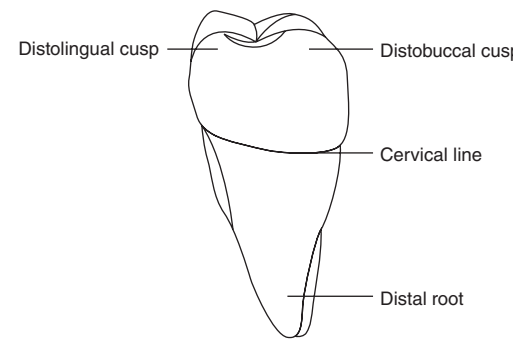


Figure 17.32 Distal aspect of the mandibular third molar.

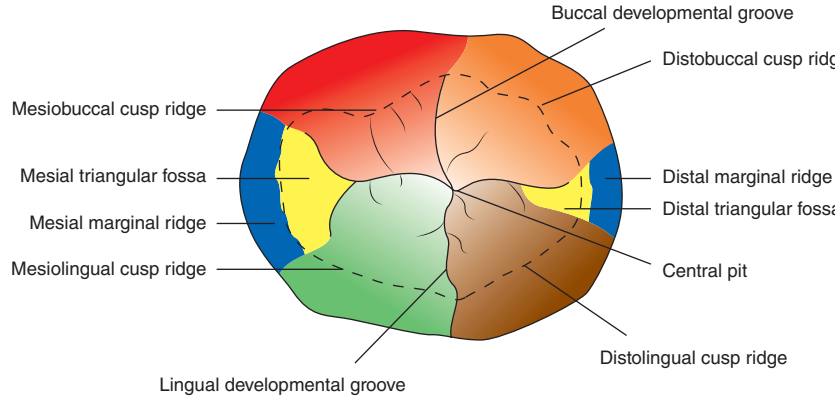


Figure 17.33 Occlusal aspect of the mandibular third molar.

3. **Root:** The distal root is seen from this aspect. The buccal outline is convex from the cervical line to the apex. The lingual outline is convex from the cervical third to the middle third.
4. The lingual outline of the mesial root is also seen from this aspect.

Occlusal Aspect (Fig. 17.33)

1. **Shape of the crown:** The shape of the crown is roughly oval in the occlusal aspect.
2. **Outlines of the crown:** The outline of the crown is roughly oval with four cusps. The groove pattern in the third molar is a '+' type.
3. **Occlusal surface:** The occlusal surface has a much wrinkled appearance because of the presence of supplemental grooves and occlusal pits.

Mandibular molars show variations in cuspal patterns which are depicted in **Figure 17.34**.

VARIATIONS IN MANDIBULAR MOLARS

1. **Protostylid:** Presence of an extra tubercle on the buccal side of the mesiobuccal cusp.
2. **Accessory ridges:** Extra ridge present in some teeth paralleling the mesial marginal ridge.
3. **Roots:** The first mandibular molar presents with three roots in some teeth. The second mandibular molar presents with a single root in some teeth instead of the usual two roots.
4. In mandibular first molars, an additional distal canal and a third mesial canal, known as *middle mesial canal*, are common variations.

CLINICAL CONSIDERATIONS: MANDIBULAR MOLARS

1. They are the most common teeth to be affected by dental caries because they are the first permanent teeth to erupt and their occlusal morphology favours retention of food.
2. Early loss of the first molars leads to severe problems in occlusion and mastication.
3. Buccal pits occur commonly in the buccal surface and are more susceptible to dental caries.
4. Occasionally, the mandibular first molar has three roots, and the third root is called *radix entomolaris*.
5. The mandibular third molar is the most commonly impacted teeth.

The differentiating features of mandibular first, second and third molars are listed in **Table 17.2**.

Table 17.2 Differences Between the Mandibular Molars

Aspect	Mandibular First Molar	Mandibular Second Molar	Mandibular Third Molar
Occlusal aspect	Pentagonal	Rectangular	Ovoid
	The cuspal pattern is in the shape of Y	The cuspal pattern is in the shape of +	The cuspal pattern varies between two shapes: + and Y
Cusps	Five cusps are present	Four cusps are present	Four cusps are present
	The distal cusp makes the fifth cusp along with two buccal cusps and two lingual cusps	The distal cusp is absent	The distal cusp is absent
Roots	The roots are divergent	Roots are closer together	Roots are fused
	The mesial root is wide buccolingually	The mesial root is slightly narrower than in the first molars	The mesial root is narrower than in the first and second molars

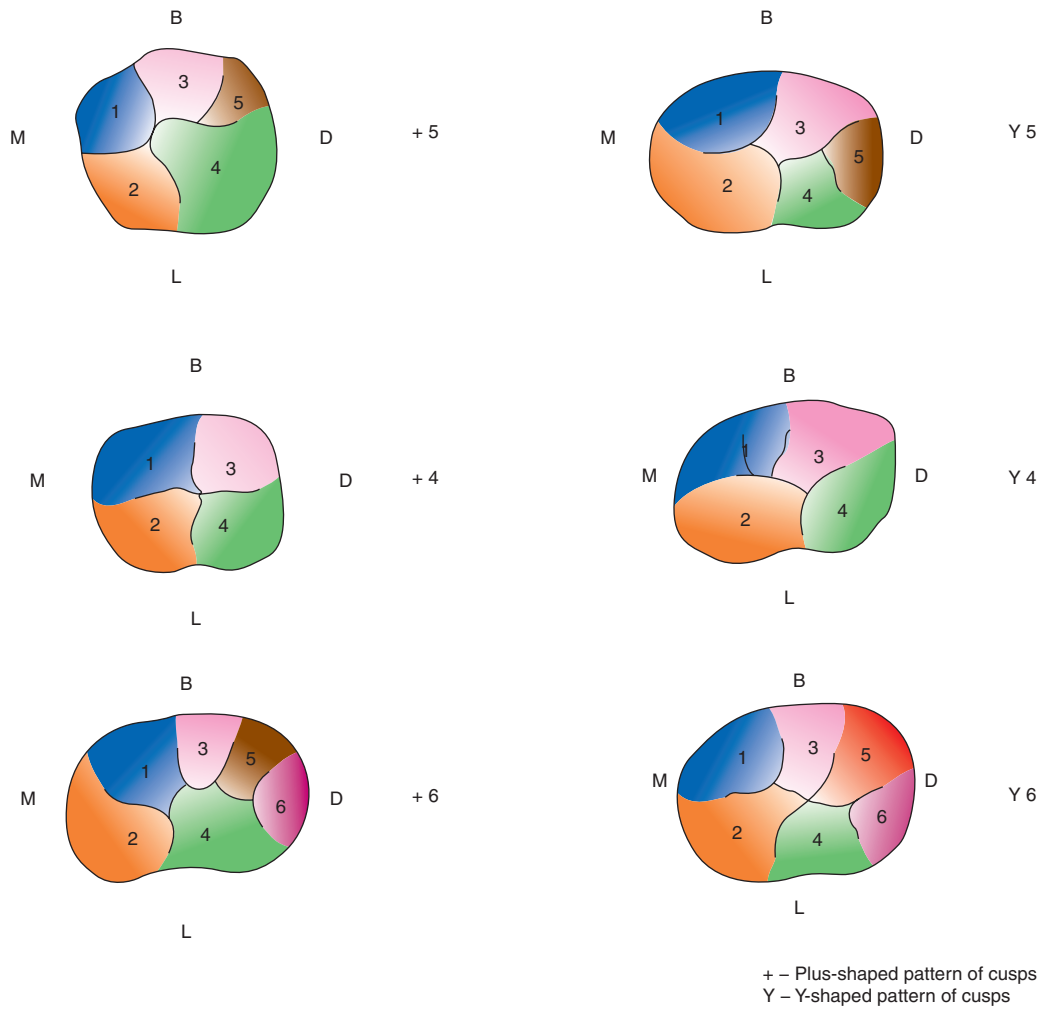
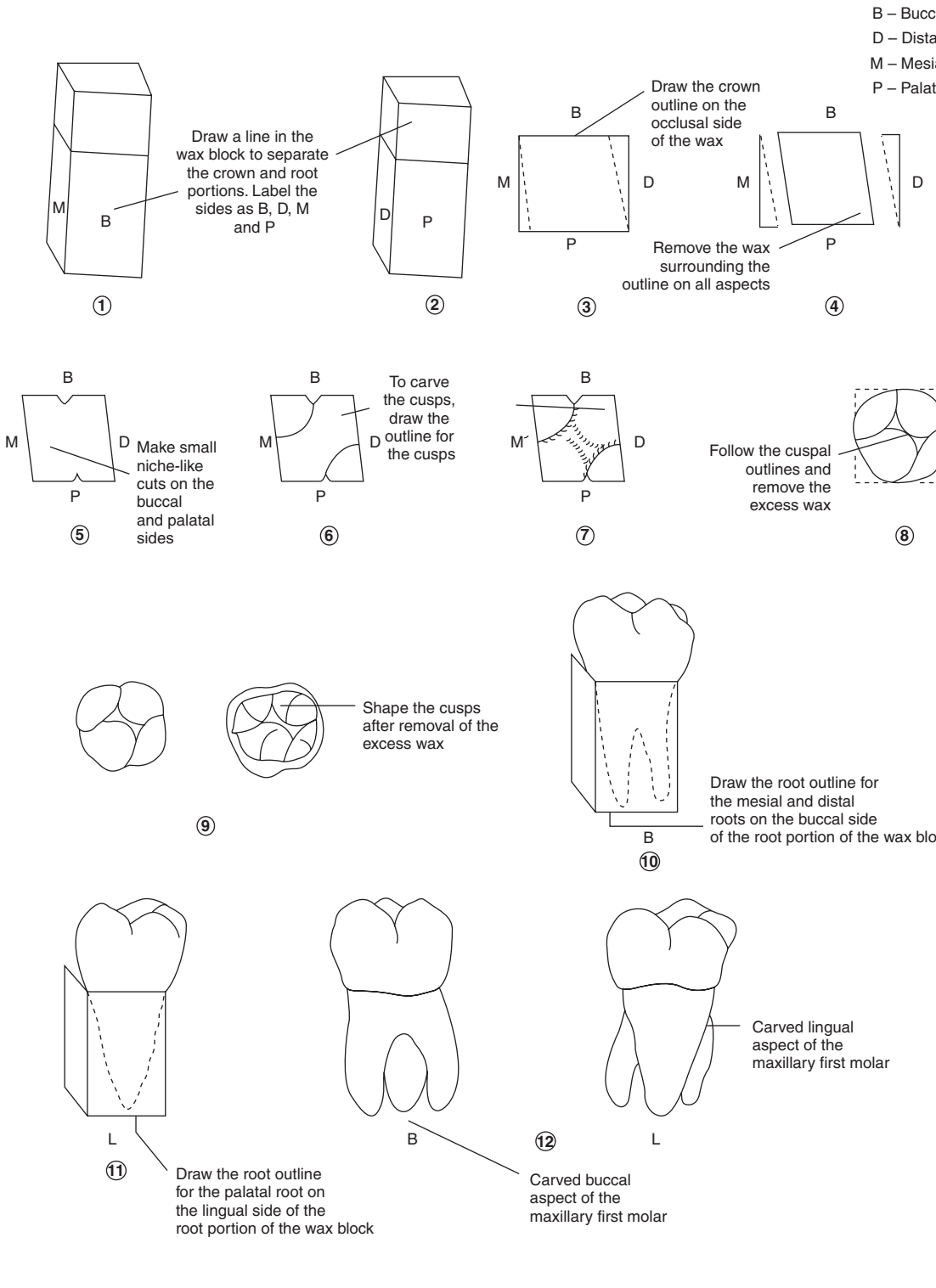


Figure 17.34 Variations in cuspal patterns in mandibular molars. 1, mesiobuccal cusp; 2, mesiolingual cusp; 3, distobuccal cusp; 4, distolingual cusp; 5, distal cusp; 6, supplementary cusp. *B*, buccal; *D*, distal; *L*, lingual; *M*, mesial.

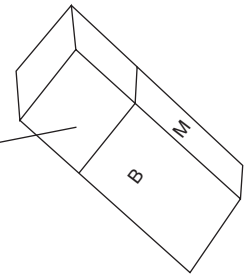
STEPS FOR CARVING A MAXILLARY FIRST MOLAR



SECTION II

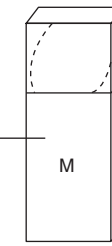
STEPS FOR CARVING A MANDIBULAR FIRST MOLAR

B – Buccal
D – Distal
M – Mesial
P – Palatal



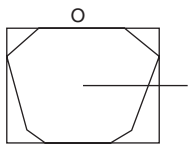
Draw a line in the wax block to separate the crown and root portions. Label the sides as B, D, L and M

①



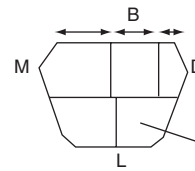
Draw the proximal outline on the mesial and distal sides. Note that a mild lingual tilt is given

②

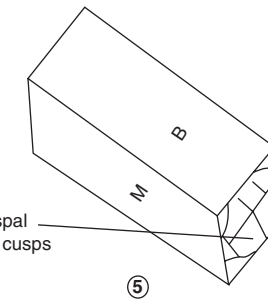


Draw the occlusal outline on the occlusal aspect

③

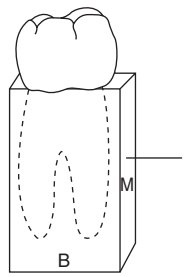


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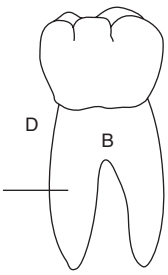
Draw the cuspal outlines for the cusps

⑤



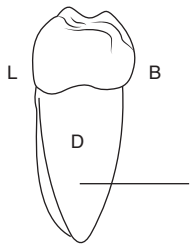
Draw the root outline on the buccal and lingual aspects

⑥



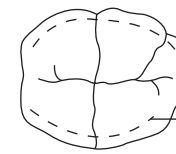
Carved buccal aspect of the mandibular first molar

⑦



Carved proximal aspect of the mandibular first molar

⑧



Carved occlusal aspect of the mandibular first molar

⑨

Key Points

Maxillary First Molars

1. The spaces between the roots of the maxillary first molars are known as *furcation crotches*.
2. The first evidence of calcification of the maxillary first molar is at birth.
3. The oblique ridge runs from the mesiopalatal cusp to the distobuccal cusp.
4. Four major cusps are present in the maxillary first molar. The mesiopalatal cusp is the largest of all cusps and the distolingual is the smallest.
5. The cusp of Carabelli is seen on the mesiopalatal cusp of the maxillary first molar.
6. Three roots are seen. The palatal root is the largest of all roots and the distal root is the smallest.

Maxillary Second Molars

1. The maxillary second molar is smaller than the maxillary first molar.
2. The cusp of Carabelli is absent in the maxillary second molar.
3. The oblique ridge is less prominent in this tooth.
4. The distopalatal cusp is very small when compared to that of the first molar.

Maxillary Third Molars

1. In The third maxillary molar, the crown shows significant lingual convergence.
2. The occlusal surface of this tooth is heart shaped as the distopalatal cusp is absent or poorly developed.
3. Its root trunk is longer when compared with the first and the second maxillary molars.

Mandibular First Molars

1. The mandibular first molar is the first permanent tooth to erupt in the oral cavity.
2. The mesiobuccal developmental and the distobuccal developmental grooves are seen in the buccal surface.
3. In this type of tooth, the lingual cusps are higher than the buccal cusps.
4. The root trunk is 3 mm wide in the buccal aspect whereas it is 4 mm in the lingual aspect.
5. The mesial and distal surfaces of the root show a shallow developmental depression extending from the cervical line to the apex.
6. The occlusal groove pattern is Y shaped.

Mandibular Second Molars

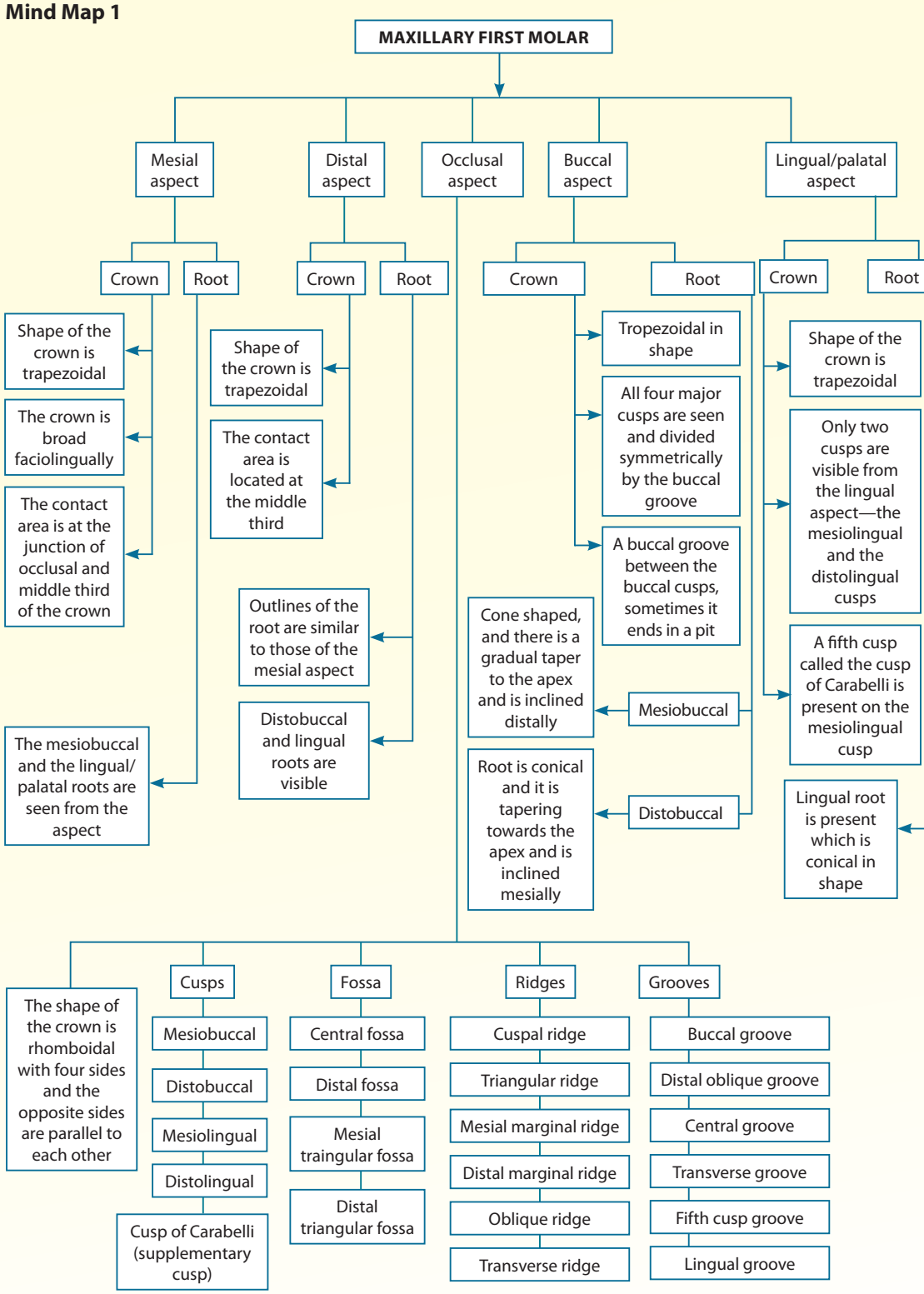
1. In the mandibular second molar, the mesiodistal width and the labiolingual width are almost the same.
2. Its occlusal outline is rectangular.
3. The occlusal groove pattern is '+' shaped.

Mandibular Third Molars

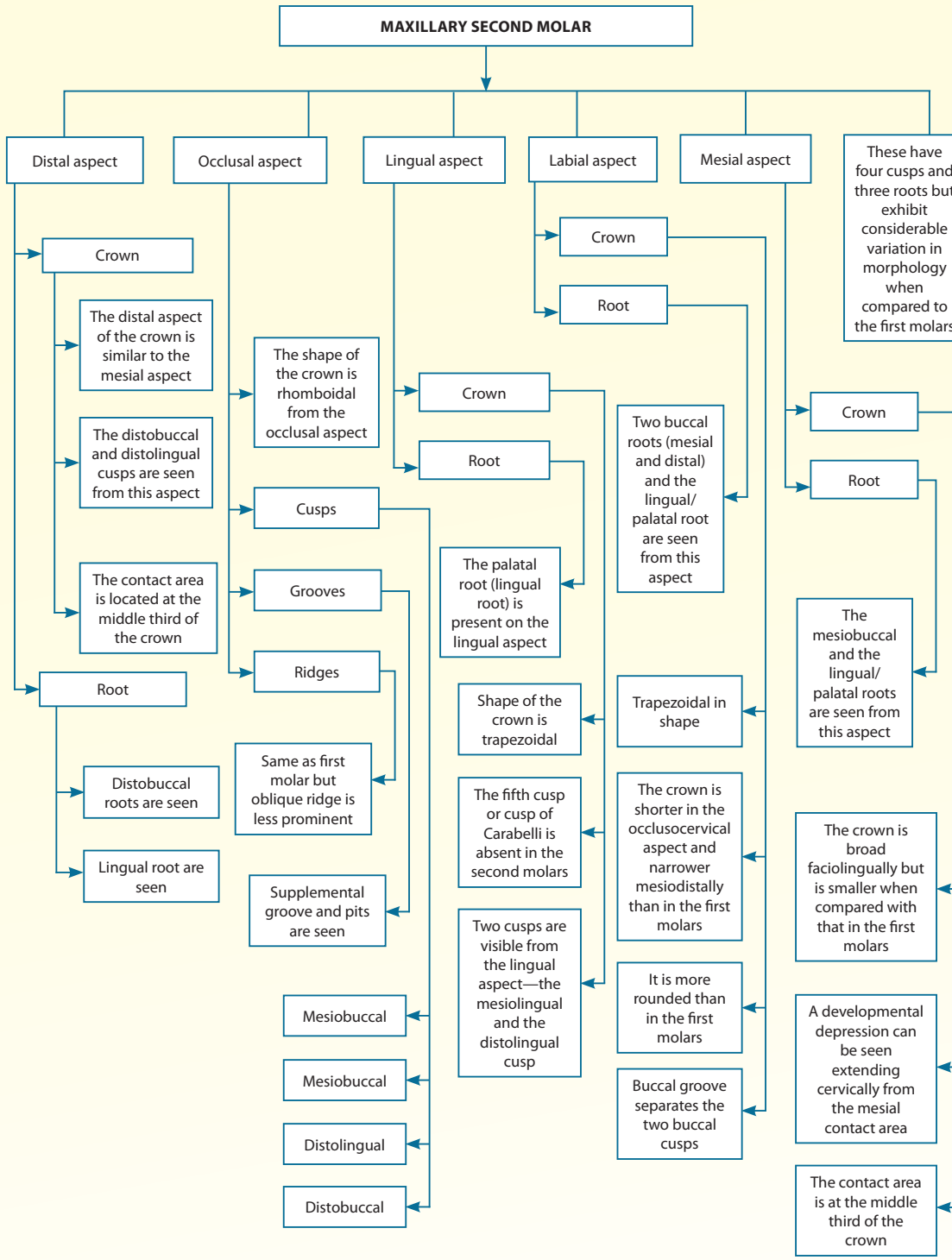
1. The mandibular third molar exhibits considerable variation in morphology.
2. In the mandibular third molar, the contact area is present in the mesial side on the middle third of the crown and is positioned more buccally. Posteriorly, there is no contact for the third molar.
3. Occlusal surface is wrinkled because of the presence of supplementary grooves in this molar.

Mind Maps

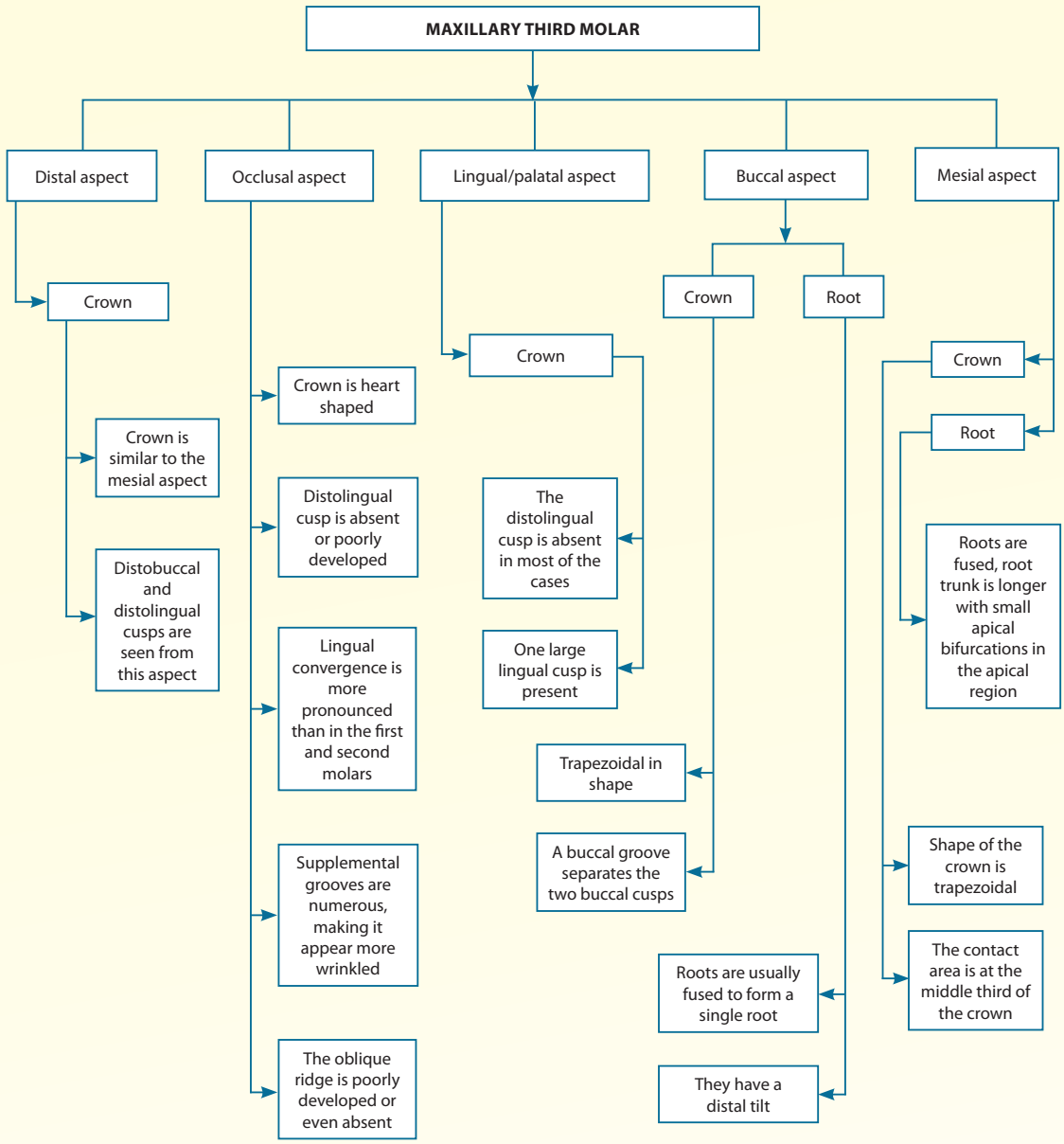
Mind Map 1



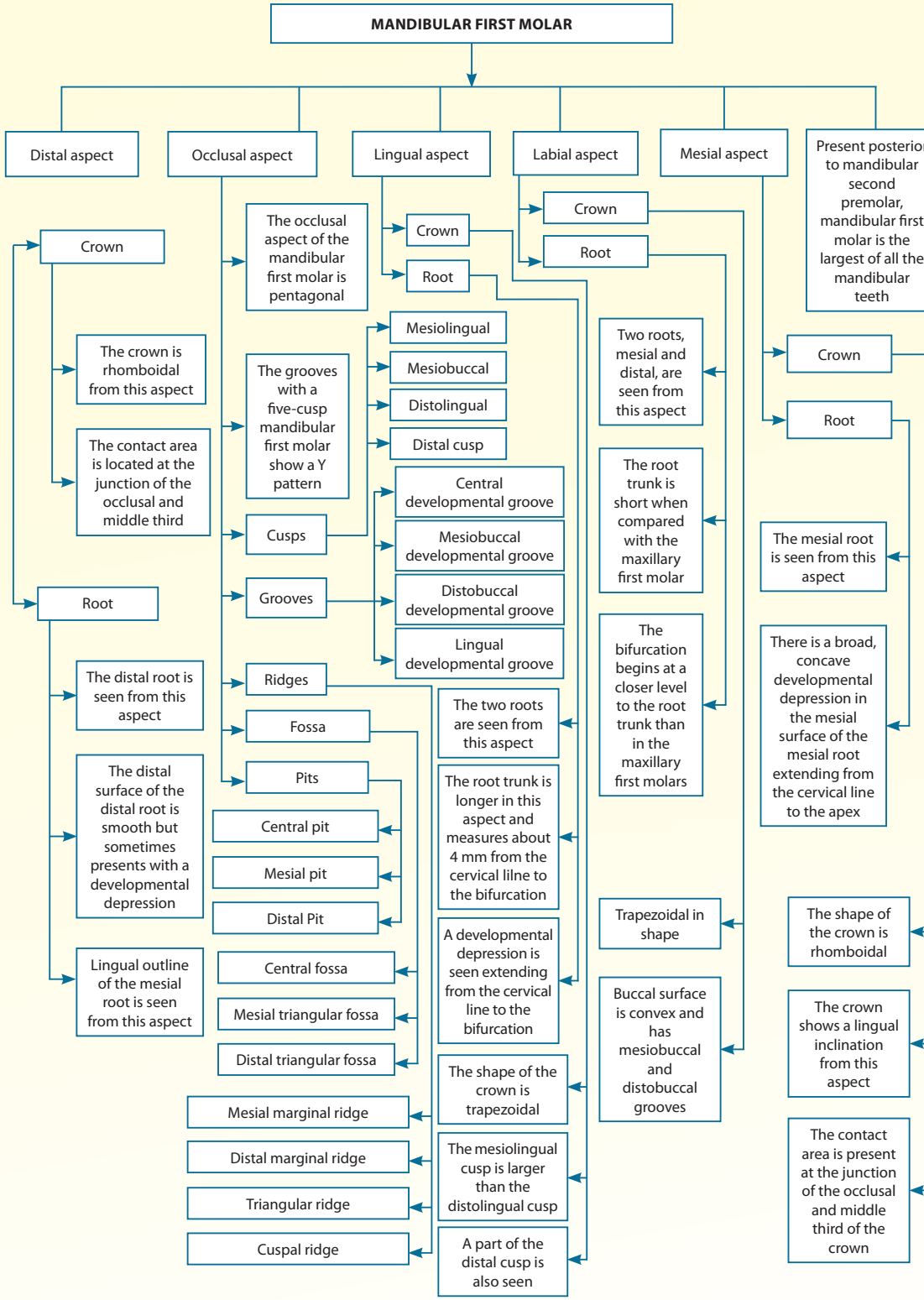
Mind Map 2


MAXILLARY SECOND MOLAR
Distal aspect
Occlusal aspect
Lingual aspect
Labial aspect
Mesial aspect
These have four cusps and three roots but exhibit considerable variation in morphology when compared to the first molars
Crown
The distal aspect of the crown is similar to the mesial aspect
The distobuccal and distolingual cusps are seen from this aspect
The contact area is located at the middle third of the crown
Root
Distobuccal roots are seen
Lingual root are seen
The shape of the crown is rhomboidal from the occlusal aspect
Cusps
Grooves
Ridges
Same as first molar but oblique ridge is less prominent
Supplemental groove and pits are seen
Mesiobuccal
Mesiobuccal
Distolingual
Distobuccal
Crown
Root
The palatal root (lingual root) is present on the lingual aspect
Shape of the crown is trapezoidal
The fifth cusp or cusp of Carabelli is absent in the second molars
Two cusps are visible from the lingual aspect—the mesiolingual and the distolingual cusp
Crown
Root
Two buccal roots (mesial and distal) and the lingual/palatal root are seen from this aspect
Trapezoidal in shape
The crown is shorter in the occlusocervical aspect and narrower mesiodistally than in the first molars
It is more rounded than in the first molars
Buccal groove separates the two buccal cusps
Crown
Root
The mesiobuccal and the lingual/palatal roots are seen from this aspect
The crown is broad faciolingually but is smaller when compared with that in the first molars
A developmental depression can be seen extending cervically from the mesial contact area
The contact area is at the middle third of the crown

Mind Map 3

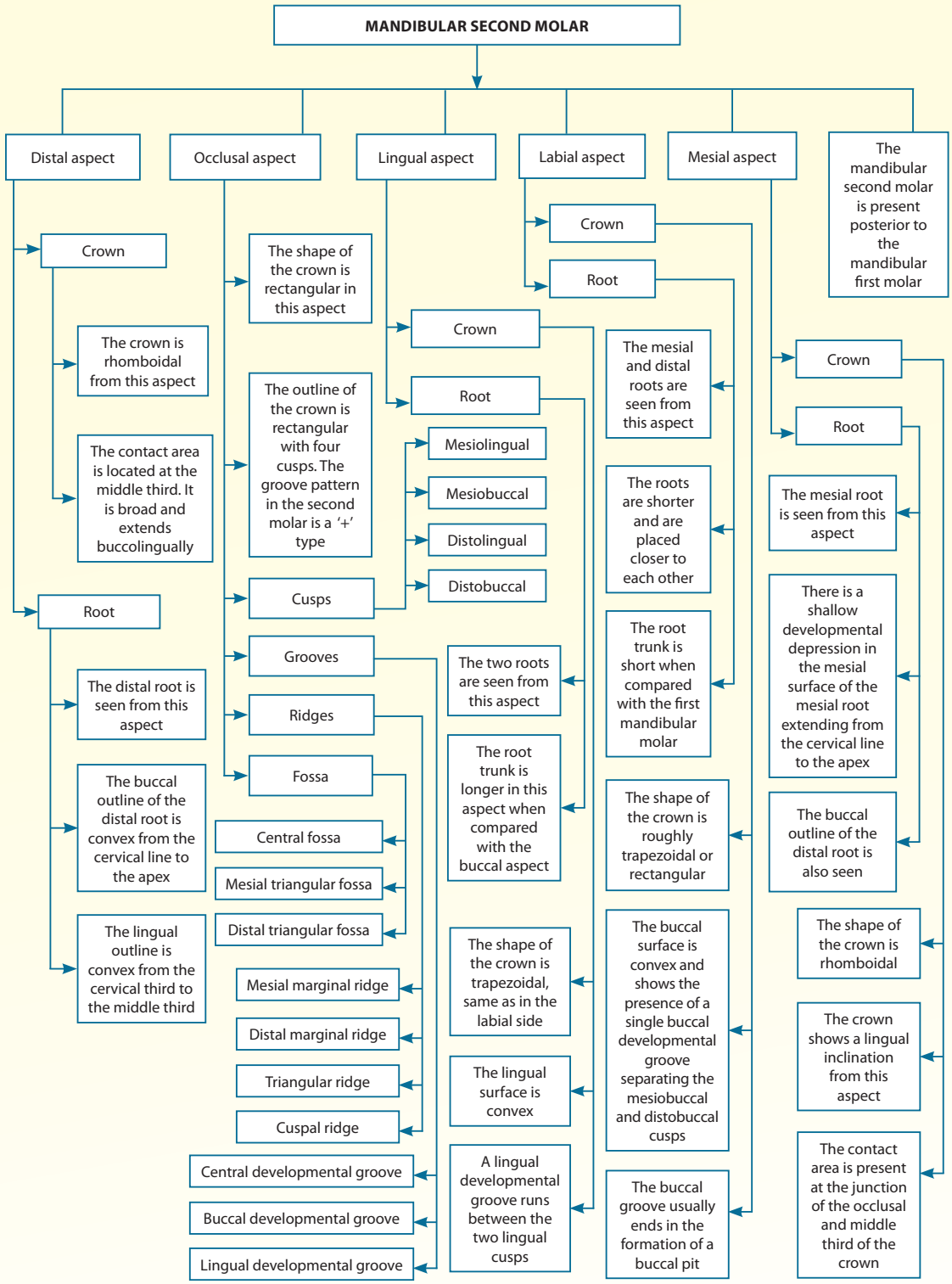

MAXILLARY THIRD MOLAR
Distal aspect
Occlusal aspect
Lingual/palatal aspect
Buccal aspect
Mesial aspect
Crown
Crown is similar to the mesial aspect
Distobuccal and distolingual cusps are seen from this aspect
Crown is heart shaped
Distolingual cusp is absent or poorly developed
Lingual convergence is more pronounced than in the first and second molars
Supplemental grooves are numerous, making it appear more wrinkled
The oblique ridge is poorly developed or even absent
Crown
The distolingual cusp is absent in most of the cases
One large lingual cusp is present
Crown
Root
Trapezoidal in shape
A buccal groove separates the two buccal cusps
Roots are usually fused to form a single root
They have a distal tilt
Crown
Root
Roots are fused, root trunk is longer with small apical bifurcations in the apical region
Shape of the crown is trapezoidal
The contact area is at the middle third of the crown

Mind Map 4

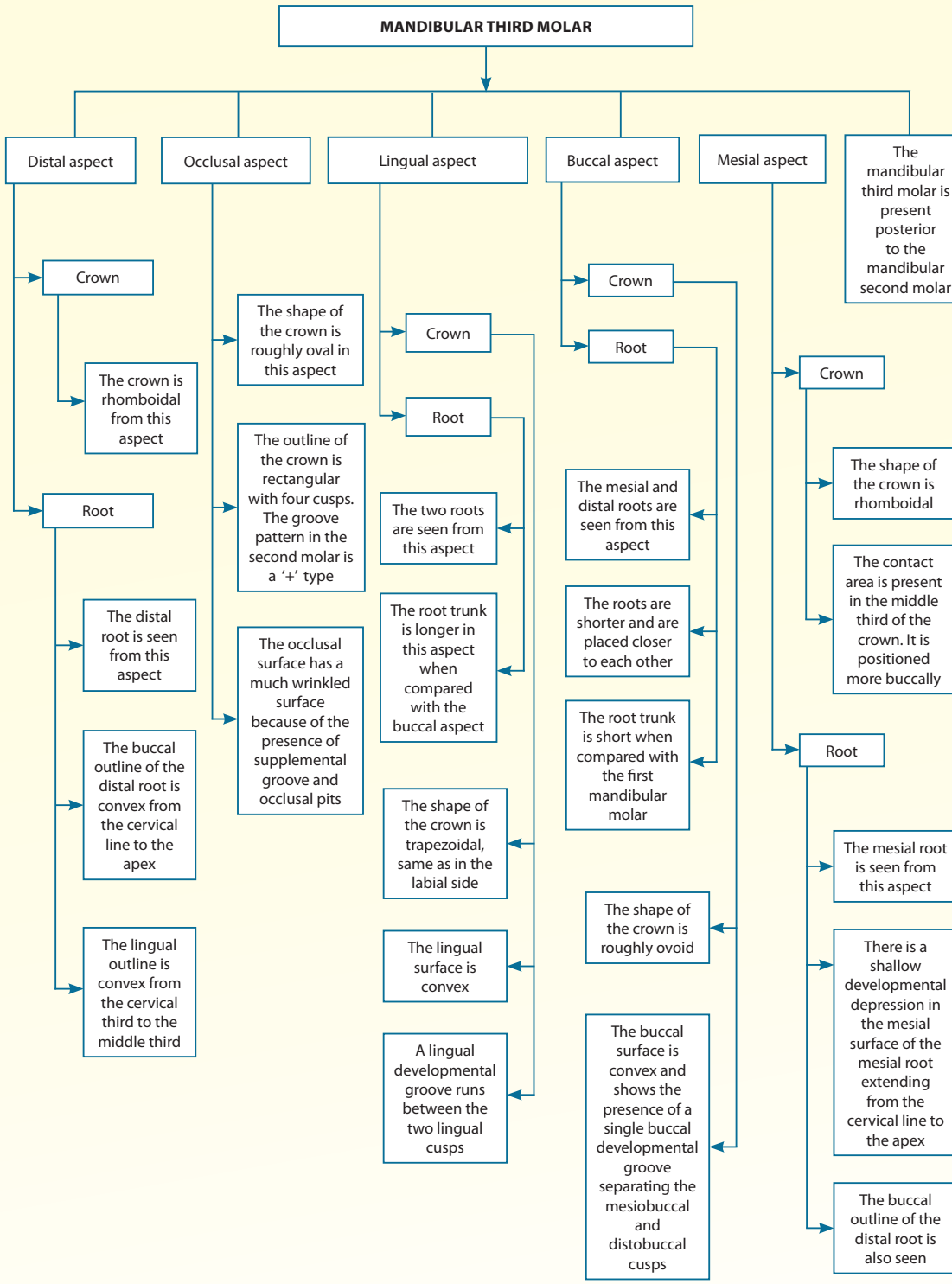


SECTION II

Mind Map 5


MANDIBULAR SECOND MOLAR
Distal aspect
Occlusal aspect
Lingual aspect
Labial aspect
Mesial aspect
The mandibular second molar is present posterior to the mandibular first molar
Crown
The crown is rhomboidal from this aspect
The contact area is located at the middle third. It is broad and extends buccolingually
Root
The distal root is seen from this aspect
The buccal outline of the distal root is convex from the cervical line to the apex
The lingual outline is convex from the cervical third to the middle third
The shape of the crown is rectangular in this aspect
The outline of the crown is rectangular with four cusps. The groove pattern in the second molar is a '+' type
Cusps
Grooves
Ridges
Fossa
Central fossa
Mesial triangular fossa
Distal triangular fossa
Mesial marginal ridge
Distal marginal ridge
Triangular ridge
Cuspal ridge
Central developmental groove
Buccal developmental groove
Lingual developmental groove
Crown
Root
Mesiolingual
Mesiobuccal
Distolingual
Distobuccal
The two roots are seen from this aspect
The root trunk is longer in this aspect when compared with the buccal aspect
The shape of the crown is trapezoidal, same as in the labial side
The lingual surface is convex
A lingual developmental groove runs between the two lingual cusps
Crown
Root
The mesial and distal roots are seen from this aspect
The roots are shorter and are placed closer to each other
The root trunk is short when compared with the first mandibular molar
The shape of the crown is roughly trapezoidal or rectangular
The buccal surface is convex and shows the presence of a single buccal developmental groove separating the mesiobuccal and distobuccal cusps
The buccal groove usually ends in the formation of a buccal pit
Crown
Root
The mesial root is seen from this aspect
There is a shallow developmental depression in the mesial surface of the mesial root extending from the cervical line to the apex
The buccal outline of the distal root is also seen
The shape of the crown is rhomboidal
The crown shows a lingual inclination from this aspect
The contact area is present at the junction of the occlusal and middle third of the crown

Mind Map 6


MANDIBULAR THIRD MOLAR
Distal aspect
Occlusal aspect
Lingual aspect
Buccal aspect
Mesial aspect
The mandibular third molar is present posterior to the mandibular second molar
Crown
The crown is rhomboidal from this aspect
Root
The distal root is seen from this aspect
The buccal outline of the distal root is convex from the cervical line to the apex
The lingual outline is convex from the cervical third to the middle third
The shape of the crown is roughly oval in this aspect
The outline of the crown is rectangular with four cusps. The groove pattern in the second molar is a '+' type
The occlusal surface has a much wrinkled surface because of the presence of supplemental groove and occlusal pits
Crown
Root
The two roots are seen from this aspect
The root trunk is longer in this aspect when compared with the buccal aspect
The shape of the crown is trapezoidal, same as in the labial side
The lingual surface is convex
A lingual developmental groove runs between the two lingual cusps
Crown
Root
The mesial and distal roots are seen from this aspect
The roots are shorter and are placed closer to each other
The root trunk is short when compared with the first mandibular molar
The shape of the crown is roughly ovoid
The buccal surface is convex and shows the presence of a single buccal developmental groove separating the mesiobuccal and distobuccal cusps
Crown
The shape of the crown is rhomboidal
The contact area is present in the middle third of the crown. It is positioned more buccally
Root
The mesial root is seen from this aspect
There is a shallow developmental depression in the mesial surface of the mesial root extending from the cervical line to the apex
The buccal outline of the distal root is also seen

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Multiple Choice Questions

1. The outline of the crown in the maxillary molar is
   (a) Rhomboidal
   (b) Trapezoidal
   (c) Square
   (d) None
2. The cusp of Carabelli is related to which cusp?
   (a) Mesiolingual
   (b) Distolingual
   (c) Distobuccal
   (d) Mesiobuccal
3. The outline of the occlusal surface of the maxillary first molar is
   (a) Square
   (b) Rhomboidal
   (c) Trapezoidal
   (d) Parallelogram
4. The largest cusp in the permanent maxillary first molar is
   (a) Mesiolingual
   (b) Distolingual
   (c) Mesiobuccal
   (d) Distobuccal
5. In the maxillary first molar, describe the cusps from the largest to the smallest.
   (a) Mesiobuccal, mesiolingual, distolingual, distobuccal
   (b) Mesiolingual, mesiobuccal, distobuccal, distolingual
   (c) Mesiolingual, mesiobuccal, distolingual, distobuccal
   (d) Mesiobuccal, distobuccal, distolingual, mesiolingual
6. In the maxillary first molar, which two cusps unite to form the oblique ridge?
   (a) Mesiolingual and distobuccal
   (b) Mesiolingual and mesiobuccal
   (c) Distolingual and distobuccal
   (d) Distolingual and mesiobuccal
7. The transverse ridge in the permanent maxillary first molar is formed by the
   (a) Triangular ridges of the mesiolingual and distobuccal cusps
   (b) Triangular ridges of the distobuccal and mesiobuccal cusps
   (c) Buccal ridge of the mesiolingual cusp and the lingual ridge of the mesiobuccal cusp

(d) Distal marginal ridge with triangular ridge of the distobuccal cusp

8. Major fossae of the maxillary first molar are
   (a) Mesial and distal triangular fossae
   (b) Central and distal fossae
   (c) Mesial fossa and mesial triangular fossa
   (d) Central and mesial fossae
9. The heart-shaped outline form, an occlusal aspect view, is seen in the
   (a) Maxillary second molar
   (b) Maxillary third molar
   (c) Mandibular first molar
   (d) Mandibular second molar
10. The largest permanent tooth/teeth in the mandibular arch is/are
   (a) 38
   (b) 38 and 48
   (c) 36 and 46
   (d) 47
11. The buccal aspect of the permanent mandibular first molar is
   (a) Trapezoidal
   (b) Hexagonal
   (c) Rectangular
   (d) Rhomboidal
12. The maxillary first, second and third molars can be differentiated by the
   (a) Number of roots
   (b) Cusp of Carabelli
   (c) Size of the distolingual cusp
   (d) All of the above
13. The point of bifurcation seen in the buccal aspect of the permanent mandibular first molar is
   (a) 4 mm
   (b) 3 mm
   (c) 1.5 mm
   (d) 3.5 mm
14. The mesiodistal width is more than the buccolingual width in
   (a) 46
   (b) 26
   (c) 34
   (d) 27
15. The three root canals of the mandibular first molar are
   (a) Mesiobuccal, mesiolingual and distal
   (b) Mesial, distal and palatal
   (c) Mesial, distobuccal and distolingual
   (d) Mesiobuccal, mesiolingual and palatal
16. The occlusal aspect of the mandibular first molar is
   (a) Rhomboidal
   (b) Pentagonal
   (c) Rectangular
   (d) Trapezoidal
17. The tooth which is characterized by five pulp horns is the
   (a) Maxillary first molar
   (b) Mandibular first molar
   (c) Mandibular second molar
   (d) Maxillary second molar
18. The mandibular first molar has _____ cusps.
   (a) 5
   (b) 4
   (c) 3
   (d) 2
19. The largest cusp of the mandibular first molar is
   (a) Mesiobuccal
   (b) Mesiolingual
   (c) Distobuccal
   (d) Distolingual
20. The size of cusps in the mandibular first molar from the smallest to the largest is
   (a) Distolingual, distobuccal, mesiolingual, mesiobuccal
   (b) Distobuccal, distolingual, mesiolingual, mesiobuccal
   (c) Mesiobuccal, mesiolingual, distobuccal, distolingual
   (d) Mesiolingual, mesiobuccal, distolingual, distobuccal

21. The occlusal surface of the permanent mandibular first molar has
    (a) One major and two minor fossae
    (b) Two major and one minor fossae
    (c) Three major and two minor fossae
    (d) One major and one minor fossae
22. The first permanent tooth to erupt in the oral cavity is the
    (a) Permanent mandibular first molar
    (b) Permanent mandibular second molar
    (c) Maxillary central incisor
    (d) Mandibular central incisor
23. The characteristic plus pattern groove is seen in the occlusal aspect of the
    (a) Maxillary first molar
    (b) Mandibular first molar
    (c) Mandibular second molar
    (d) Maxillary second molar
24. Which of the following is true of the occlusal aspect of the mandibular second molar?
    (a) It has four cusps
    (b) It has three primary developmental grooves
    (c) The occlusal aspect is rectangular
    (d) All of the above
25. The most common tooth to get impacted is the
    (a) Permanent mandibular first molar
    (b) Permanent mandibular second molar
    (c) Permanent mandibular third molar
    (d) None of the above



CHAPTER 18

Morphology of Pulp Chambers and Canals

Overview

The morphology of anatomical crown in terms of size, shape and contour often reflects the internal anatomy of the pulp chamber space. Similarly, the external outline or morphology of individual roots reflects the intraradicular anatomy. The pulp chamber has a triangular configuration with a broad base towards the incisal edge and the apex towards the cervical aspect follows the external contour of the crown in permanent incisors and canines. Pulp horns are commonly seen distinctly in mandibular incisors. The pulp canals are commonly bifurcated at the apical end in mandibular incisors unlike maxillary incisors. Maxillary premolars are composed of two root canals (buccal and palatal) while mandibular premolars possess a single root canal. Palatal root canals are larger than buccal root canals. Buccal and palatal pulp horns are usually present with varying degrees of prominence in the premolars. Permanent maxillary molars are composed of four root canals with two root canals in the mesiobuccal root and a single canal each in the distobuccal and the palatal root. Palatal canals are usually the largest and root canals commonly demonstrate curvature towards the apex. Permanent mandibular molars are composed of three root canals with two root canals in the mesial root and a single root canal in the distal root. The distal canal is usually the largest canal and root canals commonly demonstrate curvature towards the apex similar to maxillary molars. Pulp horns corresponding to the well-developed cusps are more prominent in mandibular molars unlike maxillary molars. The deciduous incisors and canines have a single root canal. The pulp chamber is larger than in permanent teeth, with pointed pulp horns, and the root canals are wider in the coronal aspect. Deciduous molars have four root canals in each tooth. The maxillary deciduous molars have two canals in the mesial root, accounting for four in total and mandibular deciduous molars have two canals in each of the two roots. The pulp chamber is very close to the coronal surface and the furcation area in deciduous molars.

INTRODUCTION

The internal anatomy of the pulp chamber space is defined by the morphology of anatomical crown in terms of size, shape and contour. The intraradicular anatomy is defined by the external outline or morphology of individual roots. Knowledge of the morphology and anatomy of pulp is important for restorative and endodontic treatment procedures.

Wide variations exist in the intraradicular anatomy or the root canals. Various classification systems have been put forth to improve the understanding of the root canal configuration (**Box 18.1**).

MORPHOLOGY OF PULP CHAMBERS AND CANALS IN DECIDUOUS TEETH

The pulp chambers in deciduous teeth are relatively larger than their permanent counterparts. They have certain common features as follows:

1. The pulp chambers of deciduous teeth exhibit great variation in size and location.
2. Pulp horns are closer to the outer surface.
3. The mesial pulp horn is located higher when compared with other pulp horns.
4. There is usually a pulp horn under each cusp.

Deciduous Incisors and Canines

The morphology of the pulp chambers and canals follows the outline of the tooth. The deciduous incisors and canines have a single root canal. The

Box 18.1 Vertucci's Classification (Fig. 18.1)

- **Type I:** A single canal extends from the pulp chamber to the apex.
- **Type II:** Two separate canals leave the pulp chamber and join short of the apex to form one canal.
- **Type III:** One canal leaves the pulp chamber, divides into two in the root and then merges to exist as one canal.
- **Type IV:** Two separate and distinct canals extend from the pulp chamber to the apex.
- **Type V:** One canal leaves the pulp chamber and divides short of the apex into two separate and distinct canals with separate apical foramina.
- **Type VI:** Two separate canals leave the pulp chamber, merge in the body of the root and redivide short of the apex as two distinct canals.
- **Type VII:** One canal leaves the pulp chamber, divides and then rejoins within the body of the root and finally redivides into two distinct canals short of the apex.
- **Type VIII:** Three separate and distinct canals extend from the pulp chamber to the apex and taper towards the apex. There is no demarcation between the pulp chamber and the root canal.

chamber is larger than in permanent teeth, with pointed pulp horns. The root canals are wider in the coronal aspect and taper towards the apex. There is no demarcation between the pulp chamber and the root canal.

Deciduous Molars

Deciduous molars have four root canals in each tooth. The maxillary deciduous molars have two canals in the mesial root, accounting for four in total, and the mandibular deciduous molars have two canals in each of the two roots. The pulp chamber is very close to the coronal surface and the furcation area. Care should be taken during restorative procedures.

Applied Morphology

Since the pulp is very close to the coronal surface and furcation area in deciduous molars, care should be taken during restorative procedures so as to prevent untoward pulpal exposures.

MORPHOLOGY OF PULP CHAMBERS AND CANALS IN PERMANENT TEETH

Intracoronal and Intraradicular Anatomy

Maxillary Central Incisor (Fig. 18.2)

1. **Intracoronal anatomy**
   (a) The pulp chamber is broader from mesial to distal direction than from the facial to

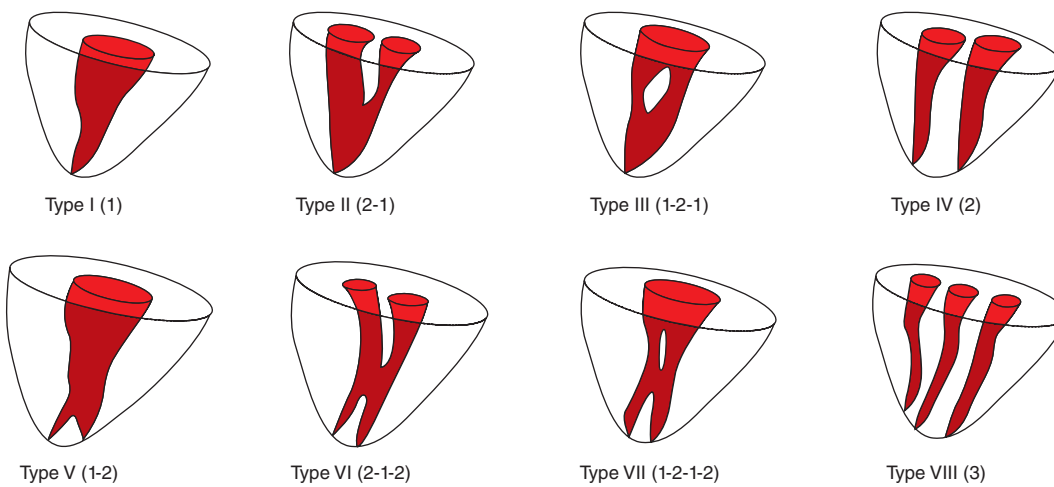


Figure 18.1 Vertucci's classification.

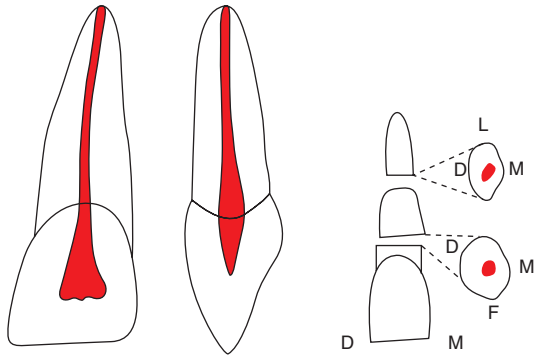


Figure 18.2 Sections of the permanent maxillary central incisor. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

palatal direction, following the external contour of the crown.

(b) Two or three slender extensions of pulp tissue form pulp horns, usually towards incisal edges, in young teeth.

(c) As the mesial and distal surface margins converge in a direction opposite to that of incisal edge, the chamber space has a triangular configuration with a broad base towards the incisal edge and the apex towards the cervical aspect.

2. **Intraradicular anatomy**

(a) The coronal pulp space converges towards the neck of the tooth and continues into the root.

(b) The central incisor usually contains a single root canal; rarely, it may contain more than one canal. The dimensions of the root are wider labiopalatally than in the mesiodistal direction.

(c) The pulp canal is a tubular structure which is wide near the coronal region and narrows down to a circular or oval-shaped apical foramen.

(d) The shape of the root canal at various levels is as follows:

- *Cervical:* Wider in the mesiodistal dimension
- *Midroot:* Ovoid
- *Apical third:* Round

Maxillary Lateral Incisor (Fig. 18.3)

1. **Intracoronal anatomy**

(a) The anatomy is similar to that of a central incisor but of smaller dimensions.

(b) Pulp horns may or may not be present.

(c) The mesial and distal surface margins converge and narrow down towards the cervical region more when compared with the central incisor.

2. **Intraradicular anatomy**

(a) The root canal begins at the orifice in a small triangular form and ends in a circular or oval-shaped apical foramen.

(b) Similar to the central incisor, there may be more than one canal in about less than 5% of people; if there are two canals, they are placed in the labiopalatal direction.

(c) The shape of the root canal at various levels is as follows:

- *Cervical:* Wider in the labiopalatal dimension
- *Midroot:* Ovoid
- *Apical third:* Generally round and gradually curved

Maxillary Canine (Fig. 18.4)

1. **Intracoronal pulp space**

(a) The crown is wider in dimension in the labiopalatal direction, and the pulp space follows this feature.

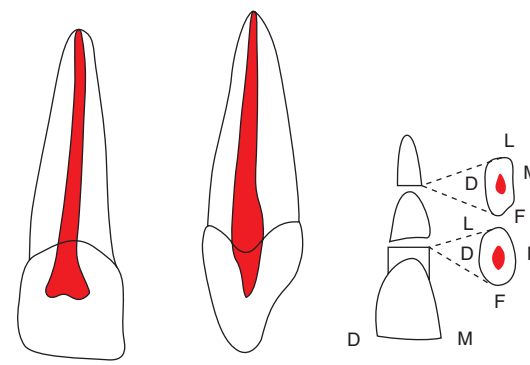
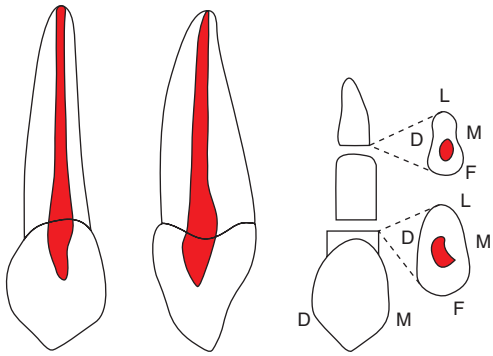
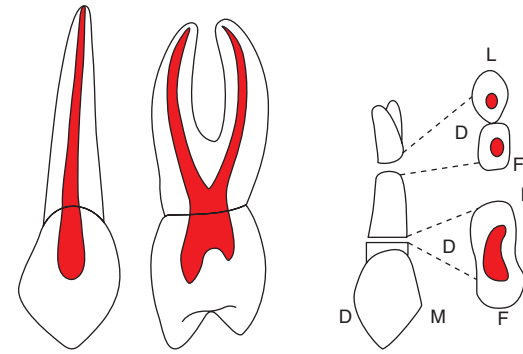


Figure 18.3 Sections of the permanent maxillary lateral incisor. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.



Mesiodistal section | Labiolingual section | Cross-section at cervical third and apical third

Figure 18.4 Sections of the permanent maxillary canine. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.



Mesiodistal section | Buccolingual section | Cross-section at cervical third and apical third

Figure 18.5 Sections of the permanent maxillary first premolar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

(b) Pulpal extensions to form pulp horns are absent. The large pulp space constricts to have an oval configuration, which continues into the root.

2. **Intraradicular anatomy**
   (a) The maxillary canine has a single root. It is the longest and largest of all teeth.
   (b) The canal space begins in an oval form and continues in the same way till the root apex. The space narrows down near the apical region.
   (c) A gentle buccal curvature of the root outline is a common occurrence at the apex, which makes the internal canal also curved near the apex.
   (d) The shape of the root canal at various levels is as follows:
   - *Cervical:* Wider in the mesiodistal dimension
   - *Midroot:* Ovoid
   - *Apical third:* Round

Maxillary First Premolar (Fig. 18.5)

1. **Intracoronal anatomy**
   (a) The tooth has two cuspal eminences, buccal and palatal, with a hexagonal crown form. The buccal pulp horn is higher than the palatal pulp horn.
   (b) The pulp space in the crown of premolar is wider in the buccolingual direction and is kidney shaped in cross-section.
   (c) The space does not constrict much near the cervical part as there are two separate roots and two canals.
2. **Intraradicular anatomy**
   (a) The anatomy follows the external outline form of the two slender roots separately.
   (b) The palatal canal is relatively larger in dimension than the buccal canal.
   (c) There is a possibility of three canals occurring, with one in the palatal root and two in the buccal root.
   (d) The root canals show a curvature towards the buccal aspect as they follow the root outline.
   (e) The shape of the root canal at various levels is as follows:
   - *Cervical:* Very wide buccolingually
   - *Midroot:* Slightly ovoid
   - *Apical third:* Round

Maxillary Second Premolar (Fig. 18.6)

1. **Intracoronal anatomy:** It is similar to the maxillary first premolar, but smaller and has rounded corners in contrast to the first premolar.
2. **Intraradicular anatomy**
   (a) The number of roots and the internal anatomy of roots differ. It can have a single root or more, up to three roots (not very common), and a single canal

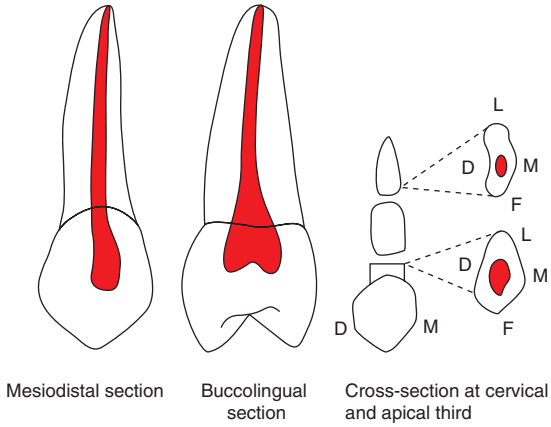


Figure 18.6 Sections of the permanent maxillary second premolar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

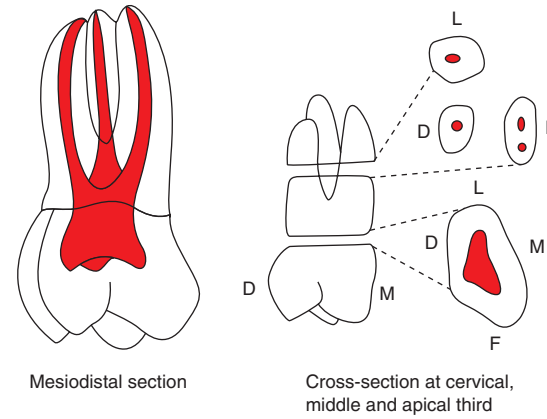


Figure 18.7 Sections of the permanent maxillary first molar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

or two canals within the same root or different roots.

(b) The roots are more slender than in the maxillary first premolar and hence the root canal space is narrower and oval.

(c) The shape of the root canal at various levels is as follows:

- *Cervical:* Very wide in the mesiodistal dimension
- *Midroot:* Ovoid
- *Apical third:* Round

Maxillary First Molar (Fig. 18.7)

1. **Intracoronal anatomy**

(a) The crown has a large dimensional pulp space from the buccal to the lingual direction with four cuspal prominences (mesiobuccal, distobuccal, mesiopalatal and distopalatal). The extra cusp on the mesiopalatal cusp is called the cusp of Carabelli.

(b) The shape of the chamber is rhomboidal because of the external contour of the crown.

(c) The coronal pulp space is continuous with root canal at the level of the floor of the pulp chamber, near the area of division of the root known as the *furcation area*.

2. **Intraradicular anatomy**

(a) There are usually three roots (palatal, mesiobuccal and distobuccal).

(b) The intraradicular pulp anatomy depends on the number of canals, as a second canal in the mesiobuccal root is a common occurrence.

(c) The palatal root is the largest and has a single palatal canal; more than one canal can occur in palatal root. The distobuccal root can also have more than one canal.

(d) The shape of the root canal at various levels is as follows:

- *Cervical:* Triangular
- *Apical third:* Round

Maxillary Second Molar (Fig. 18.8)

1. **Intracoronal anatomy**

(a) It appears identical to the maxillary first molar.

(b) Three or four cusps are present.

(c) The crown form, which dictates the pulp space anatomy, may be rhomboidal or a triangle with rounded edges.

2. **Intraradicular anatomy**

(a) The maxillary second molar has three roots but they converge more towards each other than the maxillary first molar. This convergence causes curvature of the root canals.

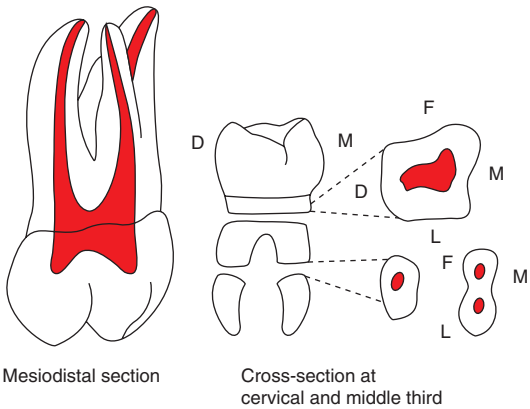


Figure 18.8 Sections of the permanent maxillary second molar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

(b) The number of canals varies from two to four, with three canals occurring more commonly.

(c) The shape of the root canal at various levels is as follows:

- *Cervical:* Triangular
- *Apical third:* Round

Maxillary Third Molar (Fig. 18.9)

1. Large variation is seen both in the intracoronal and intraradicular anatomy because of the shape, size, number of cusps and roots, and the spatial orientation of roots.
2. The tooth has two to four cusps; the intracoronal anatomy depends on the number of cusps.
3. Three roots and three canals is a common occurrence.
4. The root can exhibit curvature of different nature.
5. The intracoronal and intraradicular anatomy of maxillary third molar cannot be generalized.

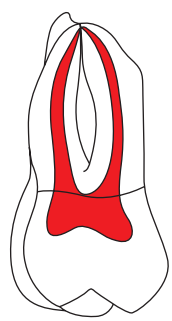


Figure 18.9 Mesiodistal section of the permanent maxillary third molar.

Mandibular Central Incisor (Fig. 18.10)

1. **Intracoronal anatomy**
   (a) It has a small pulp chamber with three distinct pulp horns at birth.
   (b) The crown is flat mesiodistally.
   (c) The pulp chamber is wide labiolingually. The cross-section in the cervical third is ovoid and tapers incisally.
2. **Intraradicular anatomy**
   (a) It has a single root which is flat and narrows mesiodistally and wide labiolingually.
   (b) At the cementoenamel junction, the pulpal outline is oval. The outline of the middlethird of the root is also oval but more constricted and narrower than at the cementoenamel junction.
   (c) The root is straight in 60% of the cases. Nearly 70% of the cases have one canal and one apical foramen, whereas 22% of the cases show one canal which bifurcates into two and exits into one apical foramen.
   (d) The shape of the root canal at various levels is as follows:
   - *Cervical:* Wider labiolingually
   - *Midroot:* Ovoid
   - *Apical third:* Round

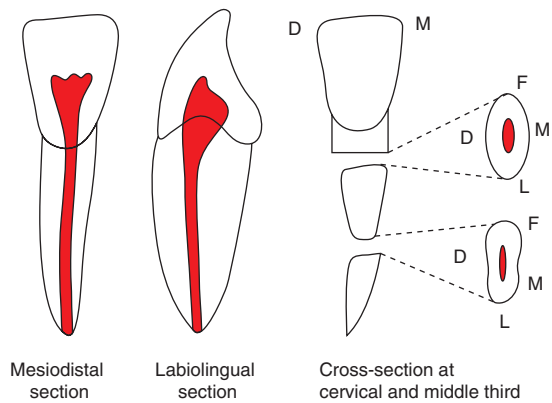


Figure 18.10 Sections of the permanent mandibular central incisor. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

Mandibular Lateral Incisor (Fig. 18.11)

1. **Intracoronal anatomy**: The configuration of the pulp chamber is similar to the central incisor but with larger dimensions.
2. **Intraradicular anatomy**
   (a) The root of the lateral incisor is larger than the central incisor, but the root canal configuration is almost similar.
   (b) The distal curve of the root is sharper.
   (c) The incidence of two root canals at the apex is same as in the central incisor.
   (d) The cross-sectional anatomy is also similar to the central incisor.
   (e) The shape of the root canal at various levels is as follows:
   - *Cervical:* Wider in the labiolingual direction
   - *Midroot:* Ovoid
   - *Apical third:* Round

Mandibular Canine (Fig. 18.12)

1. **Intracoronal anatomy**
   (a) It has a prominent pulp horn. The pulp chamber is wide labiolingually.
   (b) Usually one pulp horn is present in adults. There is no distinct demarcation between the pulp chamber and the root canal.
   (c) The pulp chamber tapers at the incisal one-third of the crown and is wide at the cervical third. It is ovoid in the cervical third of the crown.

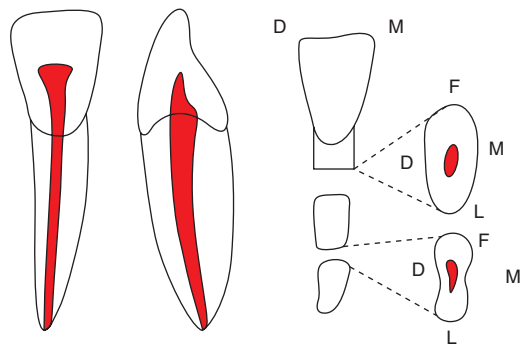


Figure 18.11 Sections of the permanent mandibular lateral incisor. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

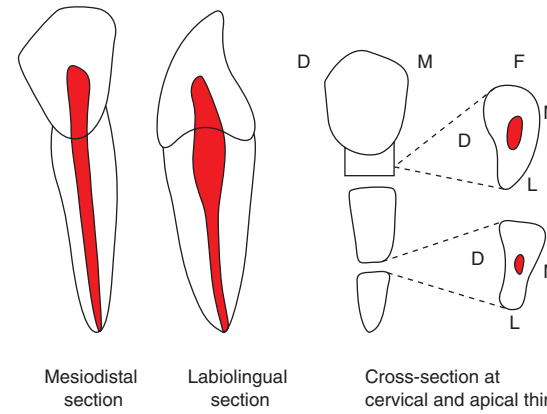


Figure 18.12 Sections of the permanent mandibular canine. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

2. **Intraradicular anatomy**
   (a) The root is broad in the middle third and tapers in the apical third.
   (b) The cross-section in the cervical and middle third is ovoid, whereas in the apical third, it is round.
   (c) Usually the root canals are straight, but sometimes distal curvatures are present. One canal exiting in one foramen is usually seen. If two canals are present, they join before exiting the apex. Sometimes two roots and two canals are present.
   (d) The shape of the root canal at various levels is as follows:
   - *Cervical:* Wider in the labiolingual direction
   - *Midroot:* Ovoid
   - *Apical third:* Round

Mandibular First Premolar (Fig. 18.13)

1. **Intracoronal anatomy**
   (a) The mesiodistal width of the pulp chamber is wide.
   (b) A prominent buccal pulp horn is present under the well-developed buccal cusp. In young tooth, a smaller lingual pulp horn is present.
   (c) In cross-section, the pulp chamber is ovoid, with greater diameter buccolingually.

SECTION II

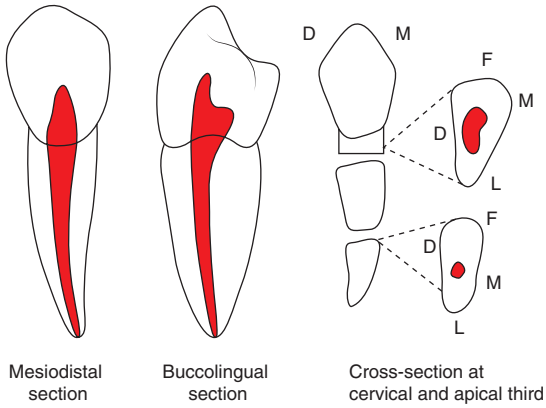


Figure 18.13 Sections of the permanent mandibular first premolar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

(d) If only one canal is present, then there is no distinct division between the pulp chamber and the root canal.

2. **Intraradicular anatomy**
   (a) The tooth exhibits wide variation in the intraradicular anatomy.
   (b) It has a short, conical root. The root may divide in the apical third into two or three.
   (c) The possibilities of variation in the root canal and foramen pattern are as follows:
   - One canal and one foramen—70%
   - One canal bifurcates into two canals, exits in two foramina—24%
   - Two canals exit in two foramina—1.5%
   - One canal bifurcates into two canals and unites in the apical third and exits in one foramen—4%
   - Three canals exit in three foramina—0.5%
   - If one canal is present, it is cone shaped and simple in outline. It is narrow mesiodistally and broader buccolingually and tapers towards the apical third
   - In cross-section, the cervical and middle third are ovoid, whereas the apical third is round.

   (d) The shape of the root canal at various levels is as follows:
   - *Cervical:* Wider in the buccolingual dimension
   - *Midroot:* Ovoid
   - *Apical third:* Round

Mandibular Second Premolar (Fig. 18.14)

1. **Intracoronal anatomy**
   (a) It is similar to the first premolar except that the lingual pulp horn is larger than in the first premolar.
   (b) The pulp chamber is wider buccolingually.
   (c) The separation of the pulp chamber and the root canal can be seen.

2. **Intraradicular anatomy**
   (a) It has one root and one canal, which may be curved distally.
   (b) The cross-section in the cervical third is rectangular or triangular.
   (c) In 2.5% of cases, the single canal bifurcates into two foramina.
   (d) The shape of the root canal at various levels is as follows:
   - *Cervical:* Wider buccolingually
   - *Midroot:* Long ovoid
   - *Apical third:* Round

Mandibular First Molar (Fig. 18.15)

1. **Intracoronal anatomy**
   (a) The shape of the pulp cavity is rectangular or trapezoid.
   (b) It has four pulp horns: mesiobuccal, mesiolingual, distobuccal and distolingual.
   (c) Three distinct orifices are present: mesiobuccal, mesiolingual and distal.

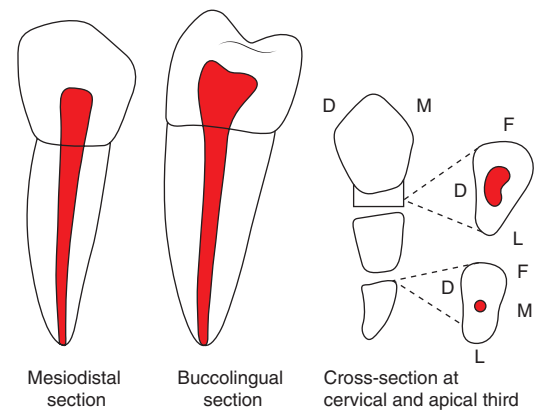


Figure 18.14 Sections of the permanent mandibular second premolar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

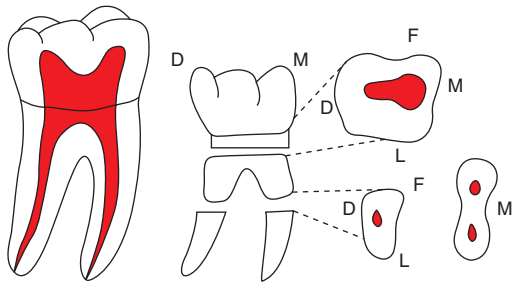


Figure 18.15 Sections of the permanent mandibular first molar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

2. **Intraradicular anatomy**
   (a) It has two mesial canals and one distal canal.
   (b) An additional distal canal and a third mesial canal, known as *middle mesial canal*, are common variations.
   (c) Access opening is usually trapezoid, with round corners, or rectangular, if a second distal canal is present.
   (d) Occasionally, the mandibular first molar has three roots and the third root is called *radix entomolaris*.
   (e) The shape of the root canal at various levels is as follows:
   - *Cervical:* Oval
   - *Midroot:* Ovoid
   - *Apical third:* Round

Mandibular Second Molar (Fig. 18.16)

1. **Intracoronal anatomy**
   (a) The tooth is smaller than the mandibular first molar.
   (b) Two mesial orifices are located close together.
   (c) The pulp horns are rather prominent.
   (d) The pulp chamber of the mesial root is well demarcated.
   (e) In cross-section, the pulp chamber is square or rectangular.
2. **Intraradicular anatomy**
   (a) Two canals in mesial root and one in distal root are present.

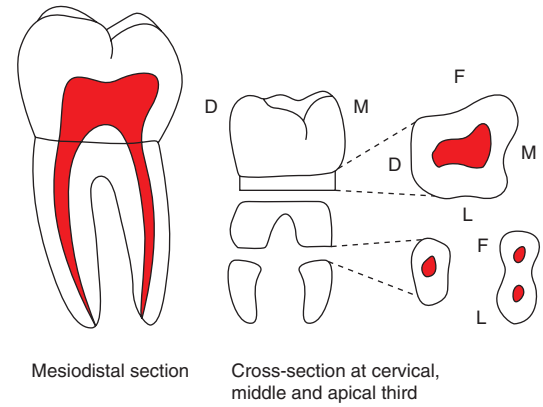


Figure 18.16 Sections of the permanent mandibular second molar. *D*, distal; *F*, facial; *L*, lingual; *M*, mesial.

   (b) Canals taper from the pulp chamber to the apex.
   (c) Mesial canals have greater curvature than the distal canal.
   (d) The cross-section at the midroot level is kidney shaped or in the shape of the number 8.
   (e) Mesial canals either have one foramen or exit as two or more foramina.
   (f) Joining of two mesial canals is most common.
   (g) C-shaped canals may occur in fused roots.
   (h) The distal root may have two canals in occasional cases.
   (i) The shape of the root canal at various levels is as follows:
   - *Cervical:* Oval
   - *Midroot:* Ovoid
   - *Apical third:* Round

Mandibular Third Molar (Fig. 18.17)

1. **Intracoronal anatomy**
   (a) The tooth is anatomically unpredictable and must be evaluated on the basis of its root structure and form.
   (b) The pulp chamber anatomically resembles that of the first and second molars.
   (c) The large pulp chamber with many anomalous configurations such as C-shaped root canal orifices can be observed.

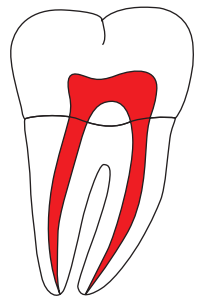


Figure 18.17 Section of the permanent mandibular third molar.

2. **Intraradicular anatomy**
   (a) The tooth may have one to four roots and one to six canals.
   (b) The root canals are large and short.
   (c) C-shaped canals occur due to the fusion of mesial or distal root on either the buccal or lingual surface.

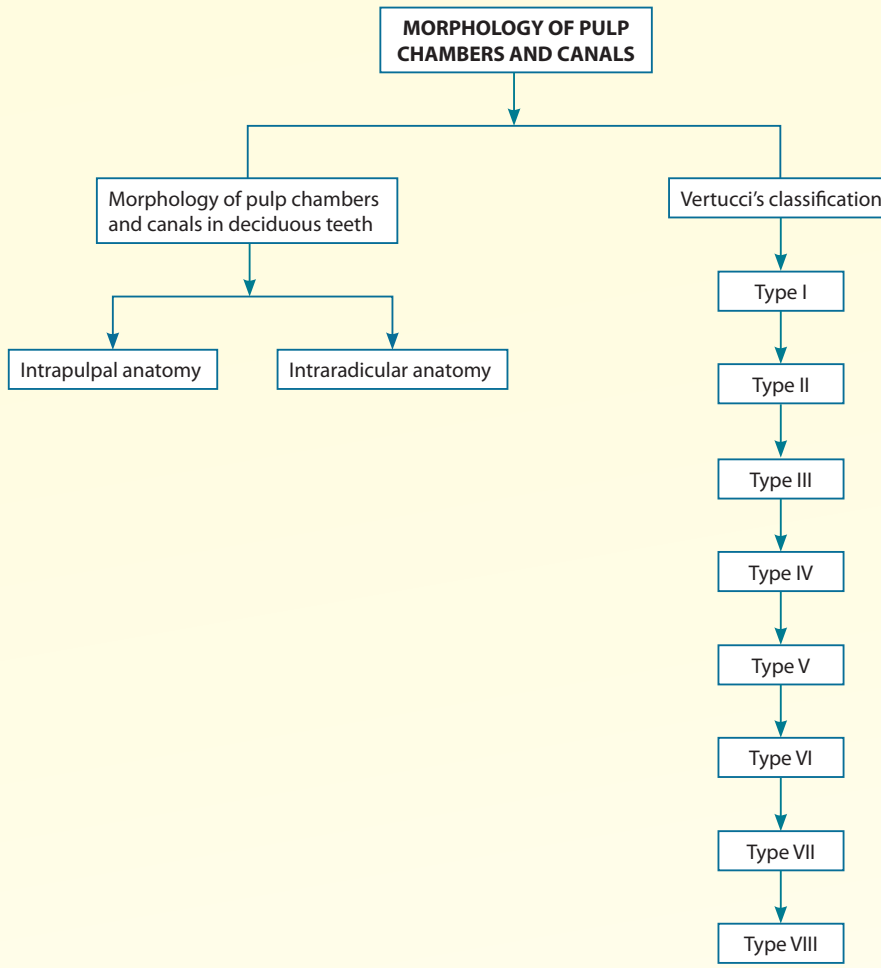
ANATOMICAL VARIATIONS

1. The general anatomy discussed earlier is most commonly present, but there can be variations in shape, size and form of teeth.
2. These variations can also be due to ageing, rate of dentin deposition, metabolic disorders, trauma and ethnicity or heredity.
3. The occurrence of anomalies is more in permanent dentition than in primary dentition and more in the maxilla than in the mandible.
4. Variations can also be seen in the number of roots, for example, two roots in the mandibular lateral incisor and the mandibular canine, and fused roots in the third molars and mandibular second molars.
5. The variations in root canals are as follows:
   (a) Presence of additional root canals such as the second root canal in the distal root of the mandibular first molar and the second mesiobuccal canal in the maxillary first molar.
   (b) There can be variations in the morphology of the root canal system such as bifurcation and joining of root canals, which forms the basis of Vertucci's classification.
   (c) Anomalies of the external morphology of tooth can also affect the internal anatomy, for example, taurodontism, dilacerations, dens evaginatus, dens invaginatus, talon cusps, fusion, germination, dentinogenesis and amelogenesis imperfecta.

Key Points

1. The pulp is present in a space called *pulp chamber* in the crown and *root canal* in the root.
2. The maxillary central incisor has a triangular pulp space configuration.
3. The maxillary canine has an oval pulp space configuration.
4. The maxillary first premolar has a kidney-shaped pulp space, with buccal and palatal pulp horns.
5. The maxillary second premolar has a hexagonal pulp chamber.
6. The maxillary first molar and second molar have rhomboidal pulp chambers with four pulp horns (mesiobuccal, mesiopalatal, distobuccal and distopalatal) and three root canals (mesiobuccal, distobuccal and palatal). Sometimes four root canals are also seen.
7. The mandibular central incisor, lateral incisor and canine have ovoid pulp space configuration.
8. The mandibular first premolar and the second premolar have ovoid pulp space configuration, with buccal and lingual pulp horns and one root and one canal.
9. The mandibular first molar has rectangular to trapezoid pulp space configuration, with four pulp horns (mesiobuccal, mesiolingual, distobuccal and distolingual) and two root canals.
10. The third root in a mandibular first molar is called *radix entomolaris*.
11. The mandibular second molar has a rectangular pulp space configuration.

Mind Map



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Multiple Choice Questions

1. The pulp chamber with a broad base towards the incisal edge and apex towards the cervical aspect is seen in the
   (a) Permanent maxillary central incisor
   (b) Permanent maxillary lateral incisor
   (c) Permanent mandibular central incisor
   (d) Permanent maxillary canine
2. The buccal pulp horn is higher than the palatal pulp horn in the case of the
   (a) Permanent maxillary first premolar
   (b) Permanent maxillary second premolar
   (c) Permanent maxillary first molar
   (d) None of the above
3. A common occurrence in the permanent maxillary first molar is the
   (a) Presence of the mesiobuccal canal—2
   (b) Absence of the distobuccal canal
   (c) Absence of the mesiobuccal canal—1
   (d) None of the above
4. Large variation in the intracoronal and intraradicular anatomy is present in the
   (a) Permanent maxillary second premolar
   (b) Permanent maxillary first premolar
   (c) Permanent maxillary first molar
   (d) Permanent maxillary third molar
5. The mandibular permanent lateral incisor has
   (a) Pulp chamber configuration similar to that of the mandibular central incisor
   (b) Incidence of single root with two root canals
   (c) Root larger than in the mandibular central incisor
   (d) All of the above
6. The presence of two roots is commonly seen in which anterior teeth?
   (a) Permanent maxillary central incisor
   (b) Permanent maxillary lateral incisor
   (c) Permanent mandibular central incisor
   (d) Permanent mandibular canine
7. The middle mesial canal is most commonly seen in the
   (a) Permanent maxillary second premolar
   (b) Permanent maxillary first molar
   (c) Permanent mandibular first molar
   (d) Permanent mandibular third molar
8. C-shaped canals are commonly seen in the
   (a) Permanent maxillary second premolar
   (b) Permanent maxillary first molar
   (c) Permanent mandibular first molar
   (d) Permanent mandibular third molar



CHAPTER 19

Alignment and Occlusion

Overview

Alignment and occlusion of the dentition are important determinants of the masticatory function. Activities such as chewing, swallowing and speaking depend on the position of teeth and occlusion. Tooth alignment is determined by various factors such as arch width and tooth size. The way in which maxillary and mandibular teeth articulate is called occlusion. Dental occlusion involves the teeth, temporomandibular joint (TMJ) and muscles of mastication. The relationship of teeth in centric occlusion, centric relation and during function involves occlusion. This chapter discusses the stages of development of occlusion from the gum pad stage to the permanent dentition stage which determines tooth position in the dental arches.

INTRODUCTION

Occlusion is the way in which the maxillary and mandibular teeth articulate. The practice of all branches of dentistry requires thorough knowledge of occlusion. Dental occlusion is much more complex, involving the teeth, temporomandibular joint (TMJ) and muscles of mastication. Occlusion involves the relationship of teeth in centric occlusion, centric relation and during function. Occlusion is defined in the *Glossary of Prosthodontic Terms* as the 'static and dynamic contact relationship between the occlusal surfaces of the teeth during function'.

DEVELOPMENT OF OCCLUSION

During the development of the orofacial complex, the oral motor functions are acquired and are modified according to the eruption of the teeth (deciduous and permanent dentition). The development of the oral motor functions is related to the development of occlusion. Dental occlusion undergoes significant changes from birth to adulthood. The stages of occlusion are arbitrarily divided into four stages which include predentate or gum pad stage, deciduous dentition stage, mixed dentition stage and permanent dentition stage.

1. Pre-dentate stage
   (a) Gum pad stage
   (b) Precociously erupted primary teeth
2. Dentate stage
   (a) Deciduous dentition stage
   (b) Mixed dentition stage
   (c) Permanent dentition stage

Gum Pad Stage

The alveolar processes at the time of birth are known as gum pads. This stage extends from birth till the eruption of the first deciduous tooth, usually the mandibular central incisors, which erupt at 6–10 months of age. Gum pads are pink, firm and resilient and are covered by a dense layer of fibrous periosteum. The upper gum pad is horseshoe shaped and the lower is 'U' shaped. The labiobuccal portion and the lingual portion of the gumpads are separated by a groove called dental groove.

The labiobuccal portion differentiates first and is divided into 10 segments by grooves called transverse grooves. Each segment represents one developing tooth sac. The transverse groove between the canine and first deciduous molar is called the lateral sulcus. This sulcus determines the future canine relationship. The lingual portion differentiates later and remains relatively smooth. The upper and lower gum pads are separated from the palate and the floor of the mouth respectively by a groove called gingival groove. The maxillary and mandibular gum pads occlude only at the posterior region, with an anterior open bite relationship. The growth of the gum pads takes places in all three planes, i.e. forward, downwards and lateral planes.

Occasionally, there may be presence of teeth in the gum pads at the time of birth and these are termed natal teeth. Teeth that erupt during the first month of age are called neonatal teeth. In both natal and neonatal teeth, the mandibular incisors are commonly seen.

Precociously Erupted Primary Teeth

These are those teeth which are present at the rime of birth before deciduous teeth are present. They are of two types:

1. Natal
2. Neonatal

Natal teeth are teeth that are present above the gumline (have already erupted) at birth and neonatal teeth are teeth that emerge through the gingiva during the first month of life (neonatal period)

Deciduous Dentition Stage

The deciduous dentition stage extends from the time of eruption of the first primary tooth to the eruption of the first permanent tooth. The timing of eruption of deciduous teeth (**Table 19.1**; **Fig. 19.1**) varies and is controlled by both hereditary and environmental factors. A 6-month delay or acceleration in eruption is considered normal.

The primary arch form and width is established largely at the age of 9 months. The normal range of overjet varies between 0 and 4 mm.

Interdental Spacing

The presence of generalized spacing in primary dentition is a common finding. Spaces develop in the dental arch due to the growth of the jaws. According to Foster, almost 75% of the individuals have generalized spacing in their deciduous dentition. In addition to the generalized spacing, localized spaces known as *primate spaces* are also seen in the deciduous dentition. The primate space or simian space or anthropoid space is seen in the maxillary arch between the lateral incisors and canine and in the mandibular arch between the canine and the first primary molar (**Fig. 19.2**). Sufficient interdental spaces in deciduous dentition are essential for the permanent teeth to erupt into proper position without crowding. The absence of interdental spacing in the deciduous dentition is an indicator of the development of crowding in the permanent dentition (**Table 19.2**).

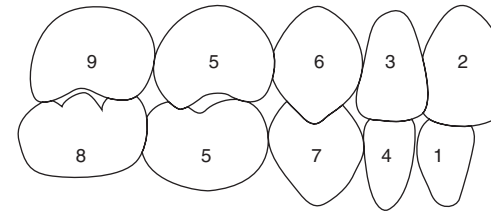


Figure 19.1 Sequence of eruption of deciduous dentition with chronology of eruption in months. 1, mandibular central incisors at 6–10 months; 2, maxillary central incisors at 8–10 months; 3, maxillary lateral incisors at 9–13 months; 4, mandibular central incisors at 9–16 months; 5, maxillary and mandibular first molars at 16–23 months; 6, maxillary canine at 16–22 months; 7, mandibular canine at 17–23 months; 8, mandibular second molars at 23–31 months; 9, maxillary second molars at 25–33 months.

Table 19.1 Chronology of the Eruption of Deciduous Teeth

	Time Period (Months)	
	Maxilla	**Mandible**
Central incisor	8–10	6–10
Lateral incisor	9–13	10–16
Canine	16–22	17–23
First molar	13–19	14–18
Second molar	25–33	23–31

Table 19.2 Probability of the Appearance of Crowding in Permanent Dentition, Based on the Available Spaces in Deciduous Dentition

Spaces in Deciduous Dentition	Probability of Crowding
>6 mm	None
3–5 mm	20%
<3 mm	50%
No spacing	66.66%
Crowding	100%

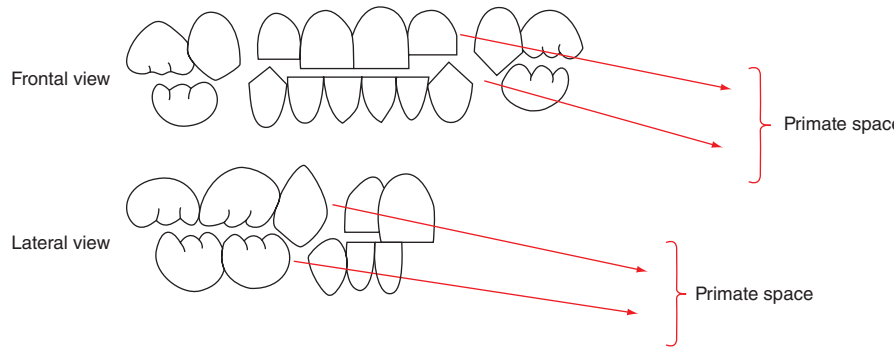


Figure 19.2 Frontal and lateral views of the deciduous dentition.

Applied Morphology

Importance of Interdental Spacing in Deciduous Dentition

Sufficient interdental spaces in deciduous dentition are essential for the permanent teeth to erupt into proper position without crowding. The absence of interdental spacing in the deciduous dentition is an indicator of the development of crowding in the permanent dentition (**Table 19.2**).

Occlusion in Deciduous Dentition

By the age of 2–3 years, all the primary teeth are completely erupted and are in normal alignment and occlusion. The teeth are arranged in an arch form that is confined to a segment of ellipse in both maxilla and mandible. Each tooth in the maxillary and mandibular arches occludes with two teeth of the opposing arch, except mandibular central incisor and maxillary second molar.

Anterior Occlusion The mesial surfaces of the central incisors approximate each other at the midline, and the upper and the lower midlines coincide. The upper central incisors occlude with the lower central incisors and the mesial third of the lower lateral incisors. The upper lateral incisors occlude with the distal portion of the lower lateral incisors and the mesial portion of the canine. The upper canine occludes with the distal portion of the lower canine and the mesial third of the lower first molar. The lower anteriors occlude with the upper anteriors lingually, just above the incisal edges (**Fig. 19.2**).

Posterior Occlusion The upper first molar occludes with the distal two-third of the lower first molar and the mesial marginal ridge and mesial triangular fossae of the lower second molar. The upper second molar occludes with the lower second molar, with the distal surface of the former projecting slightly over the distal surface of the latter (**Fig. 19.2**).

Jaw-to-jaw relationship and condyle position in relation to occlusion are considered relatively less important in deciduous occlusion because of the rapidly growing and changing neuromuscular system.

Molar Relationship in Deciduous Dentition

The distal surfaces of the maxillary and mandibular second deciduous molars are known as *terminal planes*. The molar relationship in the deciduous dentition is described by Moyers on the basis of the relationship of their terminal planes as the flush terminal plane, mesial step and distal step (**Box 19.1**).

Flush Terminal Plane The mesiodistal dimension of the mandibular second molar is greater than that of the maxillary second molar, leaving the distal surface of the two teeth in the same

Box 19.1 Molar Relationship in the Deciduous Dentition Stage

- **Class I molar relationship:** Mesiobuccal cusp of the maxillary first permanent molar occluding in the buccal groove of the mandibular first molar
- **Class II molar relationship:** Distobuccal cusp of the maxillary first permanent molar occluding in the buccal groove of the mandibular first molar
- **Class III molar relationship:** Mesiobuccal cusp of the maxillary first permanent molar occluding the embrasure between the mandibular first and second molars

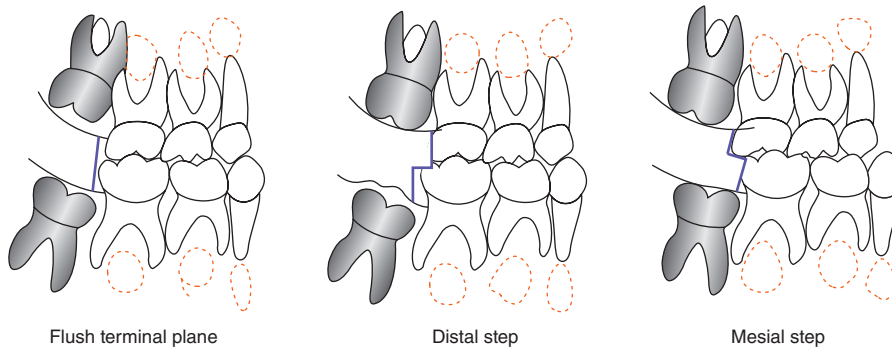


Figure 19.3 Flush terminal plane relationship of the primary molars. A mesial step in the deciduous dentition leads to a class I or class III molar relation in the permanent dentition. A distal step in the deciduous Dentition leads to a class II molar relation in the permanent dentition.

plane, known as the *flush terminal plane*. This flush terminal plane relationship is necessary for the normal eruption of the upper and lower permanent first molars and their occlusion.

Mesial and Distal Step Any deviation in the flush terminal plane resulting in the mesial step or distal step due to either caries or disturbances in differential jaw growth may interfere with the development of normal occlusion. In the distal step, the mandibular terminal plane is distal (posterior) to the maxillary terminal plane. In the mesial step, the mandibular terminal plane is mesial (anterior) to the maxillary terminal plane (**Fig. 19.3**).

The terminal plane relationship is relative and does not identify the true anteroposterior position of the maxillary and mandibular dental arches.

The overjet, overbite and the anteroposterior relationship of the dentition do not undergo significant changes during this stage unless influenced by the environmental factors.

Mixed Dentition Stage or Transitional Stage

The transition from the deciduous dentition to permanent dentition begins at the age of 6 years, from the eruption of the mandibular incisors to the shedding of the last primary tooth (the maxillary canine) at the age of 11–12 years (**Table 19.3**; **Fig. 19.4**).

As each tooth erupts, its antimere (same tooth on the opposing side) will erupt in 6 months. Mandibular teeth always erupt before their maxillary counterparts.

Applied Morphology

Importance of Determination of Terminal Plane Relationship in Deciduous Dentition

Determination of the terminal plane relationship in the deciduous dentition stage is important because the erupting permanent molars are guided into occlusion by the distal surfaces of the deciduous second molar. A mesial step in the deciduous dentition indicates a greater probability of class I molar relationship and a lesser probability of class III molar relationship in the permanent dentition. A distal step in the deciduous dentition usually develops into a class II molar relationship in the permanent dentition.

Table 19.3 Chronology of the Eruption of Permanent Dentition

	Time Period (Years)	
	Maxilla	**Mandible**
Central incisor	7–8	6–7
Lateral incisor	8–9	7–8
Canine	11–12	9–10
First premolar	10–11	10–12
Second premolar	10–12	11–12
First molar	9–10	6–7
Second molar	12–13	11–13
Third molar	17–21	17–21

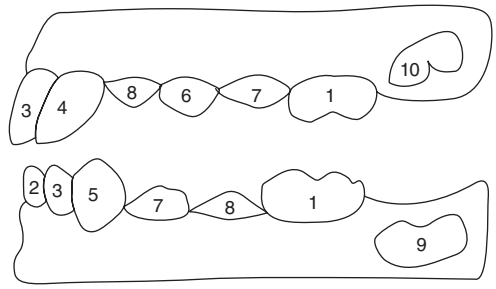


Figure 19.4 Preferred sequence of eruption of permanent dentition and chronology of eruption in years. 1, maxillary and mandibular first molars at 6–7 years; 2, mandibular central incisors at 6–8 years; 3, maxillary central and mandibular lateral incisors at 7–8 years; 4, maxillary lateral incisors at 8–9 years; 5, mandibular canine at 9–10 years; 6, maxillary first premolars at 10–11 years; 7, mandibular first and maxillary second molars at 10–12 years; 8, maxillary canine and mandibular second premolars at 11–12 years; 9, mandibular second molars at 11–13 years; 10, maxillary second molars at 12–13 years.

Spacing (Broadbent Phenomenon)

A transitional diastema (spacing) appears between the maxillary incisors during the mixed dentition stage. This transitional spacing between the maxillary incisors is due to the mesial crowding of the roots of the maxillary incisors due to pressure from the erupting canine. The roots become upright after the eruption of the permanent canine and the diastema disappears. For this reason, any attempt to correct maxillary midline spacing should be attempted only after the eruption of the permanent canine.

Applied Morphology

Since transitional spacing self-corrects with the eruption of canine, any attempt to correct maxillary midline spacing should be attempted only after the eruption of the permanent canine.

Molar Relationship

The transition from the flush terminal plane relationship to class I molar relationship takes place due to mesial shift of lower molars and differential maxillomandibular growth. Mesial shift takes place in two stages:

1. Early mesial shift of mandibular molars utilizing the primate space
2. Late mesial shift utilizing the leeway space

Leeway Space of Nance The sum of the mesiodistal width of the primary canine and molars is larger than the sum of the mesiodistal width of their succedaneous teeth (permanent canines and premolars). The difference is called the *leeway space*. The leeway space is greater (1.8 mm per side) in the mandibular arch than the in the maxillary arch (0.9 mm per side). This leeway space differential between the two arches results in increased mesial drift of the lower molar, which results in class I molar relation (**Fig. 19.5**).

The maxilla and mandible usually grow forwards and downwards. During the transitional dentition stage, the growth of the maxilla is almost completed and the mandible grows relatively more forward than the maxilla, contributing to the transition from the terminal plane relationship to the class I molar relationship.

Permanent Dentition

Intra-Arch Tooth Alignment

Intra-arch tooth alignment refers to the relationship of the teeth with each other within the same arch. The orientation of the occlusal plane, inclination of the tooth, contact points and form of the occluding surfaces of the teeth influence the proper alignment of teeth in the arch.

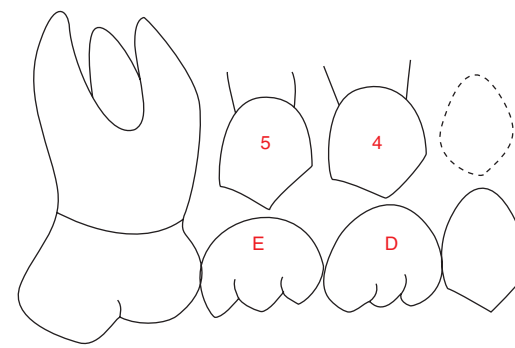


Figure 19.5 Leeway space in the maxillary arch. The combined mesiodistal width of D and E is greater than the combined mesiodistal width of 4 and 5.

Orientation of the Occlusal Plane

The plane of occlusion is that which passes through the occlusal surface of the posterior teeth and incisal edges of the anterior teeth in the mandibular arch. The occlusal plane is not a flat surface; there are curves incorporated conforming to the arrangement of the teeth in the dental arch, in both the anteroposterior and the mesiodistal planes. These compensatory curves of the occlusion compensate for the path of the condyle and permit maximum utilization of tooth contact during the functional movement of the mandible.

Anteroposterior Curve Ferdin and Graf von Spee, German embryologists (1855–1937), were the first to describe the relationship of the mandibular teeth in the sagittal plane. While viewing from a point perpendicular to the first molars, they noted a curvature of the mandibular occlusal plane that begins at the incisal edges and tip of the lower cuspid, follows the buccal cusps of the premolar and molars and continues on to the ramus. They described this anteroposterior curvature of the occlusal plane as the *curve of Spee or curve of Von Spee*. An ideal curve of Spee is aligned such that a continuation of this arc would extend through the condyles and would form a segment of a circle with a 4-inch radius (**Fig. 19.6**).

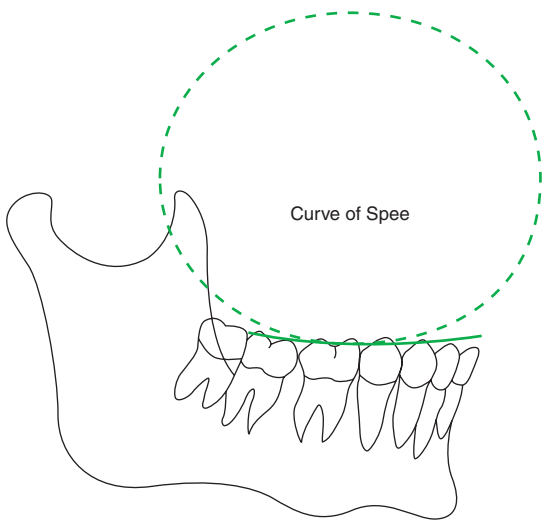


Figure 19.6 Lateral view of the mandible showing the curve of Spee.

The normal depth of curve of Spee is 1.5 mm as measured at the second premolar region, where the curve assumes its maximum depth. The curve of Spee accommodates the vertical overlap of the upper and lower anteriors and allows for the normal functional protrusive movement of the mandible. The pull of the main muscle of mastication—the masseter—is at a perpendicular angle with the curve of Spee to adapt for favourable loading of force on the teeth.

Bonwill observed that the distance between the condyles as well as the distance from the mesial contact of the mandibular incisors to the centre of each condyle was 4 inches, forming an equilateral triangle. This triangle, known as *Bonwill's triangle*, formed the basis for the curve of Monson.

Monson visualized the occlusal plane to be a three-dimensional spherical curvature involving the right and left incisors, cuspids, bicuspids, molars and condyles. This *curve of Monson*, as described by Monson in 1932, is a segment of the surface of a sphere of 4 inches (20 cm) radius, with its centre in the region of the glabella (the area in the frontal bone above the nasion and between the eyebrows). According to Monson, all the buccal cusps and incisal edges of the mandibular teeth conform to the segment of this sphere, and the masticatory forces converge at the centre of the sphere (vectors of the glabella) (**Fig. 19.7**). This theory that the masticatory forces converge at the centre of the sphere was discarded later as Dempster and colleagues proved that the longitudinal axis of the roots of the teeth do not converge towards a common centre.

Mediolateral Curve The *curve of Wilson* is the mediolateral curve that contacts the buccal and lingual cusp tips of each side of the arch. It results from the lingual inclination of the lower posterior teeth, making the lingual cusps lower than the buccal cusps on the mandibular arch. The buccal cusps are higher than the lingual cusps on the maxillary arch because of the buccal inclination of the upper posterior teeth. The shape of the curve in the mandibular dental arch is concave and that of the maxillary dental arch is convex (**Fig. 19.8**).

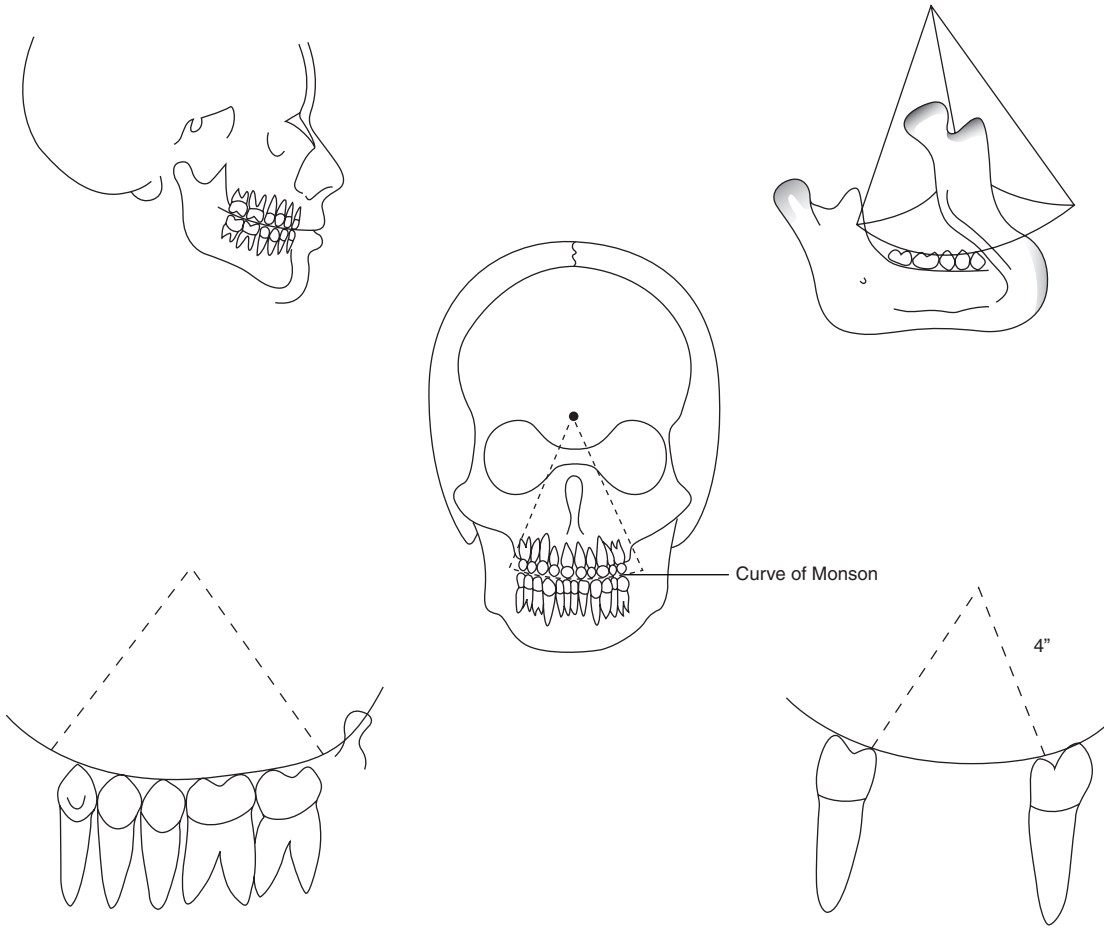


Figure 19.7 Curve of Monson as a segment of a sphere of 4-inch radius with the glabella at its centre.

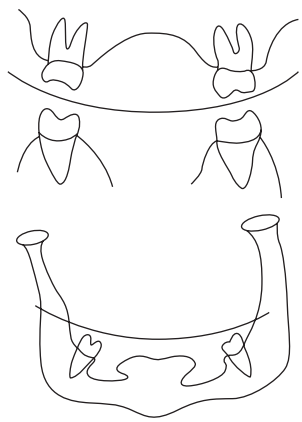


Figure 19.8 Curve of Wilson due to the buccal and lingual inclination of the maxillary and mandibular posteriors.

This curve permits the mediolateral jaw movements during mastication and provides easy access to the occlusal table as the tongue lays the food on the occlusal surfaces. The food is also stopped from going past the chewing position by the taller buccal cusps.

Orientation of the Long Axis of the Tooth The long axes of the teeth are oriented in such a way that the occlusal forces are directed parallel to the long axes during the function. When the dental arch is viewed from the lateral side, the mesiodistal relationship of the teeth can be observed by considering the long axes of the teeth. In the mandibular arch, both the anterior and the posterior teeth are mesially inclined. In maxillary teeth, the anteriors are mesially

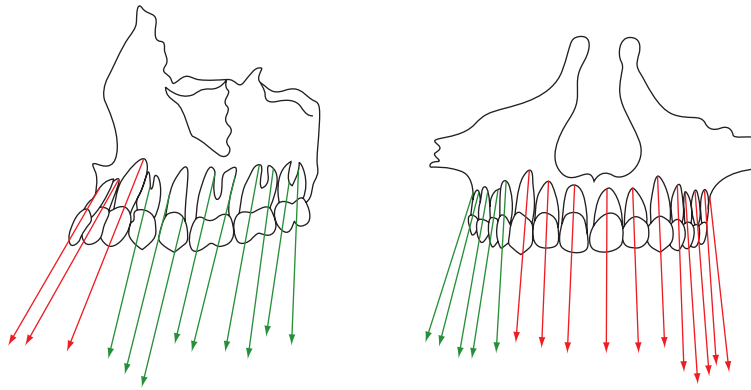


Figure 19.9 Orientation of the long axes of teeth in the maxillary arch. Lateral view showing the distal inclination of the posteriors and frontal view showing the buccal inclination of the posteriors.

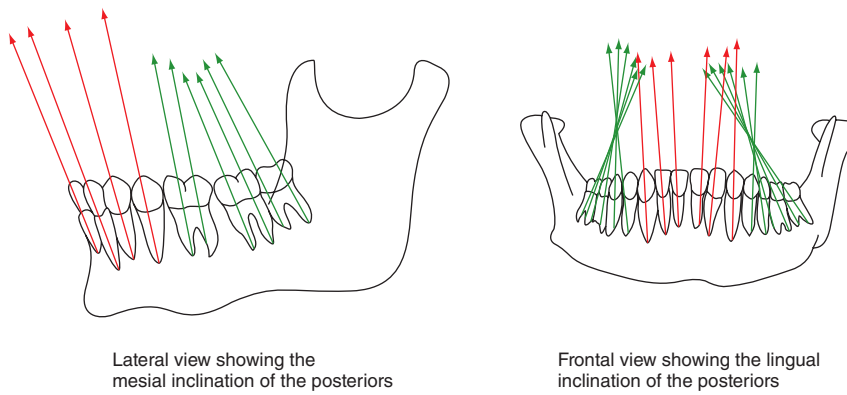


Figure 19.10 Orientation of the long axes of teeth in the mandibular arch.

inclined while the posteriors are inclined distally (**Figs 19.9** and **19.10**).

This pattern of mesiodistal inclination of the teeth conforms to the curve of Spee in the mandibular arch and a reverse curve of Spee in the maxillary arch. These two curves fit perfectly with each other when the arches occlude.

When the dental arches are seen from the frontal view, the buccolingual axial inclination can be seen and the mandibular posteriors have a slight lingual inclination. The mesiodistal axial inclination of the tooth is the angle formed by the long axis of the tooth and the median plane (**Table 19.4**). The faciolingual axial inclination is the angle formed by the long axis of the tooth and the occlusal plane.

Forms of Occluding Surfaces of the Teeth

The incisal and occlusal surfaces of the tooth crowns are either convex or concave at all contacting surfaces (**Fig. 19.11**). The occlusal surface of the posterior teeth is formed of cusps, grooves and sulci. The area between the buccal and lingual cusp tips is known as the *occlusal table*, comprising 50–60% of the total buccolingual width of the tooth. The occlusal table is formed by the inner incline of the cusps whereas the rest of the occlusal surface is formed by the outer inclines (**Fig. 19.12**).

Table 19.4 Axial Inclination of the Maxillary and Mandibular Dentition

	Central Incisor	Lateral Incisor	Canine	First Premolar	Second Premolar	First Molar	Second Molar
Mesiodistal axial inclination of tooth							
Maxilla	2°	7°	17°	9°	5°	10°	8°
Mandible	14°	10°	9°	6°	6°	0°	2°
Buccolingual axial inclination of tooth							
Maxilla	28°	26°	16°	5°	6°	8°	10°
Mandible	22°	23°	12°	9°	9°	20°	20°

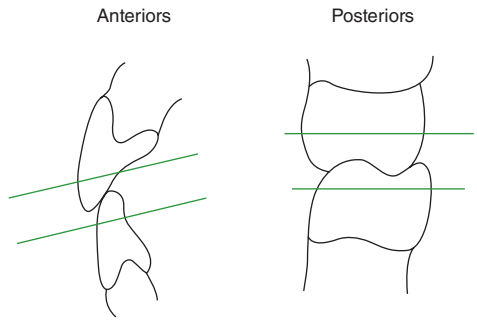


Figure 19.11 Form of the occluding surfaces.

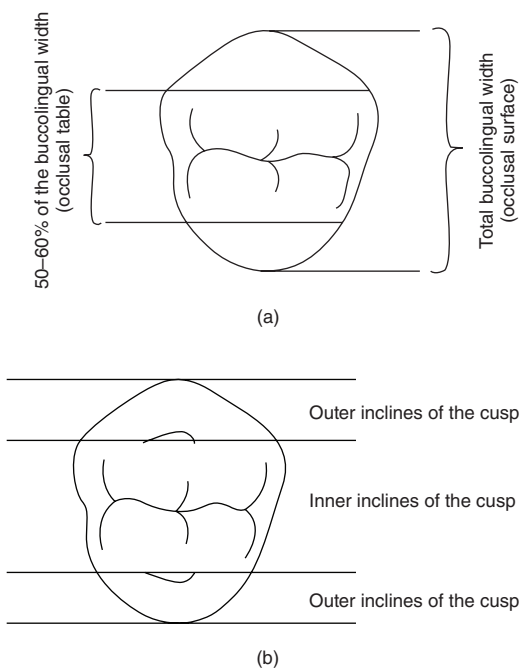


Figure 19.12 (a) Occlusal table and (b) cuspal inclines.

RELATIONSHIP OF THE MAXILLARY AND MANDIBULAR TEETH

Centric occlusion is the relationship between the maxillary and mandibular dentition when they are in maximum occlusal contact. It refers to the maximum intercuspation position of the upper and lower posterior teeth. It is also known as the *maximal intercuspal position, acquired occlusion* or *habitual occlusion*. This position is independent of the position or alignment of the condyle–disc complex.

Centric relation or *centric jaw relation* refers to the most posterior position of the mandible relative to the maxilla (maximum retruded position of the mandible). It is the relationship of the mandible to the skull as it rotates around the hinge axis before any translatory movement of the condyle begins.

It can also be described as the relationship of the condyle to the glenoid fossae. In the centric jaw relation, the condyles articulate with the thinnest avascular portion of the articular disc, and the *condyle–disc complex* is in an *anterior–superior position* against the *posterior slopes of the articular eminence* (**Fig. 19.13**).

The centric relation is independent of tooth position or vertical dimension. It is a bone-to-bone relationship guided by the jaw muscles, without tooth contact or one or few teeth contacting initially before closing into the maximum intercuspation position. It is most often behind the maximum intercuspation position by 1–2 mm.

SECTION II

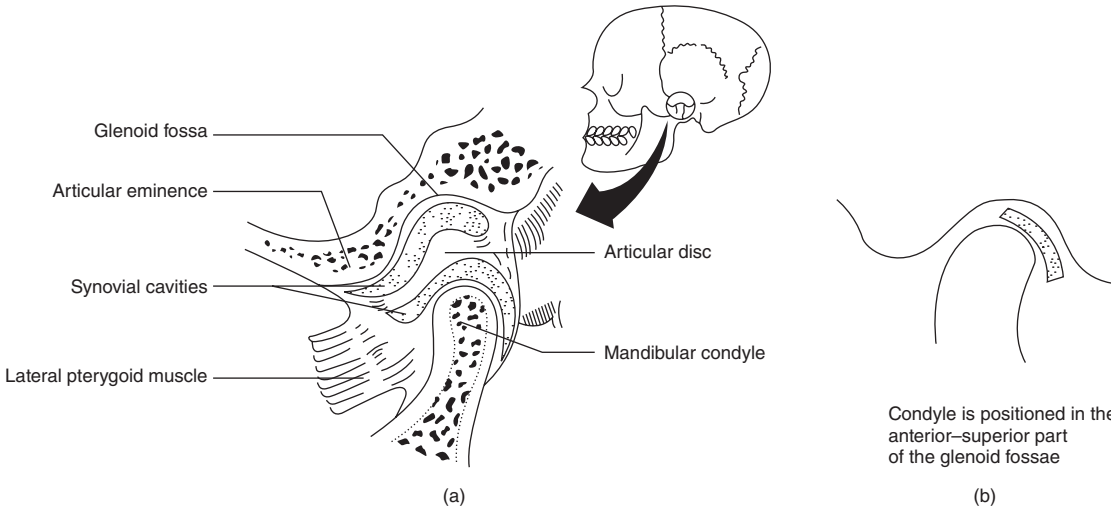


Figure 19.13 (a) Temporomandibular joint. (b) Relationship of the condyle to the fossae in the centric relation position.

Centric Occlusion Coinciding with the Centric Jaw Relation

It is a rare but ideal occurrence in nature when there is a maximum intercuspation of maxillary and mandibular teeth as the mandible closes in the most retruded centric relation position. This occurs because of balance between the guidance offered by the jaw muscles, the condylar position and the maximum intercuspation of teeth. Only in less than 1% of the population does centric occlusion coincide with centric relation. Centric occlusion always coincides with centric relation in complete denture rehabilitation.

Applied Morphology

Complete dentures for edentulous patients are fabricated in such a way that centric occlusion always coincides with centric relation.

Occlusion

Arch Form

The shape in which the teeth are arranged in the maxilla and mandible when viewed from the occlusal surface is known as the *arch form*. The outline following the labial and buccal surfaces of the maxillary and mandibular teeth usually resembles a segment of an ellipse. The maxillary arch form is generally larger than the mandibular arch form. Many authors have described the general shape of the dental arch to be paraboloid, ellipsoid, rotund, a catenary curve, U shaped or horseshoe shaped (**Fig. 19.14**). A variation from this could be a V-shaped arch tapered in the anterior region due to constriction of the maxilla or a wide square-shaped arch.

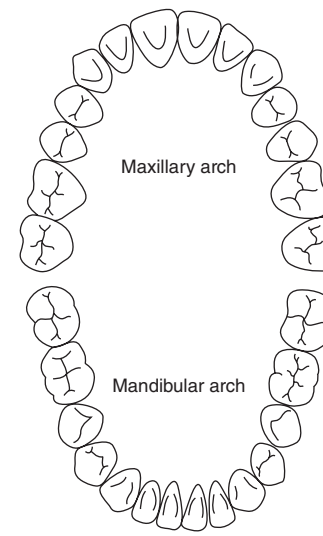


Figure 19.14 Maxillary and mandibular arch forms.

The arch form is determined by the shape of the underlying bone. Malpositions of individual teeth do not affect the arch form, but malpositions affecting several teeth may produce distortion in the arch form. Discrepancies between the upper and lower arch forms results in a poor occlusal relationship.

Arch Length

The length of the line beginning at the distal surface of the third molar and passing through all proximal contacts around the entire arch to the distal surface of the opposite side molar represents the *arch length*. Both the arches have approximately the same length, the lower arch being slightly smaller than the upper arch.

Arch Width

The width across the arch is known as the *arch width*. The maxillary arch width is always greater than the mandibular arch width. When the arches occlude, each maxillary tooth is positioned facial to the mandibular tooth (**Fig. 19.15**).

Overlap of Anterior Teeth

The arch form of the maxilla tends to be larger than the mandible, which results in the maxillary teeth overlapping the mandibular teeth labially in the anterior region and buccally in the posterior region. This overlap as measured in the sagittal plane between the incisal edge of the upper incisor and the labial surface of the lower incisor is known as the *horizontal overlap* or *overjet*. The overlap in the vertical plane as measured between the incisal edges of the upper and lower incisors is known as *the vertical overlap* or *overbite*. The normal horizontal overlap is 1–2 mm and vertical overlap is 2–3 mm (**Fig. 19.16**).

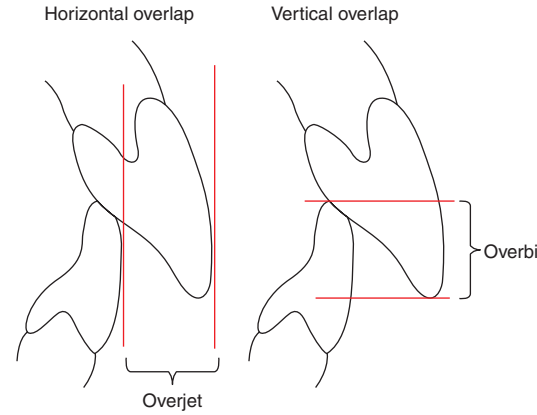


Figure 19.16 Horizontal and vertical overlap of the maxillary and mandibular anteriors.

The degree of vertical and horizontal overlaps should be sufficient to allow the jaw to function without interferences. The vertical overlap should be sufficient to allow for posterior disocclusion during anterior (protrusive) movement of the mandible. Insufficient horizontal overlap the in posterior segments can result in cheek biting. Excess horizontal and vertical overlap in the anterior region may affect the dental and facial aesthetics.

Applied Morphology

Insufficient horizontal overlap in posterior segments can result in cheek biting. Excess horizontal and vertical overlaps in the anterior region may affect the dental and facial aesthetics.

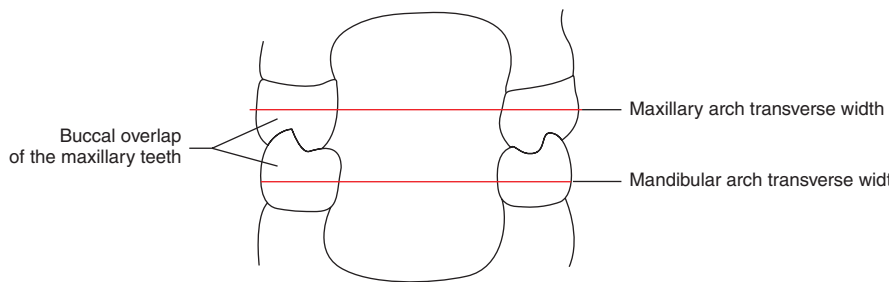


Figure 19.15 Coronal view of the maxillary and mandibular arches at the first molar region showing the buccal overlap of the maxillary posteriors. Maxillary arch transverse width is greater than mandibular arch transverse width.

SECTION II

Occlusal Relationship of the Upper and Lower Teeth

In occlusion, each tooth in the upper and lower arches occludes with two teeth in the opposing arch, with the exception of the mandibular central incisor and the maxillary third molar.

Supporting Cusp or Centric Cusps

The palatal cusps of the maxillary posteriors and buccal cusps of the mandibular posteriors occluding with the opposing central fossae are referred to as *supporting cusps* or *functional cusps*. The *centric cusps* are always broad and rounded. These cusps maintain the vertical dimension of the occlusion and aid in mastication. The centric cusp tip is present approximately at one-third the distance into the buccolingual width of the tooth (**Fig. 19.17**).

Guiding Cusps or Non-Centric Cusps

The buccal cusps of the maxillary posterior teeth and lingual cusps of the mandibular posterior teeth are called the *guiding cusps*. These cusps are sharp, with definite tips. The non-centric cusp tip is present approximately at one-sixth the distance into the buccolingual width of the tooth (**Fig. 19.17**). A small area of the outer incline of the centric cusp occludes with the inner incline of the non-centric cusp and is functional and hence known as the *functional outer aspect.* This area assists in the shearing of the food, and hence the non-centric cusp is also known as the *shearing cusp* (**Fig. 19.18**).

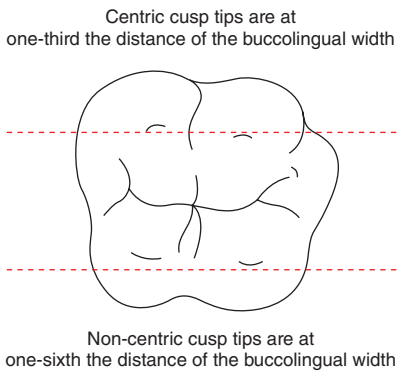


Figure 19.17 Occlusal surface of the mandibular first molar showing the position of centric and non-centric cusp tips.

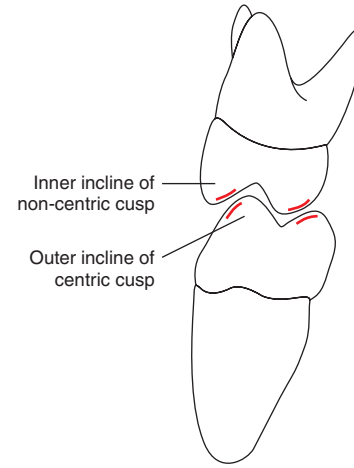


Figure 19.18 Maxillary and mandibular first molars in occlusion showing the functional outer aspects of the cusps.

Centric Stops

The areas of the teeth that makes contact with the opposing teeth in centric occlusion are known as *centric stops*. These are the areas on the supporting cusps and in the opposing arch with which the supporting cusps occlude in maximum intercuspation. Hellman proposed the following 138 possible centric stops in normal occlusion involving all 32 teeth (**Fig. 19.19**):

1. Lingual surface of the maxillary anteriors below the incisal edges—6

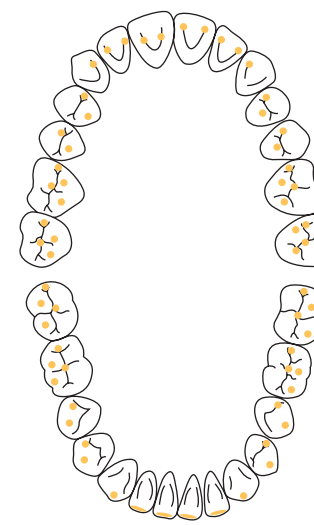


Figure 19.19 Centric stops in the maxillary and mandibular arches.

2. Labial surface of the mandibular anteriors at the incisal edges—6
3. Buccal cusps (triangular ridge) of the lower premolars and molars—16 (8 × 2)
4. Lingual cusps (triangular ridge) of the upper premolars and molars—16 (8 × 2)
5. Buccal cusp tips of the lower premolars and molars—16 (8 × 2)
6. Lingual cusp tips of the upper premolars and molars—16 (8 × 2)
7. Buccal embrasure of the lower premolars and molars—8 (4 × 2)
8. Lingual embrasure of the maxillary premolars and molars—10 (5 × 2, including canine and first premolar embrasure)
9. Distal fossae of premolars—8
10. Central fossae of molars—12
11. Mesial fossae of maxillary molars—6
12. Distal fossae of mandibular molars—6
13. Lingual grooves of maxillary molars—6
14. Buccal grooves of mandibular molars—6

Buccolingual Occlusal Contact

The normal posterior occlusal relationship is such that the maxillary lingual cusp occludes in the central fossae and marginal ridges of the lower posterior teeth (**Fig. 19.20a**). The maxillary buccal cusps occlude in the buccal groove and embrasures of the mandibular teeth (**Fig. 19.20b**). The maxillary buccal cusps overlap the mandibular buccal cusps and

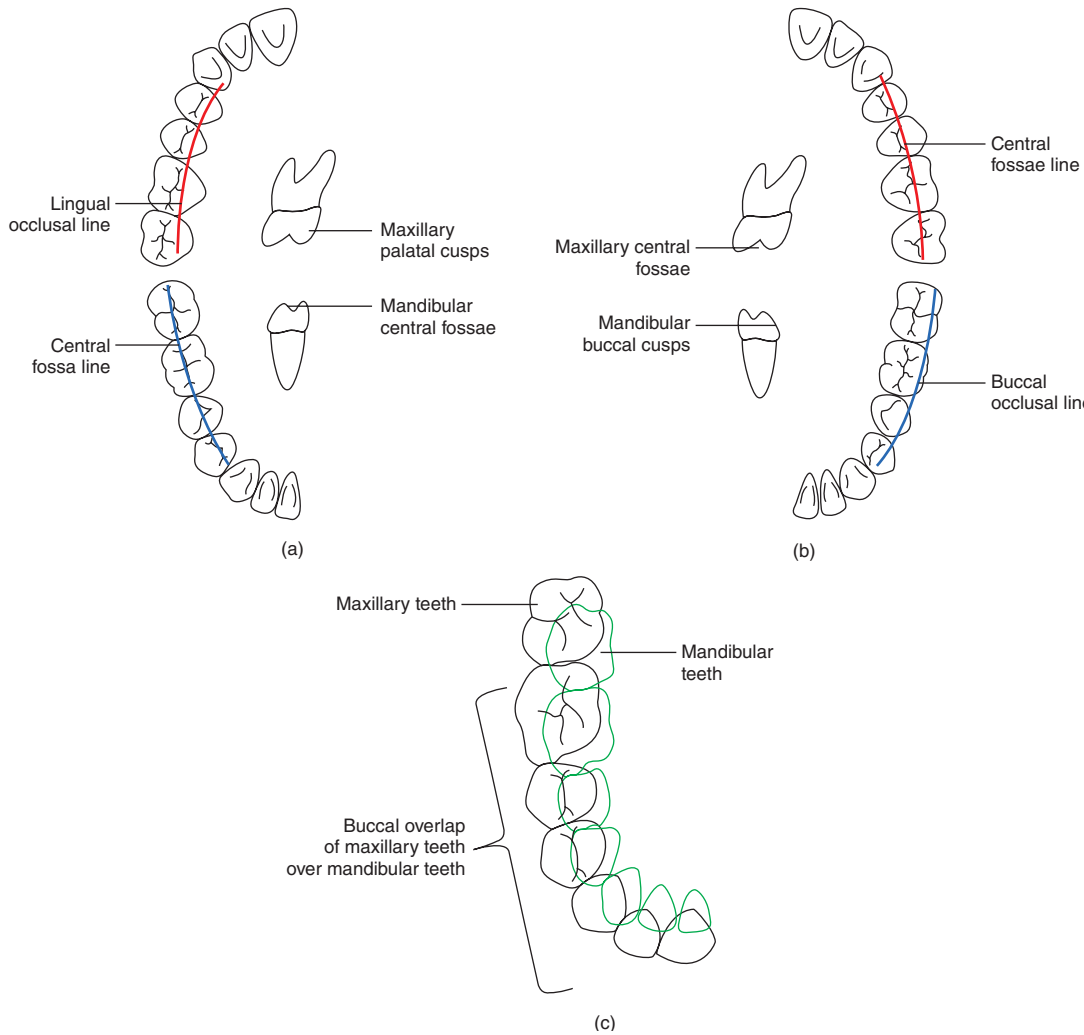


Figure 19.20 Buccolingual occlusal contacts.

the mandibular lingual cusps overlap the maxillary palatal cusps. This prevents the mucosa of the lip, cheek and tongue from falling between the occlusal surfaces of the teeth while chewing (**Fig. 19.20c**). The function of the non-centric cusp is to prevent tissue impingement during chewing and to maintain the food on the occlusal table for mastication.

Mesiodistal Occlusal Contact

Normally, the mandible is positioned slightly mesial to the maxillary arch. In the anterior region, the upper and the lower midlines coincide. The cusp tip of the maxillary canine occludes in the embrasure between the mandibular canine and the first premolar. In the posterior segment, the mesiobuccal cusp of the maxillary molar lies in the buccal groove of the mandibular first molar (**Fig. 19.21**).

Occlusal Contacts of the Posterior Teeth

The occlusal contacts of the posterior teeth fall into the following three categories:

1. Cusp–fossae
2. Cusp–embrasure
3. Cusp–marginal ridge

In a normal maxilla–mandible relationship, the mesiobuccal cusp of the maxillary first molar usually occludes with the buccal groove of the mandibular first molar. The distobuccal cusp of the maxillary first molar occludes with the buccal embrasure between the mandibular first and the second molars. The mesiolingual cusp of the maxillary first molar occludes in the central fossae of the mandibular first molar (**Figs 19.22** and **19.23**; **Tables 19.5** and **19.6**).

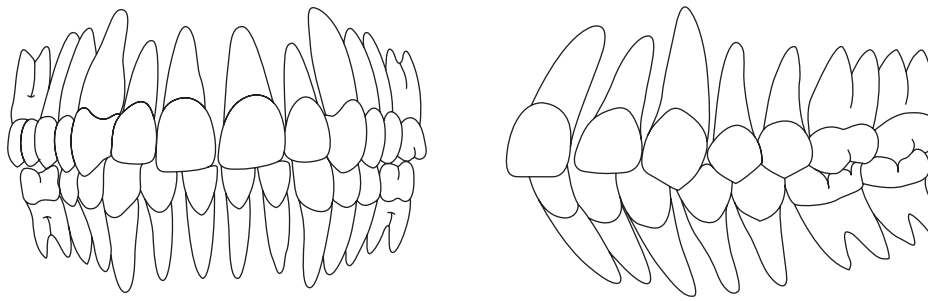


Figure 19.21 Mesiodistal occlusal contacts.

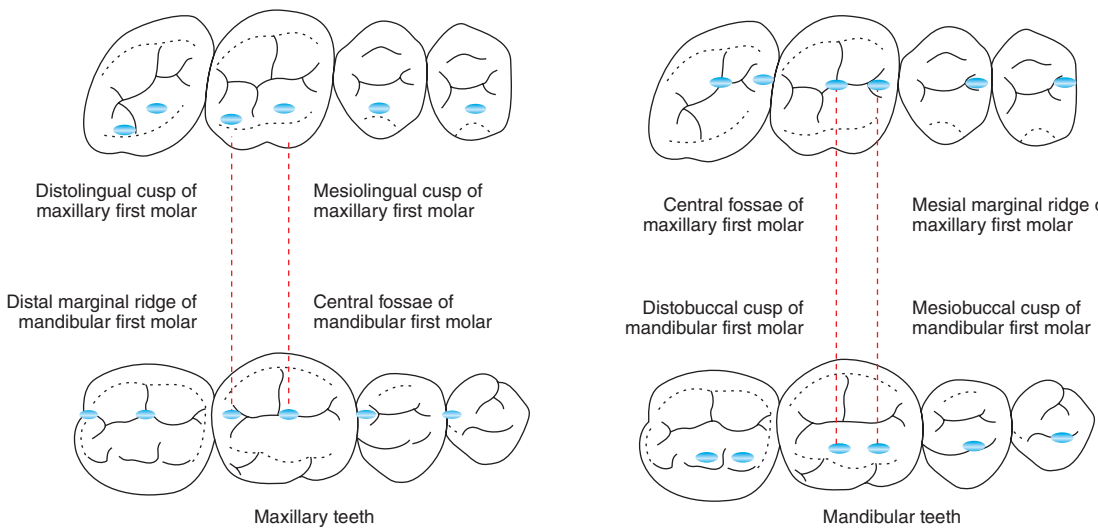


Figure 19.22 Occlusal surfaces of the posterior teeth showing the occlusal contacts of the working cusps of the maxillary and mandibular teeth.

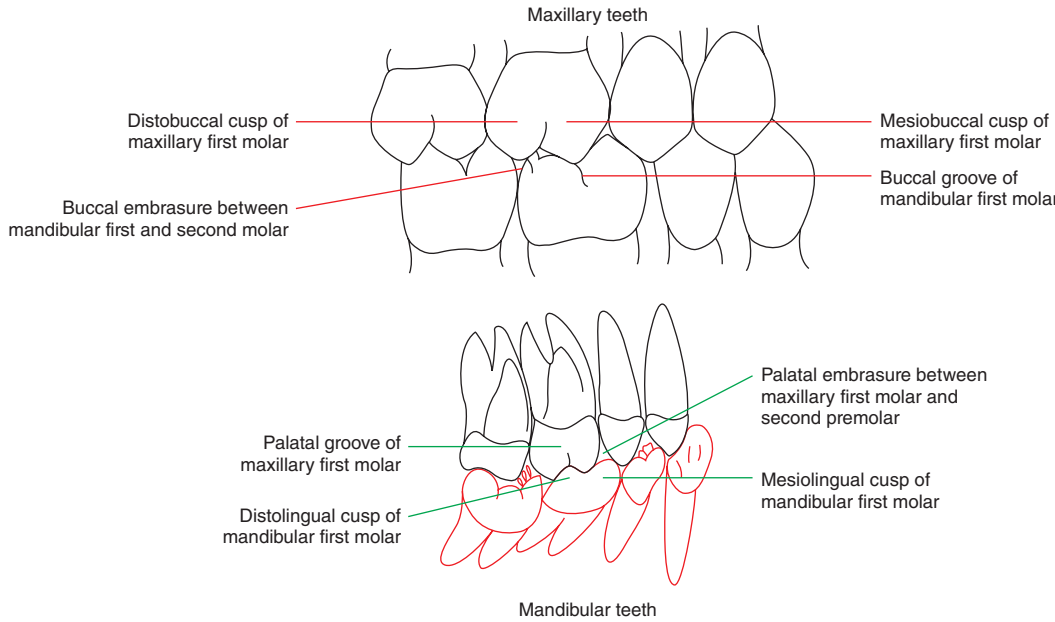


Figure 19.23 Lateral view of the occlusion from the buccal and lingual aspects of the posterior teeth showing the occlusal contacts of non-working cusps of the maxillary and mandibular teeth.

Table 19.5 Occlusal Contacts of the Cusps of Maxillary Posterior Teeth

Name of the Tooth	Name of the Maxillary Cusp	Occlusal Contacts
First premolar	Buccal cusp	Buccal embrasure between mandibular first and second premolars
	Palatal cusp	Distal marginal ridge of mandibular first premolar
Second premolar	Buccal cusp	Buccal embrasure between mandibular second premolar and first molar
	Palatal cusp	Distal marginal ridge of mandibular second premolar
First molar	Mesiobuccal cusp	Buccal groove of the mandibular first molar
	Distobuccal cusp	Buccal embrasure between mandibular first and second
	Mesiolingual cusp	molars Central fossae of mandibular first molar
	Distolingual cusp	Distal marginal ridge of mandibular first molar
Second molar	Mesiobuccal cusp	Buccal groove of the mandibular first molar
	Distobuccal cusp	Buccal embrasure between mandibular second and third
	Mesiolingual cusp	molars Central fossae of mandibular second molar
	Distolingual cusp	Distal marginal ridge of mandibular second molar

Table 19.6 Occlusal Contacts of the Cusps of Mandibular Posterior Teeth

Name of the Tooth	Name of the Cusp	Occlusal Contacts
First premolar	Buccal cusp	Mesial marginal ridge of maxillary first premolar
	Lingual cusp	Lingual embrasure between maxillary canine and first premolar
Second premolar	Buccal cusp	Mesial marginal ridge of maxillary first premolar
	Palatal cusp	Lingual embrasure between maxillary first and second premolars
First molar	Mesiobuccal cusp	Mesial marginal ridge of maxillary first molar
	Distobuccal cusp	Central fossae of maxillary first molar
	Mesiolingual cusp	Lingual embrasure between maxillary second premolar and first molar
	Distolingual cusp	Palatal groove of maxillary first molar
Second molar	Mesiobuccal cusp	Mesial marginal ridge of maxillary second molar
	Distobuccal cusp	Central fossae of maxillary second molar
	Mesiolingual cusp	Lingual embrasure between maxillary second premolar and first molar
	Distolingual cusp	Palatal groove of maxillary first molar

OCCLUSAL CONTACTS DURING CENTRIC AND ECCENTRIC POSITIONS OF THE MANDIBLE

Centric Occlusion Contacts

The lingual surfaces of the maxillary anterior teeth occlude with the labioincisal angle of the mandibular anterior teeth. The lingual cusp tips of maxillary posteriors occlude with the central fossae and the distal marginal ridges of the mandibular posterior teeth. The buccal cusp tips of the mandibular posterior teeth occlude with the central fossae and mesial marginal ridges of the maxillary posterior teeth (**Fig. 19.24**).

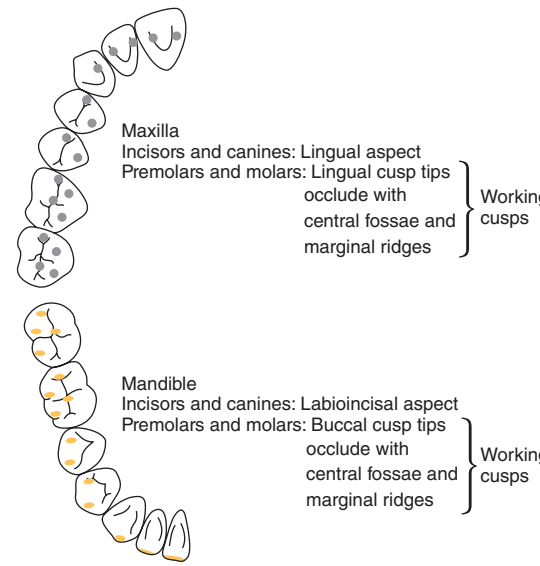


Figure 19.24 Centric occlusion contacts.

Centric Relation Contacts

In the anterior teeth, centric relation contacts will be minimal or non-existent and may coincide with centric occlusion contacts. In the maxillary posterior dentition, centric relation contacts may coincide with centric occlusion contacts on the cusp tips but may be slightly distal to the centric relation contacts on the marginal ridges and fossae. In the mandibular posterior teeth, the cusp tip marks will again coincide and be slightly mesial to the centric occlusion marks on the marginal ridges and fossae (**Fig. 19.25**).

Premature contacts of the mesial inclines of the maxillary lingual cusps and distal inclines of the mandibular buccal cusps will cause a forward slide during the closing of the mandible to centric relation (**Fig. 19.26**).

Working Contacts

During lateral excursions of the mandible, the side to which the mandible moves is known as the *working side* and that opposite is known as the

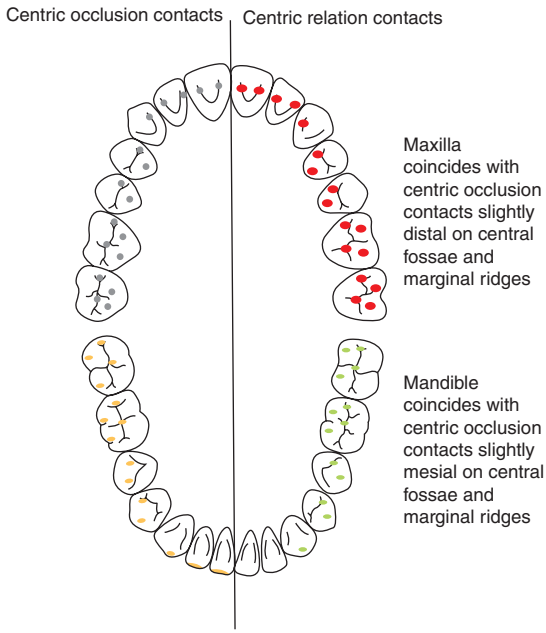


Figure 19.25 Centric relation contacts.

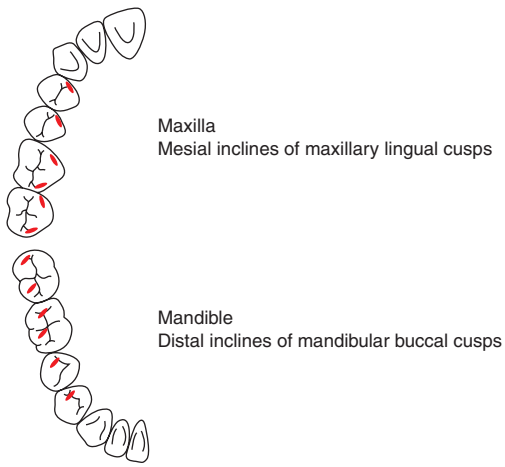


Figure 19.26 Centric relation interferences causing the forward slide.

non-working side. Working-side movements are described as movements on the side to which the mandible moves during lateral function. When the teeth are in normal alignment, a working-side movement will produce contact only on the lingual inclines of the maxillary buccal cusps and the buccal inclines of the mandibular buccal cusps, known as *working contacts* or *working-side contacts*. If a group function exists, there may be contact on the incisors (**Fig. 19.27**).

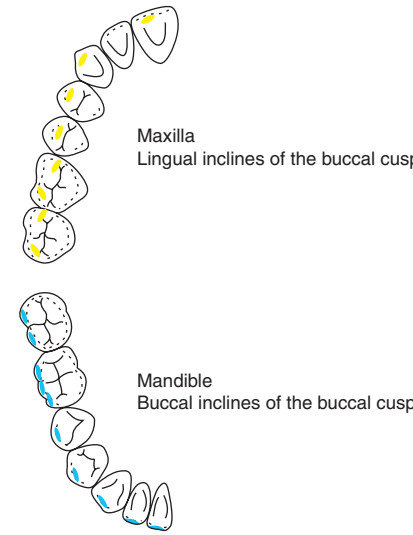


Figure 19.27 Working-side contacts during lateral excursions.

Non-Working Contacts

Non-working contacts are those made on the opposite side to which the mandible has moved in lateral excursions. The direction of the contact is from mesiolingual to distobuccal on the inner aspects of the supporting cusps of both arches. Almost all the contact areas are located on the mesial inner inclines of the maxillary supporting (lingual) cusps and the distal inner inclines of the mandibular supporting (buccal) cusps (**Fig. 19.28**).

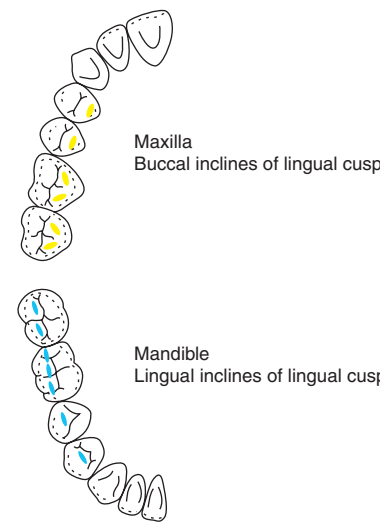


Figure 19.28 Non–working-side contacts during lateral excursions.

SECTION II

Protrusive Contacts

A protrusive movement is an anterior movement or a protrusion of the mandible. This movement produces contact on the labioincisal angle of the mandibular anterior teeth and on the lingual surfaces of the maxillary anterior teeth, incisal to centric markings. Protrusive contacts in the distal inclines of maxillary lingual cusps and on the mesial inclines of mandibular buccal cusps are undesirable and, when they occur, are considered *protrusive interferences* (**Figs 19.29** and **19.30**).

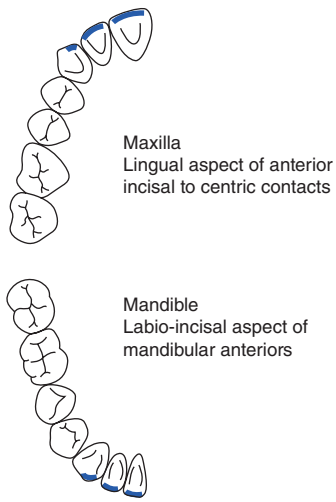


Figure 19.29 Protrusive contacts.

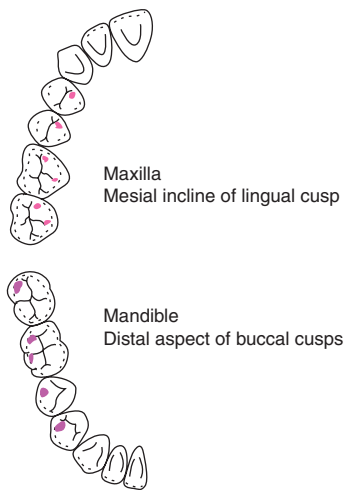


Figure 19.30 Protrusive interferences.

DETERMINANTS OF OCCLUSAL MORPHOLOGY

The movements of the mandible through its excursive pathways are guided and controlled by anterior and posterior anatomical structures. The *determinants of occlusion* are as follows:

1. **Posterior determinants:** Inclination of the condylar path or condylar guidance. It is fixed or unalterable.
2. **Anterior determinants:** Incisal guidance, orientation of the occlusal plane, cuspal angulation and compensating curves. These may be altered by selective reshaping and restorative measures.

Occlusal Stability: Factors that Determine Tooth Position

The final position of the dentition in the dental arch is influenced by the various forces acting on the teeth during and after eruption. During eruption, the teeth are guided to a position where the opposing forces are in equilibrium. After eruption, the lips and cheeks exert a light, constant, lingually directed force while in the opposite direction, the tongue exerts a labially directed force on the dentition. These forces put the dentition in a place known as *neutral position* or space where the opposing labial and lingual forces are in equilibrium (**Fig. 19.31**). Any tooth which is positioned too far lingual or labial to the arch will be aligned to a proper position in the arch by these muscular forces if space is available in the arch. Lack of space in the arch results in crowding.

Occlusal disharmony may present itself through symptoms such as facial pain, TMJ dysfunction or apical periodontitis. The signs of occlusal disharmony may present themselves as radiographic proliferative changes such as condensing osteitis, hypercementosis or mere thickening of the lamina dura. It may also produce and present itself as visible degenerative changes such as occlusal wear, bone resorption and TMJ pathology.

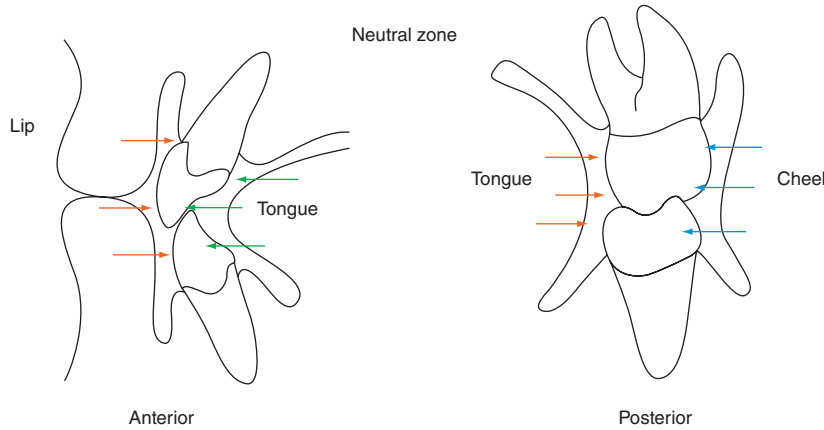


Figure 19.31 Forces acting on the anterior and posterior dentition.

Applied Morphology

Any tooth which is positioned too far lingual or labial to the arch will be aligned to a proper position in the arch by these muscular forces if space is available in the arch. Lack of space in the arch results in crowding

Even after eruption, any disturbance in the magnitude, direction or frequency of the muscular forces may shift the teeth into a position where the forces are again in equilibrium. The neutral zone is not lost; it is usually shifted to a new position. For example, an unusually large tongue or an active tongue may lead to labial flaring of the anterior teeth, resulting in anterior spacing and open bite. The shift in the neutral zone is due to the constant resting posture of the unusually large tongue on the anterior teeth. Habits such as thumb sucking may generate abnormal forces that affect the position of the teeth and disturb the occlusion.

The proximal contact and the occlusal contact are very important in maintaining the integrity of neutral zone occlusion. Any disturbance in the proximal contact as a result of caries or loss of a tooth results in mesial drifting of the distal teeth.

Loss of occlusal contact results in over eruption of the opposing teeth. When a tooth is lost, the opposing tooth extrudes and the adjacent tooth migrates into the space available. This migration disturbs the contact relationships of the teeth and the arch integrity, causing occlusal disharmony (**Fig. 19.32**).

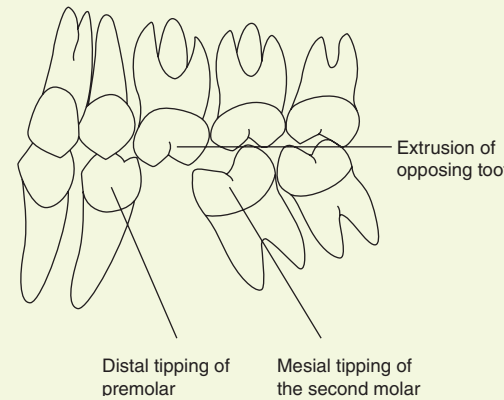


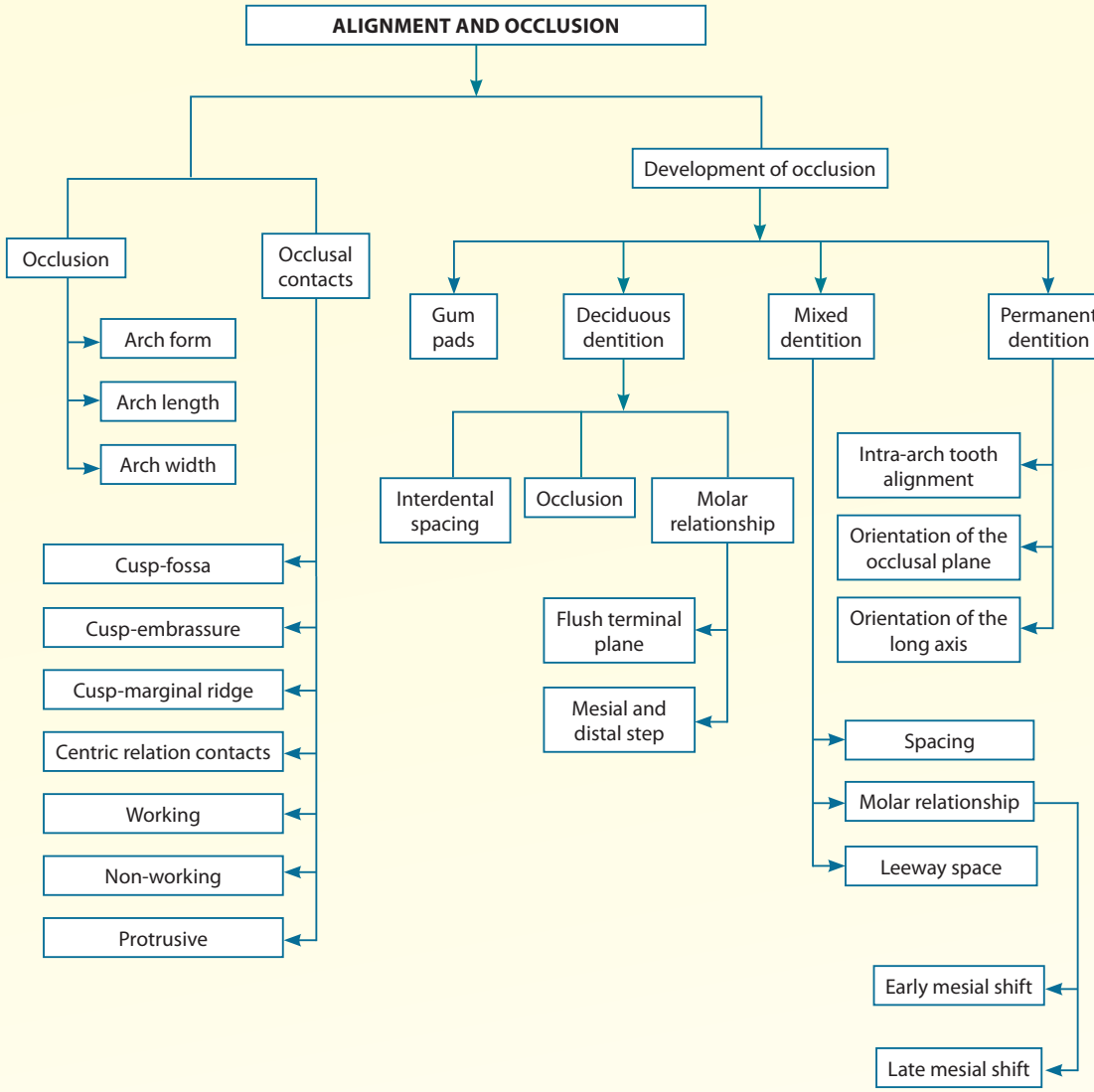
Figure 19.32 Disturbances in the arch integrity following extraction of a mandibular first molar.

Occlusal disharmony may present itself through symptoms such as facial pain, TMJ dysfunction or apical periodontitis. Signs of occlusal disharmony may present themselves as radiographic proliferative changes such as condensing osteitis, hypercementosis or as a mere thickening of the lamina dura. It may also produce and present itself as visible degenerative changes such as occlusal wear, bone resorption and TMJ pathology.

Key Points

1. Occlusion is defined in the *Glossary of Prosthodontic Terms* as the 'static and dynamic contact relationship between the occlusal surfaces of the teeth during function'.
2. The *primate space* or simian space or anthropoid space is seen in the maxillary arch between the lateral incisors and the canine and in the mandibular arch between the canine and the first primary molar.
3. The molar relationship in the deciduous dentition is described by Moyers on the basis of the relationship of their terminal planes (distal surfaces) as the flush terminal plane, mesial step and distal step.
4. A mesial step in the deciduous dentition indicates a greater probability of a class I molar relationship and a lesser probability of a class III molar relationship in the permanent dentition.
5. A distal step in the deciduous dentition usually proceeds into a class II molar relation in the permanent dentition.
6. The leeway space of Nance is greater (1.8 mm per side) in the mandibular arch than in the maxillary arch (0.9 mm per side).
7. The normal depth of the *curve of Spee* is 1.5 mm as measured at the second premolar region, where the curve assumes its maximum depth.
8. Bonwill observed that the distance between the condyles and the distance from the mesial contact of the mandibular incisors to the centre of each condyle was 4 inches forming an equilateral triangle known as the *Bonwill's triangle*.
9. This *curve of Monson* as described by Monson in 1932 is a segment of the surface of a sphere of 4-inch (20 cm) radius, with its centre in the region of the glabella.
10. In the mandibular arch, both the anterior and posterior teeth are mesially inclined. In maxillary teeth, the anteriors are mesially inclined, whereas the posteriors are inclined distally.
11. *Centric occlusion* is the relationship between the maxillary and mandibular dentition when they are in maximum occlusal contact.
12. *Centric relation* or the *centric jaw relation* refers to the most posterior position of the mandible relative to the maxilla (maximum retruded position of the mandible).
13. In centric jaw relation, the condyles articulate with the thinnest avascular portion of the articular disc and the *condyle–disc complex* is in an *anterior–superior position* against the *posterior slopes of the articular eminence*.
14. The maxillary arch width is always greater than the mandibular arch width. When the arches occlude, each maxillary tooth is positioned facial to the mandibular tooth.
15. The palatal cusps of the maxillary posteriors and buccal cusps of the mandibular posteriors occluding with the opposing central fossae are referred to as *supporting cusps* or *functional cusps*.

Mind Map


ALIGNMENT AND OCCLUSION
Occlusion
Occlusal contacts
Development of occlusion
Arch form
Arch length
Arch width
Cusp-fossa
Cusp-embrassure
Cusp-marginal ridge
Centric relation contacts
Working
Non-working
Protrusive
Gum pads
Deciduous dentition
Mixed dentition
Permanent dentition
Interdental spacing
Occlusion
Molar relationship
Flush terminal plane
Mesial and distal step
Intra-arch tooth alignment
Orientation of the occlusal plane
Orientation of the long axis
Spacing
Molar relationship
Leeway space
Early mesial shift
Late mesial shift

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Multiple Choice Questions

1. Bilateral balanced occlusion is
   (a) Seen in natural dentition
   (b) Used in denture construction
   (c) A mutually protected occlusion
   (d) Seen in deciduous dentition
2. The first deciduous tooth to erupt is the
   (a) Maxillary central incisor
   (b) Mandibular central incisor
   (c) Maxillary lateral incisor
   (d) Mandibular lateral incisor
3. The first permanent tooth to erupt is the
   (a) Maxillary central incisor
   (b) Mandibular central incisor
   (c) Maxillary first molar
   (d) Mandibular first molar
4. The last deciduous tooth to be replaced by the permanent tooth is the
   (a) Maxillary first premolar
   (b) Mandibular first premolar
   (c) Maxillary second premolar
   (d) Maxillary canine
5. The primate space is seen
   (a) Mesial to primary canine in the maxillary arch and distal to primary canine in the mandibular arch.
   (b) Mesial to primary canine in both arches
   (c) Distal to primary canine in both arches
   (d) Distal to primary canine in the maxillary arch and mesial to primary canine in the mandibular arch
6. The transient midline spacing between the maxillary permanent incisors in the mixed dentition stage is due to the
   (a) Erupting maxillary lateral incisors
   (b) Distally erupting maxillary central incisors
   (c) Erupting maxillary canines
   (d) Erupting mandibular canines
7. The curve of Spee is deepest in the
   (a) Maxillary second premolar region
   (b) Maxillary first premolar region
   (c) Mandibular first premolar region
   (d) Mandibular second premolar region
8. The curve of Wilson is a
   (a) Mediolateral curve
   (b) Mesiodistal curve
   (c) Sagittal curve
   (d) Anteroposterior curve
9. The mandibular posteriors have a
   (a) Buccal and distal inclination
   (b) Buccal and mesial inclination
   (c) Lingual and mesial inclination
   (d) Lingual and distal inclination

10. Overjet is the
    (a) Horizontal overlap of maxillary and mandibular anteriors
    (b) Vertical overlap of maxillary and mandibular anteriors
    (c) Buccal overlap of maxillary and mandibular anteriors
    (d) Buccal overlap of maxillary and mandibular posteriors
11. Overbite is the
    (a) Horizontal overlap of maxillary and mandibular anteriors
    (b) Vertical overlap of maxillary and mandibular anteriors
    (c) Buccal overlap of maxillary and mandibular anteriors
    (d) Buccal overlap of maxillary and mandibular posteriors
12. The centric or working cusps are the
    (a) Maxillary buccal cusps
    (b) Maxillary buccal cusp and mandibular lingual cusps
    (c) Maxillary palatal cusps and mandibular buccal cusps
    (d) Maxillary lingual cusps
13. The non-centric or guiding cusps are the
    (a) Maxillary buccal cusps
    (b) Maxillary buccal cusp and mandibular lingual cusps
    (c) Maxillary palatal cusps and mandibular buccal cusps
    (d) Maxillary lingual cusps
14. The working side is the
    (a) Side to which the mandible moves during lateral excursions
    (b) Opposite side to which the mandible moves during lateral excursions
    (c) Side to which the mandible moves in protrusion
    (d) Side to which the mandible moves in retrusion
15. The buccal cusps of the maxillary and mandibular posterior teeth on the working side are in contact and there is no tooth contact in the non-working side in a
    (a) Balanced occlusion
    (b) Canine-protected occlusion
    (c) Unilaterally balanced occlusion
    (d) Group function occlusion

CHAPTER 20



Functional Occlusion and Malocclusion

Overview

Occlusion is intercuspation between the upper and lower teeth in various mandibular positions and movements. Knowledge of the basic concepts of normal occlusion, functional occlusion and malocclusion is vital for understanding the occlusal inter-relationship. Functional occlusion refers to the occlusal contacts of the maxillary and mandibular teeth on the basis of laterotrusive movements from centric occlusion. Malocclusion is an appreciable deviation from the acceptable relationship of the maxillary arch and/or teeth to the mandibular arch and/or teeth that may be considered aesthetically or functionally unsatisfactory.

INTRODUCTION

The objective of modern dentistry is to restore a patient's normal contour, function, aesthetics, speech and health. This chapter focuses on the basic concepts of normal occlusion, functional occlusion and malocclusion with their relevance in oral cavity.

OCCLUSION

Knowledge regarding the occlusion of each patient contributes significantly to complete care and instruction; recognition of malocclusion assists in the referral of patients to the orthodontist, provides important points of reference for patient instruction and regulates necessary variations in techniques. This occlusal relationship of the teeth is examined and noted as a part of the oral examination.

Occlusion is defined as:

1. 'the manner in which the occlusal surfaces of the maxillary and mandibular teeth relate to each other in maximum intercuspation at all mandibular positions and movements'
2. 'the normal relation of the occlusal inclined planes of the teeth when the jaws are closed'
3. 'the interdigitation of maxillary and mandibular teeth in a static relationship or arrangement of teeth'

An individual's occlusal status is described by the intra-arch relationship, relationship of the teeth within each arch to curves of occlusion, pattern of occlusal contacts between the upper/lower teeth and other soft/hard tissues of the oral cavity.

Concept of Occlusion

Numerous theories of occlusion have been suggested:

1. Only a static relationship exists between the masticatory surfaces of the maxillary and mandibular teeth.
2. A dynamic and functional relationship of the whole masticatory system is present in addition to the existing static relationship of the teeth.
3. The components of the masticatory system (i.e. teeth, jaws, temporomandibular joint and neuromuscular system) also influence normal occlusion.

Ideal Occlusion

Ideal occlusion is a hypothetical or theoretical concept based on the anatomy of teeth with occlusal structural and functional relationships. This concept is useful in a condition when the skeletal bases of maxilla and mandible are of a correct size relative to each other and in correct harmony with the teeth of the same arch, opposite arch and all three planes of occlusion at rest.

Concept of Ideal Occlusion

1. Teeth in each arch exhibit ideal mesiodistal, buccolingual inclinations and proximal relationship at the interdental contact area.
2. Arch relationships: Each lower tooth contacts the corresponding upper tooth and the tooth anterior to it.
3. The upper arch overlaps the lower arch anteriorly and laterally when the teeth are in maximum intercuspation, centric relation and during functional movements.

Normal Occlusion

'Normal' and 'ideal' occlusion are separate entities that are not documented appropriately, resulting in somewhat unsuitable usage of these two terms interchangeably. Normal occlusion is maintained by three factors: (i) teeth cusp interdigitation, (ii) support from the upper and lower jaws and (iii) influence of the muscles labially, buccally, palatally and lingually. Teeth in the maxillary arch are in maximum contact with teeth in the mandibular arch in a definite pattern.

Edward H. Angle (1899; 1907) has stated normal or ideal occlusion as

1. 'the mesiobuccal cusp of the upper first molar occludes in the sulcus between the mesial and distal buccal cusps of the lower first molar'.
2. 'the mesial and distal inclines of the mesiobuccal cusp of the upper first molar are present between the mesial and distal buccal cusps of the lower first molar'.
3. 'the inclines of the distobuccal cusp of the upper first molar are established between the distobuccal cusp of the first lower molar and the mesiobuccal cusp of the second lower molar'.
4. 'the mesial incline of the upper canine occludes with the distal incline of the lower canine; the distal incline of the upper canine occludes with the mesial incline of the buccal cusp of the lower first premolars. ***Note:*** Each of the teeth in both jaws has two antagonists or supports in the opposite jaw, except the lower centrals and the upper third molars'.

Angle's explanation of occlusion is based on the relationship of the maxillary first permanent molar to the mandibular first permanent molar.

Keys of Occlusion

1. Andrews Six Keys to Normal Occlusion
   (a) *Molar relationship*: The mesiobuccal cusp of the upper first molar should occlude with the groove between the mesiobuccal and the middle buccal cusps of the lower first molar. The distobuccal cusp of the upper first molar should contact the mesiobuccal cusp of the lower second molar.
   (b) *Crown angulation*: The angulation of the facial axis of every clinical crown should be positive, i.e. the gingival part of the long axis of each crown in the upper jaw should be positioned distally to the occlusal part of this axis. The extent of angulation varies according to tooth type and is more pronounced among the anterior teeth. The degree of crown tip is the angle between the long axis of the crown and a line perpendicular to the occlusal plane.
      - 'Plus' (+) gingival portion of crown is distal to the incisal portion.
      - 'Minus' (–) gingival portion of crown is mesial to the incisal portion.
   (c) *Crown inclination*: Inclination refers to the labiolingual or buccolingual position of the crowns. The gingival portion of upper incisors should be inclined towards the buccal or labial surface only. The upper molar crowns should be inclined slightly more than the canines and premolars. The lower incisors should be inclined lingually only. The lingual inclination of the gingival portion of the lower teeth is more pronounced from the lower canines to the lower molars.
      - 'Plus' (+) gingival portion is lingual to the incisal portion.
      - 'Minus'(–) gingival portion is labial to the incisal portion (maxillary incisors have a positive inclination; mandibular incisors have a slightly negative inclination).
   (d) *Rotations*: Teeth must be free of undesirable rotations. Rotated molars occupy more space than rotated incisors.
   (e) *Spaces*: Spaces should be absent between teeth.

(f) *Occlusal plane*: The occlusal plane should be either flat or slightly curved (curved less than 1.5 mm).

Benett and Mclaughlin (1993) introduced Bolton's ratio to the existing six keys of normal occlusion. In this concept, the upper and lower tooth sizes should be correct and fit in appropriate dimensions to the Bolton tooth size ratio analysis.

Deviation of features described by Andrews' occurs due to the variation in dentition and/or supporting structures. As Angle (1907) and Andrews (1972) features of occlusion provided insight based only on their static relationship. Roth described the philosophy of 'ideal' occlusion based on the dynamic features of occlusion during functional movement in addition to the normal static relationship.

2. **Roth (1981)**
   (a) Centric relationship and centric occlusion should be coincident.
   (b) In protrusion, the incisors should disclude the posterior teeth, with the guidance being provided by the lower incisal edges along the palatal contour of the upper incisors.
   (c) In lateral excursions of the mandible, the canine should guide the working side and the other side should be discluded.
   (d) When the teeth are in centric occlusion, there should be even bilateral contacts in the buccal segments.

Concept of 'Normal' Occlusion

"Normal' occlusion is 'an occlusion within the accepted deviation of the ideal that does not constitute aesthetic or functional problems' (Houston et al., 1992). Multiple factors (morphology, function, psychology and sociology) and keys of occlusion are considered in normal occlusion.

In total, occlusion refers to correct crown angulation and inclination, absence of rotations, tight proximal contacts and flat occlusal plane. Roth added further prerequisite features for normal occlusion regarding the coincidence of centric relationship and centric occlusion, guidance during protrusion, lateral excursions of the mandible and posterior contacts in centric occlusion.

Ideal Versus Normal Occlusion

Ideal Occlusion

Ideal occlusion is aesthetically satisfactory, functionally acceptable and suggests variations in occlusion around an average or mean value.

Normal Occlusion

Class I molar relationship mesiobuccal cusp of the upper first molar articulates in the buccal groove of the lower first permanent molar. A static relationship of the first permanent molars, sizes, forms, interdigitating surfaces and positions of the teeth in the arches gives the greatest possible support in all directions implying that the functional aspect of occlusion is just as important as the static relationship of teeth to each other and must include six keys to normal occlusion.

Functional Occlusion

Functional occlusion refers to the occlusal contacts of the maxillary and mandibular teeth which will provide the highest efficiency throughout all excursive movements of the mandible that occur during functions such as speech, mastication and deglutition. This occlusion determines the functional impact of the temporomandibular joint and muscles of mastication on post-orthodontic retention and stability.

On the basis of laterotrusive movements from centric occlusion, several functional occlusion types were recognized, such as balanced occlusion, canine-protected occlusion, group function occlusion, mixed canine-protected and group function, flat-plane (attrition) teeth occlusion and biologic (multivaried, physiologic) occlusion.

Types of Functional Occlusion

Functional occlusion is of the following types:

1. **Protrusive functional occlusion:** It contains the eccentric contacts that occur when the mandible moves forwards. Ideally, six mandibular anterior teeth contact along the palatal inclines of the maxillary anterior teeth while the posterior teeth disocclude. This is called a '*guiding incline of the anterior teeth*'.

Disocclusion of the posterior teeth occurs in three stages: (i) initial contact, (ii) beginning of the anterior discluding factor and (iii) end-to-end position. An overjet (2–3 mm) and overbite (1.5 mm) should at least be there to obtain definite mandibular movements.

2. **Retrusive functional occlusion:** These movements become evident as the mandible moves posteriorly. This functional movement is governed by the temporomandibular joint ligaments.
3. **Lateral functional occlusion:** It demonstrates the tooth contacts that occur on canines and posterior teeth on the side towards which the mandible moves. The condyle on the side towards which movement occurs is referred to as *working side* and the condyle on the other side is *non-working or balancing side*. During lateral movement of the mandible, the condyle on the working end may rotate or move laterally, upwards and downwards. This lateral movement is called *Bennette movement*.

   During lateral movements, the functional occlusion can be of three types:

   (a) Canine-guided functional occlusion
   (b) Group functional occlusion
   (c) Mutually protected occlusion (canine protected occlusion)

Bennette Movement It can be of two types:

1. Immediate or early shift
2. Gradual or progressive shift

Balanced Occlusion

Balanced occlusion is defined in the *Glossary of Prosthodontic Terms* as 'the simultaneous contacting of the maxillary and mandibular teeth on the right and left and in the posterior and anterior occlusal areas in centric and eccentric positions, developed to lessen or limit tipping or rotating of the denture bases in relation to the supporting structures'.

Balanced occlusion can be described as the positioning of the teeth such that they have simultaneous contact in centric relation and provide a smooth sliding motion to any eccentric position. A three-point contact (usually one anterior and two posterior) at centric relation is not sufficient for balanced occlusion; instead, there should be simultaneous contact of all the teeth. Balanced occlusion is absent in natural dentition. It is one of the most important factors that affect denture stability and should have the following characteristics:

1. All the teeth of the working side (central incisor to second molar) should glide evenly against the opposing teeth without any interference or disocclusion of the other teeth.
2. There should be contacts in the balancing side, but they should not interfere with the smooth gliding movements of the working side.
3. There should be simultaneous contact during protrusion.

Canine-Guided Functional Occlusion

During lateral mandibular movement the maxillary and mandibular canines of the working side contact, causing disclusion of all posterior teeth on working and balancing sides. Lateral excursion may also be guided by the central/lateral incisors on the working side acting in a group function with canine.

Note: Canine is selected particularly due to the following reasons: longest and largest root, dense compact bone, less muscular activity when canine contacts during eccentric movement and concave palatal surface suitable for lateral guiding movement.

Group Functional Occlusion

Group function refers to the distribution of lateral forces to the group of teeth rather than protecting those teeth from contact in function and assigning all the forces to one particular tooth. This is advantageous if the periodontal ligament support of canine is compromised.

Mutually Protected Occlusion

Mutually protected occlusion is an occlusal scheme in which the posterior teeth prevent excessive contact of anterior teeth in maximum intercuspation

and the anterior teeth disengage the posterior teeth in all mandibular excursive movement. Canine-protected occlusion is a form of mutually protected articulation.

Optimum Functional Occlusion

Optimum functional occlusion describes the simultaneous contact of all the possible teeth when the mandibular condyles are in their most superioanterior positions, resting against the posterior slopes of the articular eminence with the disc properly interposed.

Criteria for the Optimal Functional Occlusion

1. Optimal orthopaedically stable joint position
2. Optimal functional tooth contact
3. Patient comfort
4. Acceptable joint–muscle inter-relationship for transfer of load
5. Mandible should close into maximum intercuspation without deflecting the condyle from the ideal relationship in the fossae
6. A stable position of the musculoskeletal joints can be maintained only when they are in harmony with a stable occlusal condition
7. The optimum occlusal conditions during mandibular closure would be provided by even and simultaneous contact of all possible teeth. This furnishes maximum stability for the mandible while minimizing the amount of force placed on each tooth during function

Treatment Objective

1. Obtain desirable facial aesthetics
2. Accepted Angle's molar relationship and tooth alignment
3. Regular monitoring of functional occlusion gnathologically
4. Stability of post-treatment tooth positions and alignment
5. Provides efficiency and longevity of the dentition, supporting structures and temporomandibular joint
6. Evaluation of occlusal disharmony
7. Occlusal interferences: Centric and excursive movements

Sign and Symptoms from Occlusal Interferences

Occlusal interferences result in tooth wear, excessive mobility, temporomandibular joint disturbances, limitation in joint movement, myofacial pain and neuromuscular contracture.

Occlusal correction

Working interferences: The side towards which the jaw moves and occurs between the buccal cusp of the maxillary and mandibular teeth

Non-working interferences: They occur on lingual cusps of maxillary teeth and buccal cusp of mandibular teeth

Diagnosis and Treatment Planning

1. Evaluate the neuromuscular positioning of the mandible to accommodate occlusal discrepancies
2. Centric relation and centric occlusion are recorded to evaluate the extent of discrepancies
3. Cephalometric tracing of the temporomandibular joint is a good indicator of the state of bony elements of joints

Occlusal and Proximal Contacts

1. **Occlusal contacts**
   (a) *Functional contacts:* They are the normal contacts that are made between the maxillary teeth and the mandibular teeth during chewing and swallowing. Each contact is momentary, so the total contact time is only a few minutes each day.
   (b) *Parafunctional contacts:* They are those contacts that are made outside the normal range of function. Parafunctional contacts result from occlusal habits and neuroses.
   - Potentially injurious to the periodontal supporting structures in the presence of dental biofilm and inflammatory factors
   - Create wear facets on the teeth

- They can be divided into the following:
  - Tooth-to-tooth contacts: Bruxism, clenching, tapping
  - Tooth-to-hard-object contacts: Nail biting; occupational use of objects such as pins
  - Tooth-to-oral-tissues contacts: Lip or cheek biting

2. **Proximal contacts:** They serve to stabilize the position of teeth in the dental arches and to prevent food impaction between the teeth.
   (a) *Drifting*: Loss of proximal contacts results in mesial shift of teeth towards the midline and adaptation of periodontal structures to the repositioned teeth in a healthy mouth.
   (b) *Pathologic migration*: It refers to migration of teeth as a result of periodontal tissue destruction.

Concepts for Eccentric Occlusion

Eccentric occlusion refers to the following key features:

1. **Anterior canine-protected occlusion:** Incisors and canines offer disocclusion of all other teeth. This occlusal concept is most easily achieved clinically.
2. **Unilateral balanced occlusion (group function):** Guidance of all the teeth of the later obtrusive side with disocclusion of the teeth on the opposite side. Majority of young adults exhibit a more or less unilateral balanced occlusion.
3. **Bilateral balanced occlusion:** All teeth remain in contact during laterotrusion.

Concept of Functional Occlusion

Functional occlusion is based on the following concepts:

1. **Passive centric and active centric stop (Fig. 20.1a)**
   (a) *Centric stop*: Contact points caused from the occlusion of the upper and lower teeth
   (b) *Passive centric stop*: Passive contact point of the maxillary dentition arch in connection with the cranium and the functional cusp of mandibular teeth
   (c) *Active centric stop*: Centric stop of the mandible that moves dynamically compared with the passive centric stop of the maxilla.
2. **Passive centric line and active centric line (Fig. 20.1b):** Upper and lower centric stops are in a complete even and simultaneous relation. An imaginary line that passes through the passive centric cusps of maxillary teeth is referred to as a *passive centric line* and an imaginary line that passes through the active centric cusps is referred to as an *active centric line*.
3. **Intercuspation of the first molar:** The occlusion of an upper and lower first molar is the most important occlusion in permanent

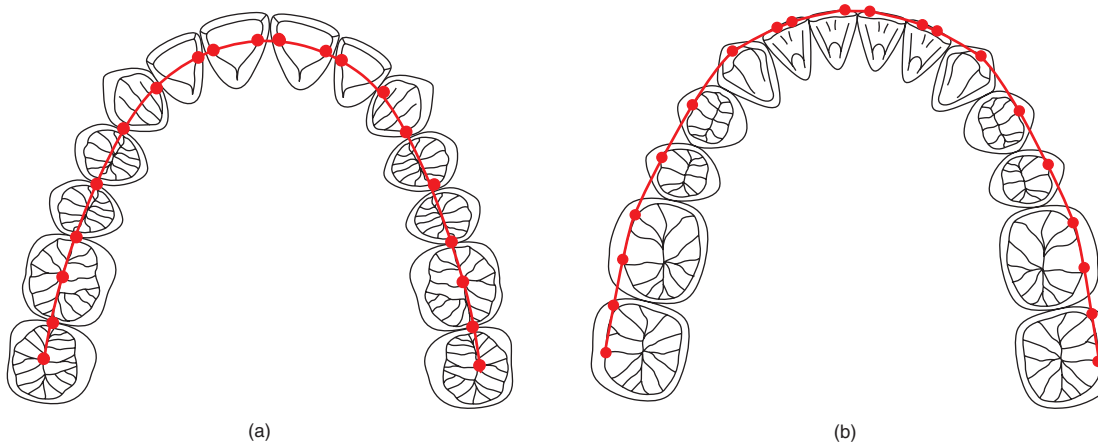


Figure 20.1 Centric stops and centric lines. (a) Passive and active centric stops. (b) Passive and active central lines.

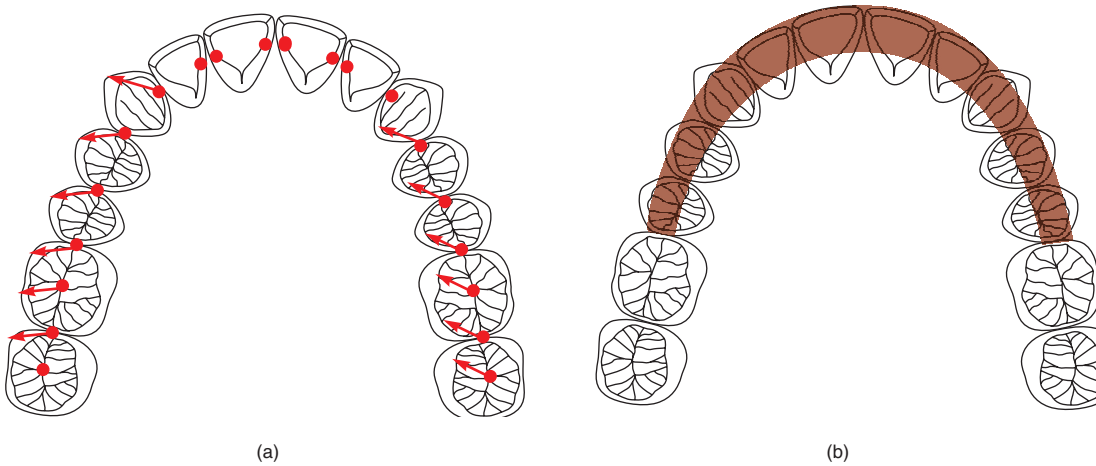


Figure 20.2 Passive centric stops and occlusal guidance.

dental articulation. The mesiolingual cusp of the upper first molar occludes in the central fossa of the lower first molar, and the distobuccal cusp of the lower first molar occludes in mesial with the transverse ridge of the upper first molar. This plays a significant role in preserving the occlusal support and the mandibular position.

4. **Passive centric and occlusal guidance (Fig. 20.2):** The active centric stops of the mandible occlude with the passive centric stops of the maxilla moving on the lingual surface of the incisors/canine and on the mesial marginal ridges of molars/premolars of the working side along the lateral excursions of the mandible. The guiding area refers to the region of the maxilla as the mandible moves from the passive centric line towards the exterior during lateral excursions.
5. **Retrusive barrier (transverse ridge [Fig. 20.3]):** The distobuccal cusp of the lower first molar engages mesial with the transverse ridge of the upper first molar and prevents the mandible from retrusion. The transverse ridge (i.e. retrusive barrier) of the upper first molar is an important structure to maintain the mandibular position.
6. **Mediotrusion:** The relation between the guidance and mediotrusion (Fig. 20.4) is essential to check the occlusal contact pattern during the bruxism.

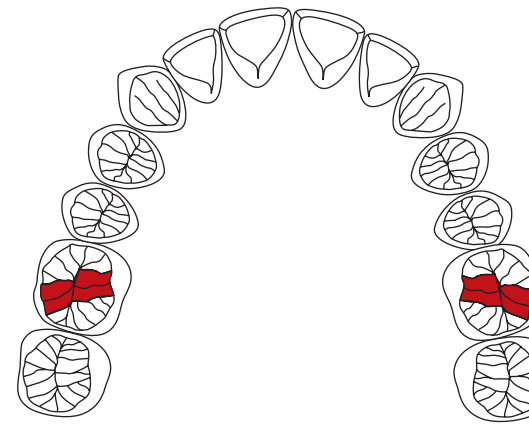


Figure 20.3 Transverse ridge.

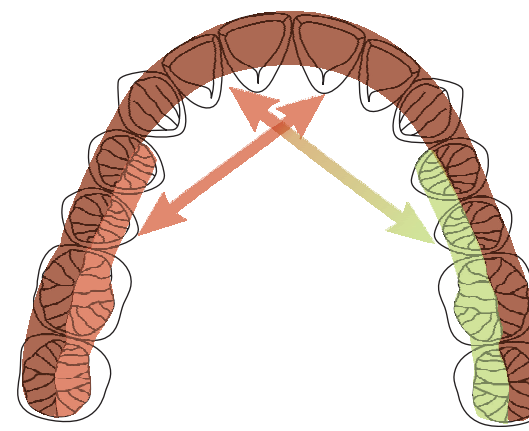


Figure 20.4 Occlusal guidance and mediotrusion.

MALOCCLUSION

Malocclusion can be defined as an appreciable deviation from the acceptable relationship of the maxillary arch and/or teeth to the mandibular arch and/or teeth that may be considered aesthetically or functionally unsatisfactory. It is a condition where there is departure from the normal relation of the teeth to other teeth in the same arch and to the teeth in the opposing arch.

Malocclusion can also be defined as follows:

1. Malalignment of an individual tooth in each arch: A tooth in an arch may occupy a position deviating from the smooth curve of the line by being tipped, displaced, rotated, infraoccluded, supraoccluded and transposed.
2. Relationship of the dental arches relative to the normal occlusion: It may occur in any of the three planes of spaces: (i) anteroposterior, (ii) vertical or (iii) transverse planes.
3. Condition of imbalance in the relative sizes and position of teeth, facial bones and soft tissues (lips, cheek and tongue).
4. Deviation of teeth from other teeth in the same arch and to the teeth in the opposite arch.
5. Dentofacial anomaly which causes disfigurement or impedes function and requires treatment if it is or is likely to be an obstacle to the patient's physical or emotional well-being.
6. Any appreciable deviation from the normal occlusion that may be perceived aesthetically unsatisfactory, thus implying imbalance in the relative size and position of teeth, facial bones and the surrounding soft tissues.
7. Malocclusion is a condition that reflects an expression of normal biologic variability in the way the maxillary and the mandibular teeth occlude.
8. An occlusion in which there is a malrelationship between the arches in any of the planes of the space or in which there are anomalies in tooth position beyond the limit of the normal.

Occlusion is a gross geometric relationship within and between the maxillary and mandibular dental arches. Any deviation from a physiologically acceptable relationship that manifests as 'imperfect positioning of the teeth when the jaws are closed' is termed *malocclusion*. The terms that are commonly related to malocclusion are given in **Table 20.1**.

Table 20.1 Terminologies Related to Dental Malocclusion

Terminology	Definition
Overjet	Increase in the horizontal distance between the labioincisal surface of the mandibular incisors and the linguoincisal surfaces of the maxillary incisors (>2–3 mm)
Underjet	Decrease in the horizontal distance between the labioincisal surface of the mandibular incisors and the linguoincisal surfaces of the maxillary incisors (<2–3 mm)
Overbite	Increase in the vertical distance by which the maxillary incisors overlap the mandibular incisors
Normal overbite	When the incisal edges of the maxillary teeth are within the incisal third of the mandibular teeth
Moderate overbite	When the incisal edges of the maxillary teeth appear within the middle third of the mandibular teeth
Severe overbite	When the incisal edges of the maxillary teeth are within the cervical third of the mandibular teeth
Ankylosis	Fusion of tooth to the bone
Anterior crossbite	Maxillary incisors are placed lingual to the mandibular incisors
Posterior crossbite	Maxillary or mandibular posterior teeth are either facial or lingual to their normal position
Edge-to-edge bite	Incisal surfaces of maxillary teeth occlude with the incisal surfaces of the mandibular teeth
End-to-end bite	Molars and premolars occlude cusp-to-cusp as viewed mesiodistally

(Continued)

Table 20.1 *(Continued)*

Terminology	Definition
Open bite	Lack of occlusal or incisal contact between certain maxillary and mandibular teeth because either or both have failed to reach the line of occlusion. As the teeth cannot be brought together, a space remains as a result of the arching of the line of occlusion
Anterior open bite	Lack of tooth contact between the anterior teeth of maxillary and mandibular arches
Posterior open bite	Lack of tooth contact between the posterior teeth of maxillary and mandibular arches
Balanced occlusion	An occlusion in which balanced and equal contacts are maintained throughout the entire arch during all excursions of the mandible. This simultaneous contacting of the maxillary and mandibular teeth on the right and left and in anterior and posterior occlusal areas occur when the jaws are in either centric or eccentric relation
Physiologic occlusion	Occlusion with dentition in its anatomical form and physiologic adaptation of the system with harmony in function or parafunction
Therapeutic occlusion	Occlusion that has been altered by appropriate therapeutic modalities in order to change a non-physiological occlusion to a one that is at least physiologic if not ideal.
Traumatic occlusion	Occlusion which produces abnormal occlusal stress that is capable of producing or has produced an injury to the periodontium
Centric occlusion	Relationship of the maxillomandibular occlusal surfaces when they are in maximum intercuspation
Eccentric occlusion	Occlusion other than centric occlusion
Static occlusion	Form, alignment and articulation of teeth within, between the arches and the relationship of teeth to their supporting structures
Dynamic occlusion	Function of the stomatognathic system as a whole comprising teeth, supporting structure, temporomandibular joint, neuromuscular and nutritive systems
Acquired or habitual occlusion	Occlusion with maximum intercuspation that occurs without the condyles being in centric relation

Malposition of Individual Teeth

1. *Mesioversion*: A tooth that has assumed a position mesial to normal.
2. *Distoversion*: A tooth that has assumed a position distal to normal.
3. *Labioversion*: A tooth that has assumed a position labial to normal.
4. *Linguoversion*: A tooth that has assumed position lingual to normal.
5. *Buccoversion*: A tooth that has assumed position buccal to normal.
6. *Supraversion*: A tooth elongated above the line of occlusion (overerupted).
7. *Torsiversion*: A tooth turned or rotated on its axis.
8. *Infraversion*: A tooth that is depressed below the line of occlusion.
9. *Transversion*: Teeth that are in a wrong sequential order.

Intra-arch Morphologic Occlusion

1. *Curve of Spee*: Anterior posterior curve of the occlusal plane, concave up and convex down
2. *Curve of Wilson*: Transverse curve of the occlusal plane, concave up and convex down

Intra-arch morphologic malocclusion: Crowding, missing teeth and ankylosed teeth

Inter-arch morphologic occlusion: It is described in three planes of space for anterior and posterior teeth

1. *Sagittal plane*: Anterior posterior
2. *Anterior teeth*: Horizontal overlap (overjet)
3. *Posterior teeth*: Angle class I, II and III occlusion

Various Systems of Malocclusion

Malocclusion can be classified by several researchers as follows:

1. Angle's classification
2. Dewey's modifications
3. Lisher's modifications
4. Bennette's classification
5. Simon's classification
6. Skeletal classification
7. Ackerman–Proffit system

Angle's Classification of Malocclusion

Edward H. Angle classified malocclusion into three classes on the mesiodistal relation of the teeth, dental arches and jaws emphasing on the occlusal relationships of the first molars.

The maxillary first permanent molar is considered the key to occlusion due to the following reasons.

1. Largest teeth and strongest tooth of anchorage
2. Arch position supports the main masticatory muscles during movements
3. Maintains the vertical distance of the upper and lower jaws in aesthetic proportions
4. Ability of the first permanent molars to control the rest of the teeth anterior and posterior to it during eruption
5. Defect in positioning of molars primarily leads to dentomaxillofacial anomalies

Angle's Class I (Fig. 20.5a) The mesiobuccal cusp of the maxillary first molar occludes in the buccal groove of the mandibular first permanent molar (normal occlusion).

Other Features

1. Crowded maxillary or mandibular anterior teeth
2. Protruded or retruded maxillary incisors
3. Anterior crossbite
4. Posterior crossbite
5. Mesial drift of molars resulting from premature loss of teeth

Angle's Class II (Fig. 20.5b; Table 20.2) The mesiobuccal cusp of the maxillary first permanent molar occludes in the space between the mesiobuccal cusp of the mandibular first permanent molar and the distal aspect of the mandibular second premolar. Also, the mesiopalatal cusp of the maxillary first permanent molar occludes mesial to the mesiolingual cusp of the mandibular first permanent molar.

Based on the *labiolingual angulations of the maxillary incisors*, Angle divided the class II malocclusion into two divisions:

1. Class II division 1
2. Class II division 2

Class II Subdivision: When the class II molar relationship occurs on one side of the dental arch

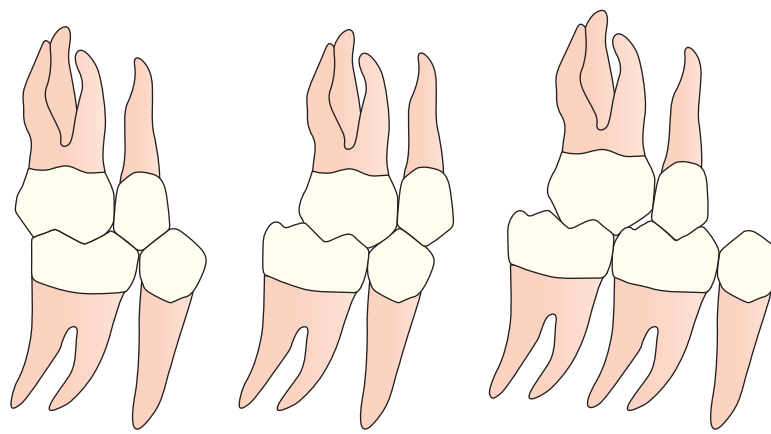


Figure 20.5 Molar relationship. (a) Class I, (b) class II and (c) class III.

SECTION II

Table 20.2 Comparison Between Class II Division 1 and Class II Division 2

Class II Division 1	Class II Division 2
Class II molar relationship along with labially/proclined tipped maxillary incisor teeth—increased overjet	Class II molar relationship along with palatally tipped maxillary central incisors and labially tipped maxillary lateral incisors
Abnormal muscle activity—hyperactive mentalis and buccinators muscles	Normal muscle activity
Convex profile with incompetent lips	Convex/straight facial profile
V-shaped deep maxillary arch	Normal maxillary arch
Normal or increased lower facial height	Decreased lower facial height

only, the malocclusion is referred to as a subdivision of its division. It can be Class II division 1 subdivision and Class II division 2 subdivision.

Angle's Class III (Fig. 20.5c; Table 20.3) The mesiobuccal cusp of the maxillary first molar occludes in the interdental space between the distal cusps of the mandibular first molar and the mesial aspect of the mesial cusp of the mandibular second molar.

Pseudo Class III (Table 20.3) This is not a true class III malocclusion but the appearance is similar. The mandible shifts anteriorly in the glenoid fossa due to premature contact of the teeth or for some other reason when the jaws are brought together in centric occlusion. Class III subdivision occurs when the malocclusion exists unilaterally.

Table 20.3 Comparison Between True Class III and Pseudoclass III

True Class III	Pseudoclass III
Hereditary	Straight
Concave profile	Straight profile
Class III molar relationship present	Class III molar relationship absent
Orthopaedic appliance and surgical appliance	Elimination of prematurity and replacement of lost teeth

Drawbacks of Angle's Classification

1. Angle's classification was exclusively based on the first molars. Hence, the classification is not possible if the first molars are missing.
2. Angle's malocclusion is considered only in the anteroposterior plane. Malocclusion in the transverse and vertical planes is not considered.
3. Individual tooth malocclusion has not been considered.
4. No differentiation between skeletal and dental malocclusion
5. Aetiology of malocclusion has not been elaborated upon

Individual Tooth Classifications

Incisor Classification (Fig. 20.6) The British Standard Institute classified incisors based upon the lower incisal edges and the cingulum of the maxillary central incisors:

1. **Class I:** The lower incisor edges occlude with or lie immediately below the cingulum of the maxillary central incisors.
2. **Class 2:** The lower incisor edges lie posterior to the cingulum of the maxillary central incisors.
   (a) *Division 1:* The maxillary central incisors are proclined or of average inclination and there is increased overjet.
   (b) *Division 2:* The maxillary central incisors are retroclined. The overbite is normally minimum but may be increased.

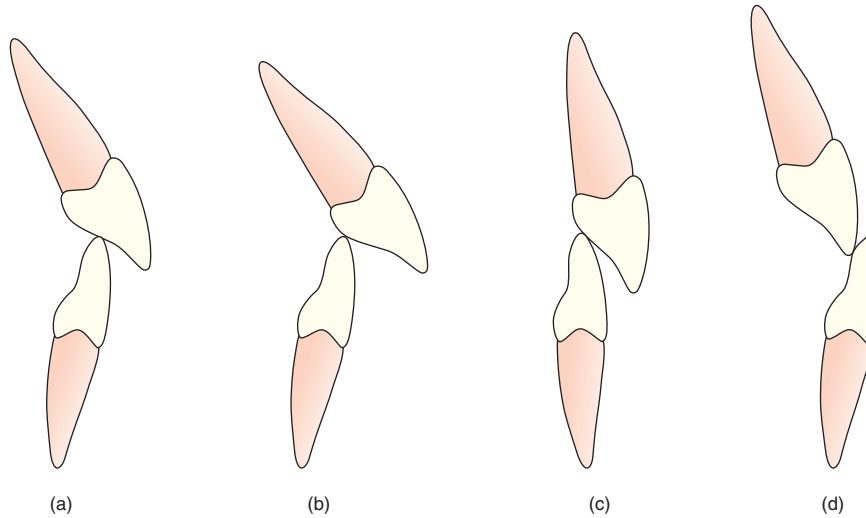


Figure 20.6 Incisor classification. (a) Class I, (b) class II division 1, (c) class II division 2 and (d) class III.

3. **Class 3:** The mandibular incisor edges lie anterior to the cingulum of the upper central incisors. The overjet is reduced or reversed.

Canine Classification

1. **Class I:** The mesial incline of the maxillary canine overlaps the distal slope of the mandibular canine.
2. **Class II:** The distal slope of the maxillary canine occludes or contacts the mesial slope of the mandibular canine.
3. **Class III:** The lower canine is displaced anterior to the maxillary canine with no overlapping of the maxillary and mandibular canines.

Ackerman–Proffit's Classification (1969) (Fig. 20.7) This classification proposed a modification of Angle's classification by recognizing five chief characteristics of malocclusion. This technique overwhelmed the weakness of Angle's scheme in numerous aspects as it included the transverse, vertical planes as well as anteroposterior planes in classifying malocclusion.

Diagnosis of Malocclusion

Clinical orthodontic records are used primarily for diagnosis, monitoring of growth and development, treatment progression and as a medico-legal requirement.

Essential diagnostic aids include the following:

1. Case history
2. Clinical examination
3. **Study models:** Impressions displaying all the erupted teeth, full depth of the palate and good soft-tissue extension.
4. **Radiographs:** They exhibit the presence or absence of dentition, morphology of teeth, relationship of teeth to dental bases and any other dental pathology.
   (a) Periapical radiographs
   (b) Lateral radiographs
   (c) Orthopantomograms
   (d) Bite wing radiographs
5. **Facial photographs:** Intraoral and extraoral photographs

Treatment of Malocclusion

Treatment of malocclusion is targeted for achieving stable static and functional occlusion, thereby producing optimal facial and dental aesthetics. Malocclusion is best treated by beginning the growth modification at late mixed dentition. Removable appliance, functional appliance and fixed appliance are the mainstay of treatment:

1. **Removable appliances:** They are also useful in treating tooth movements (tipping, overbite

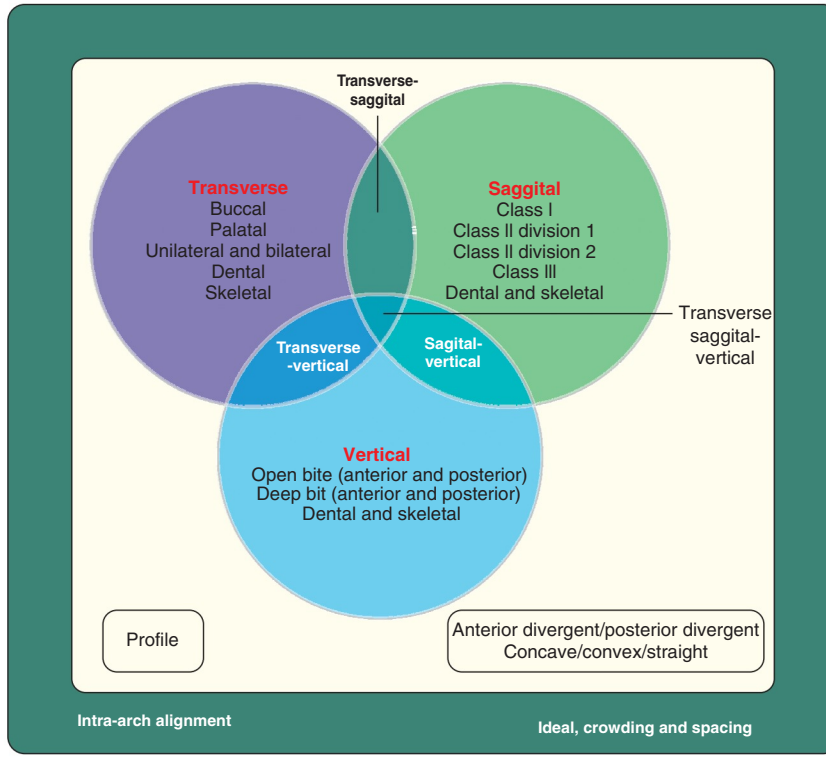


Figure 20.7 Ackerman–Proffit's classification.

reduction, crossbite correction, extrusion and intrusion) and maintaining tooth positions during retention.

2. **Functional appliances (removable/fixed):** They are mainly a group of removable appliances allowing treatment of sagittal skeletal discrepancies between the jaws.
3. **Fixed appliances:** They refer to the appliance that exerts forces via attachments such as arch wires and auxillaries fixed to the tooth surface. The control achieved with the fixed orthodontic appliance is far greater as compared to removable appliances and the teeth can be moved virtually in all the three planes of space.

Treatment consideration for orthodontic intervention also includes (i) facial growth pattern, (ii) amount of anterior–posterior discrepancy, (iii) patient age, (iv) projected patient compliance, (v) space analysis, (vi) anchorage requirements and (vii) patient and parent necessities.

Note: Special treatment, which includes (i) extraoral appliance headgear, (ii) tooth extraction, (iii) interarchelastics and (iv) orthodontics with orthognathic surgery in addition to regular functional appliances, is targeted in class II and class III malocclusion to obtain an improved overbite, overjet, intercuspation of posterior teeth, aesthetic appearance and profile compatible with the patient's skeletal morphology. In most cases of class III malocclusion, orthodontic appliances with orthognathic surgery form the major mode of treatment.

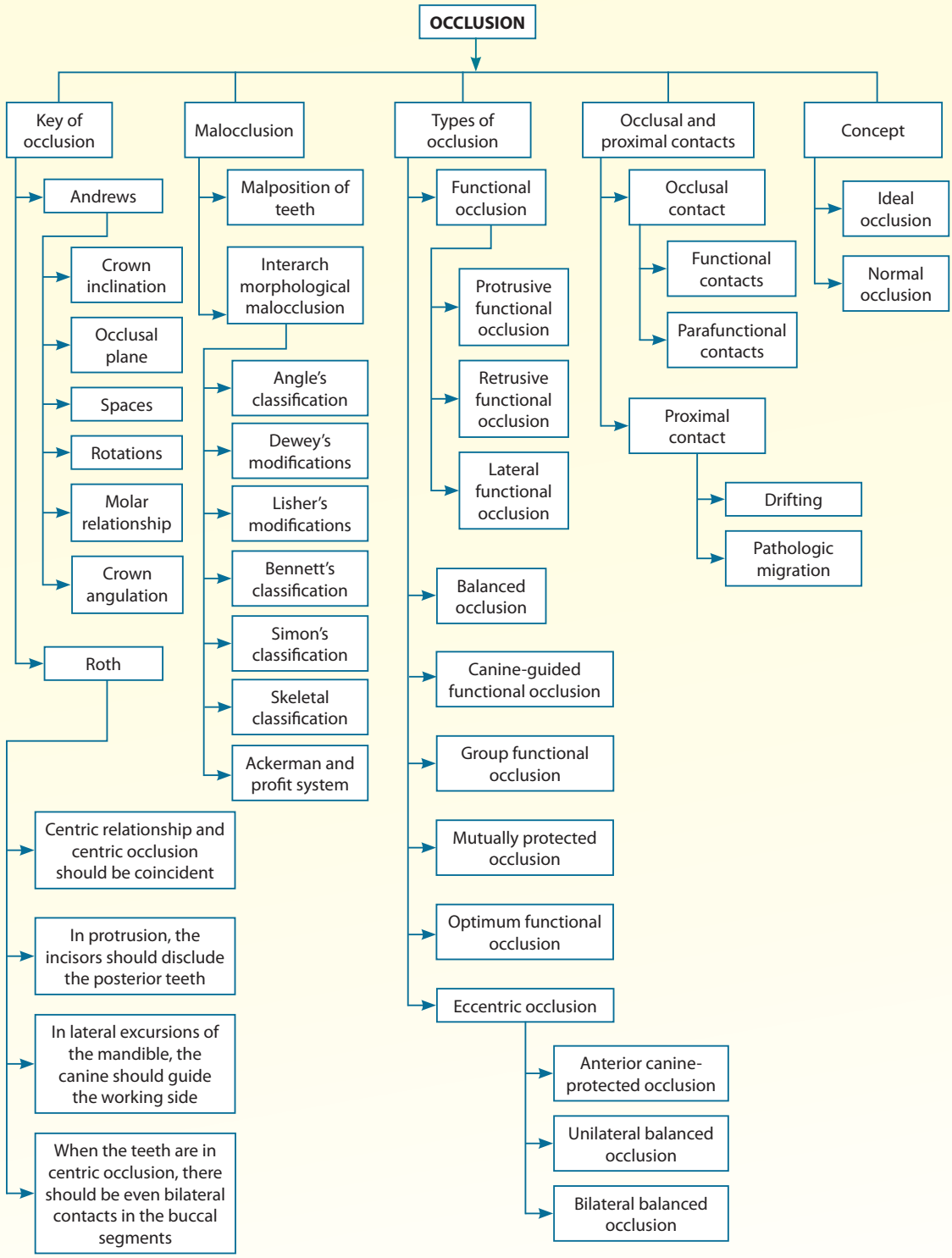
CONCLUSION

Evaluation and analysis of occlusion is important in the diagnosis and treatment of facial anomalies. Assessment of occlusion is necessary as a part of the initial oral examination to identify and eliminate gross occlusal discrepancies such as those that may inadvertently occur as a result of malpositioned teeth, skeletal malrelationship and restorative procedures.

Key Points

1. Occlusion is defined as the manner in which the occlusal surfaces of maxillary and mandibular teeth relate to each other in maximum intercuspation at all mandibular positions and movements.
2. Edward H. Angle described normal occlusion to the intercuspation of the mesiobuccal cusp of the maxillary first molar within the mesiobuccal groove of the mandibular first molar.
3. Andrews, six keys of occlusion and Roth's modification were done by taking into consideration the functional occlusion in addition to the static relationship of teeth.
4. Functional occlusion refers to the occlusal contacts of the maxillary and mandibular teeth which will provide the highest efficiency throughout all excursive movements of the mandible that occur during functions such as speech, mastication and deglutition.
5. Canine-guided functional occlusion, group functional occlusion and mutually protected functional occlusion are the three types of functional occlusion.
6. Malocclusion can be defined as an appreciable deviation from the acceptable relationship of the maxillary arch and/or teeth to the mandibular arch and/or teeth that may be considered aesthetically or functionally unsatisfactory.
7. Several types of malocclusion classifications have been proposed. Of this, Angle's classification based on the first static molar relationship is universally accepted with modifications by researchers later.
8. Removable appliances, functional appliances and fixed appliances are used to treat class I, II and III malocclusion.

Mind Map


OCCLUSION
Key of occlusion
Andrews
Crown inclination
Occlusal plane
Spaces
Rotations
Molar relationship
Crown angulation
Roth
Centric relationship and centric occlusion should be coincident
In protrusion, the incisors should disclude the posterior teeth
In lateral excursions of the mandible, the canine should guide the working side
When the teeth are in centric occlusion, there should be even bilateral contacts in the buccal segments
Malocclusion
Malposition of teeth
Interarch morphological malocclusion
Angle's classification
Dewey's modifications
Lisher's modifications
Bennett's classification
Simon's classification
Skeletal classification
Ackerman and profit system
Types of occlusion
Functional occlusion
Protrusive functional occlusion
Retrusive functional occlusion
Lateral functional occlusion
Balanced occlusion
Canine-guided functional occlusion
Group functional occlusion
Mutually protected occlusion
Optimum functional occlusion
Eccentric occlusion
Anterior canine-protected occlusion
Unilateral balanced occlusion
Bilateral balanced occlusion
Occlusal and proximal contacts
Occlusal contact
Functional contacts
Parafunctional contacts
Proximal contact
Drifting
Pathologic migration
Concept
Ideal occlusion
Normal occlusion

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2. Profitt WR. Contemporary Orthodontics, 5th Edition. Elsevier; 2007.
3. Angle EH. Classification of malocclusion. Dental Cosmos. 1899;41:248–264.
4. Andrews LF. The six keys to normal occlusion. Am J Orthodon Dentofacial Orthop 1972;62(3):296–309.
5. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod 1958;28:112.

Multiple Choice Questions

1. Angles' class II malocclusion refers to
   (a) The mesiobuccal cusp of the maxillary first permanent molar occludes in the space between the mesiobuccal cusp of the mandibular first permanent molar and the distal aspect of the mandibular second premolar.
   (b) The distobuccal cusp of the maxillary first permanent molar occludes in the space between the mesiobuccal cusp of the mandibular first permanent molar and the distal aspect of the mandibular second premolar.
   (c) The mesiobuccal cusp of the maxillary first molar occludes in the buccal groove of the mandibular first permanent molar.
   (d) The mesiobuccal cusp of the maxillary first molar occludes in the interdental space between the distal cusps of the mandibular first molar and the mesial aspect of the mesial cusp of the mandibular second molar.
2. Andrews' six keys of occlusion include the following except:
   (a) Molar relationship
   (b) Crown angulation
   (c) Crown inclination
   (d) Crown proclination
3. An increase in the horizontal distance between the labioincisal surface of the mandibular incisors and the linguoincisal surfaces of the maxillary incisors
   (a) Deepbite
   (b) Overjet
   (c) Overbite
   (d) Crossbite
4. The types of functional occlusion that are used in patients with lack of adequate periodontal support to cuspid teeth are
   (a) Group functional occlusion
   (b) Canine-guided functional occlusion
   (c) Mutually protected functional occlusion
   (d) Both a and c
5. Class III canine relationship refers to
   (a) Mesial incline of the maxillary canine overlaps the distal slope of the mandibular canine.
   (b) Distal slope of the maxillary canine occludes or contacts the mesial slope of the mandibular canine.
   (c) The lower canine is displaced anterior to the maxillary canine with no overlapping of the maxillary and mandibular canines.
   (d) Both a and b

CHAPTER 21

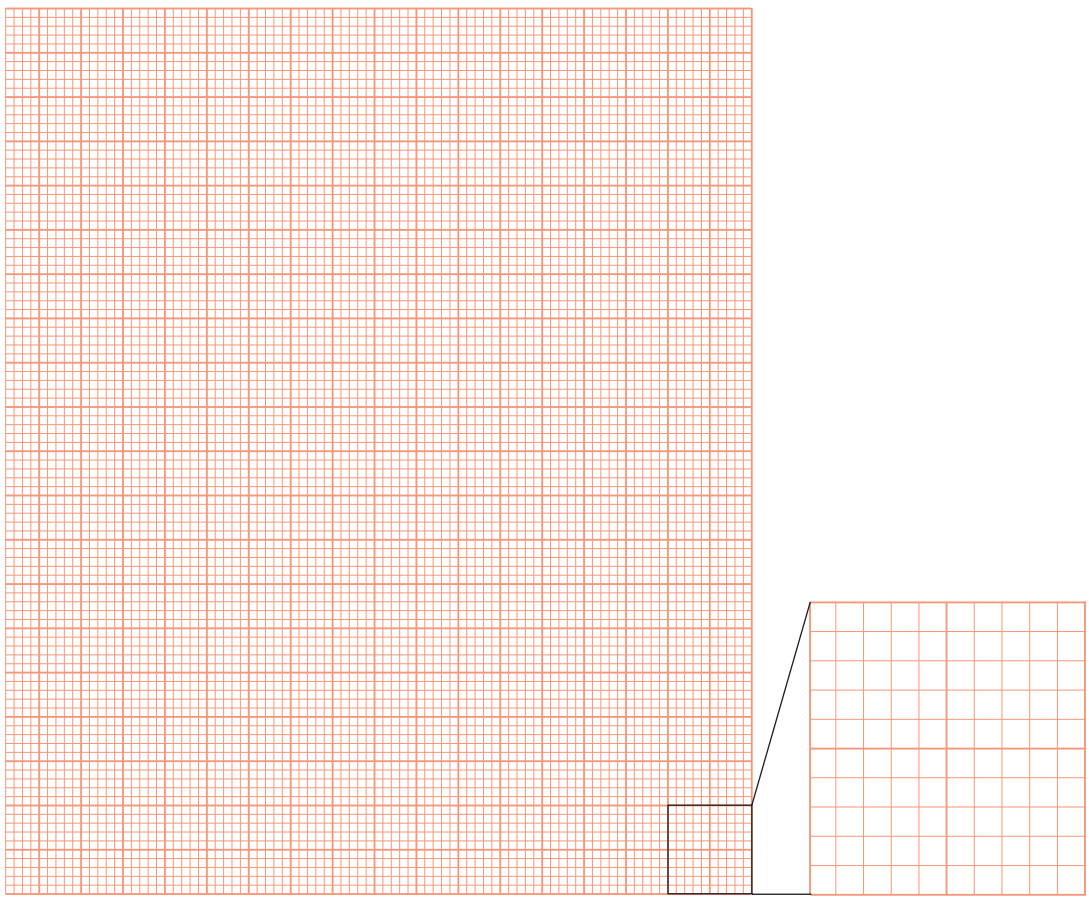


Guidelines for Drawing Tooth Morphology Diagrams

Sketching the outline of a tooth is an important process of learning tooth morphology. It enhances the sensory integration for improved retention of the characteristics of tooth.

The guidelines are as follows:

1. Tooth measurements are given in millimetre units.
2. This has to be transferred to a graph paper for accurate reproduction.
3. Description of a graph sheet: Every sheet consists of 520 1 cm^2 (26 × 20). Each square has a total of hundred 1 mm^2 (10 × 10)
4. Based on the dimensions, the outline is drawn.
5. If the length to be drawn is 10 mm, then 10 squares measuring 1 mm each are taken and marked. Further, the width is also marked accordingly.

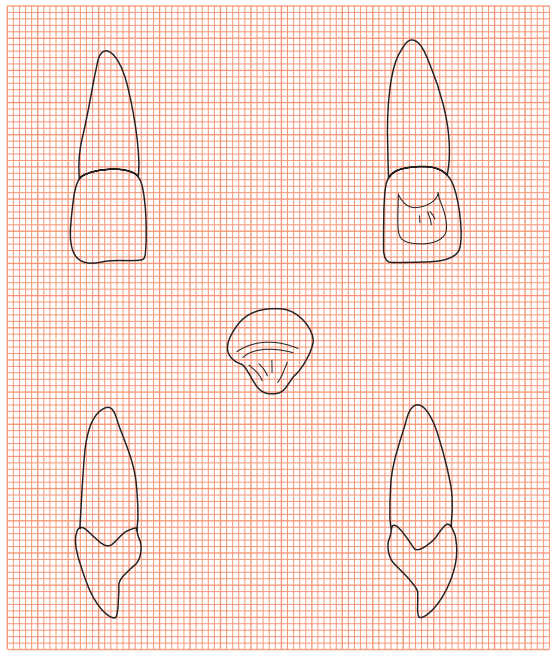


Model of a graph sheet with enlarged 1 cm square

SKETCHING A MAXILLARY RIGHT CENTRAL INCISOR

The dimensions of maxillary central incisors are as follows (*see* Fig. 13.1):

1. Length of the crown: 10.5 mm
2. Length of the root: 13 mm
3. Mesiodistal width of the crown: 8.5 mm
4. Mesiodistal width of crown at cervix: 7.0 mm
5. Labiolingual width of the crown: 6.0 mm
6. Labiolingual width of the crown at cervix: 7.0 mm
7. Depth of curvature at the mesial aspect: 3.5 mm
8. Depth of curvature at the distal aspect: 2.5 mm

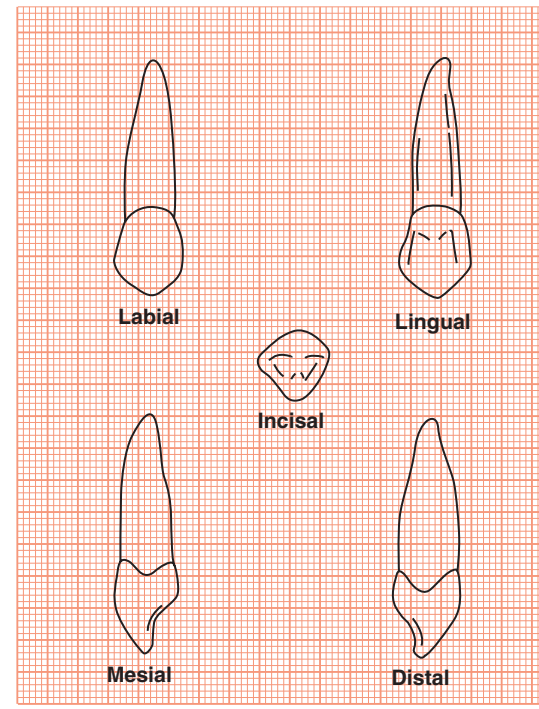


Graphical representation of maxillary right central incisor

SKETCHING A MAXILLARY RIGHT CANINE

The dimensions of maxillary canines are as follows (*see* Fig. 14.1):

1. Length of the crown: 10 mm
2. Length of the root: 17 mm
3. Mesiodistal width of the crown: 7.5 mm
4. Mesiodistal width of the crown at cervix: 5.5 mm
5. Labiolingual width of the crown: 8.0 mm
6. Labiolingual width of the crown at cervix: 7.0 mm
7. Depth of curvature at the mesial aspect: 2.5 mm
8. Depth of curvature at the distal aspect: 1.5 mm



Graphical representation of maxillary right canine

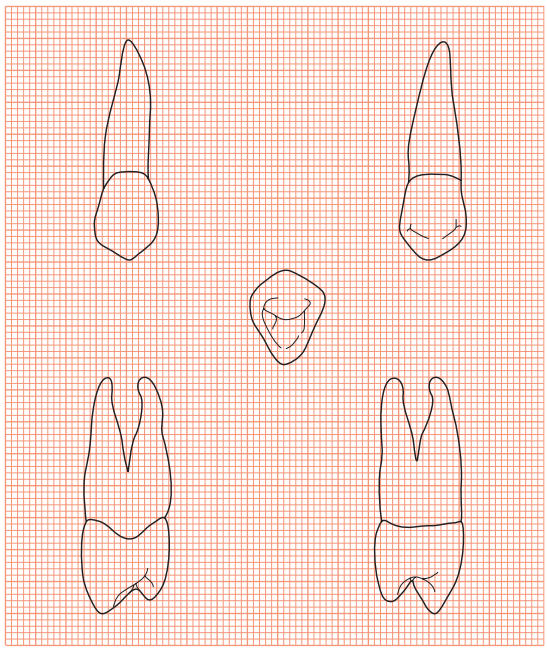
SKETCHING A MAXILLARY RIGHT FIRST PREMOLAR

The dimensions of maxillary first premolars are as follows:

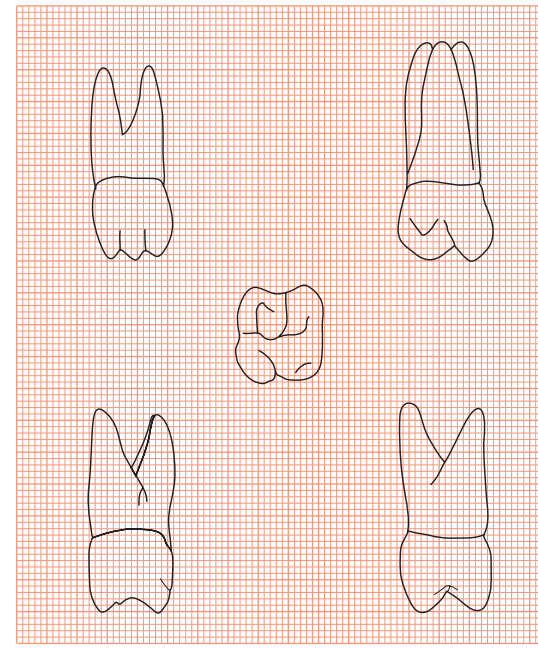
1. Length of the crown: 8 mm
2. Length of the root: 14 mm
3. Mesiodistal width of the crown: 7.0 mm
4. Mesiodistal width of the crown at cervix: 5.0 mm

5. Buccolingual width of the crown: 9.0 mm
6. Buccolingual width of the crown at cervix: 8.0 mm
7. Depth of curvature at the mesial aspect: 1.0 mm
8. Depth of curvature at the distal aspect: 0 mm

5. Buccolingual width of the crown: 11.0 mm
6. Buccolingual width of the crown at cervix: 10.0 mm
7. Depth of curvature at the mesial aspect: 0.7 mm
8. Depth of curvature at the distal aspect: 0.3 mm



Graphical representation of maxillary right first premolar



Graphical representation of maxillary right first molar

SKETCHING A MAXILLARY RIGHT FIRST MOLAR

The dimensions of maxillary first molars are as follows:

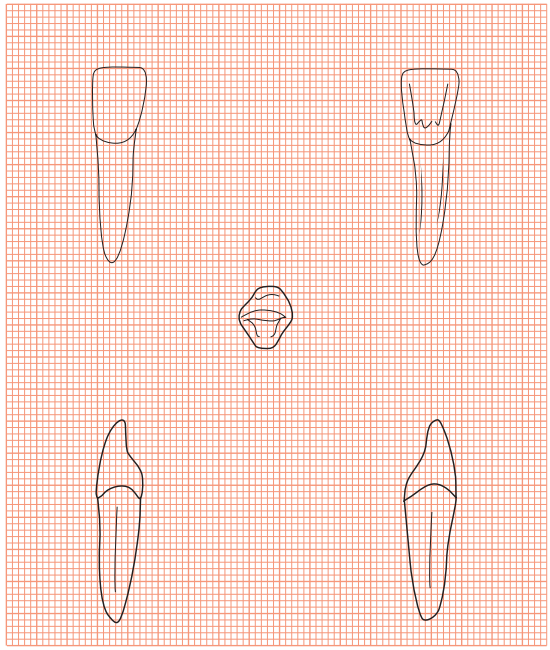
1. Length of the crown: 7.5 mm
2. Length of the root: (i) mesiobuccal: 12.9 mm, (ii) distobuccal: 12.2 mm, (iii) palatal: 13.7 mm
3. Mesiodistal width of the crown: 10.0 mm
4. Mesiodistal width of the crown at cervix: 8.0 mm

SKETCHING A MANDIBULAR LEFT CENTRAL INCISOR

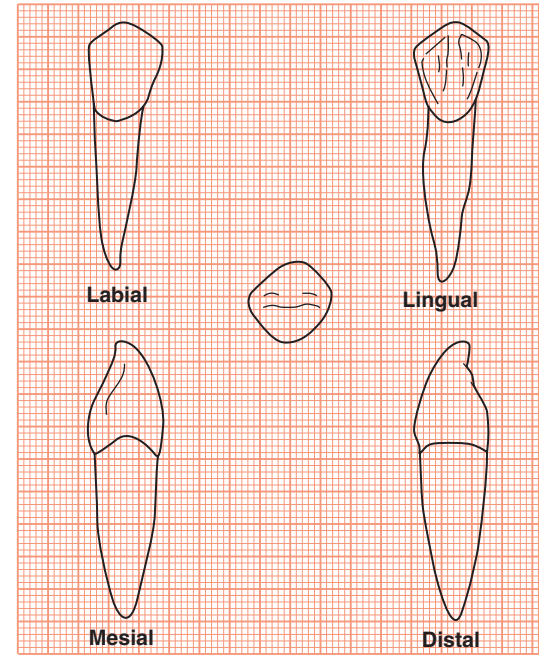
The dimensions of mandibular central incisors are as follows:

1. Length of the crown: 9.0 mm
2. Length of the root: 12.5 mm
3. Mesiodistal width of the crown: 5.0 mm
4. Mesiodistal width of crown at cervix: 3.5 mm
5. Labiolingual width of the crown: 6.0 mm
6. Labiolingual width of the crown at cervix: 5.3 mm

7. Depth of curvature at the mesial aspect: 3 mm
8. Depth of curvature at the distal aspect: 2 mm



Graphical representation of mandibular left central incisor



Graphical representation of mandibular left canine

SKETCHING A MANDIBULAR LEFT CANINE

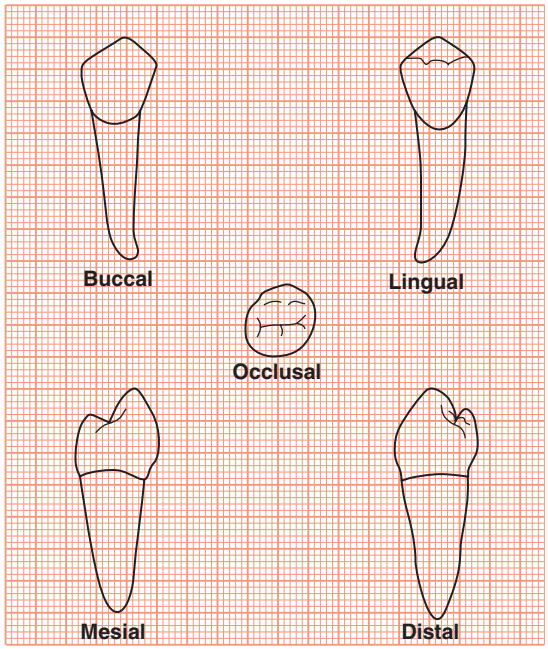
The dimensions of mandibular canines are as follows:

1. Length of the crown: 11 mm
2. Length of the root: 16 mm
3. Mesiodistal width of the crown: 7 mm
4. Mesiodistal width of the crown at cervix: 5.5 mm
5. Labiolingual width of the crown: 7.5 mm
6. Labiolingual width of the crown at cervix: 7.0 mm
7. Depth of curvature at the mesial aspect: 2.5 mm
8. Depth of curvature at the distal aspect: 1 mm

SKETCHING A MANDIBULAR LEFT FIRST PREMOLAR

The dimensions of mandibular first premolars are as follows:

1. Length of the crown: 8.5 mm
2. Length of the root: 14 mm
3. Mesiodistal width of the crown: 7 mm
4. Mesiodistal width of the crown at cervix: 5 mm
5. Labiolingual width of the crown: 7.5 mm
6. Labiolingual width of the crown at cervix: 6.5 mm
7. Depth of curvature at the mesial aspect: 1.0 mm
8. Depth of curvature at the distal aspect: 0 mm

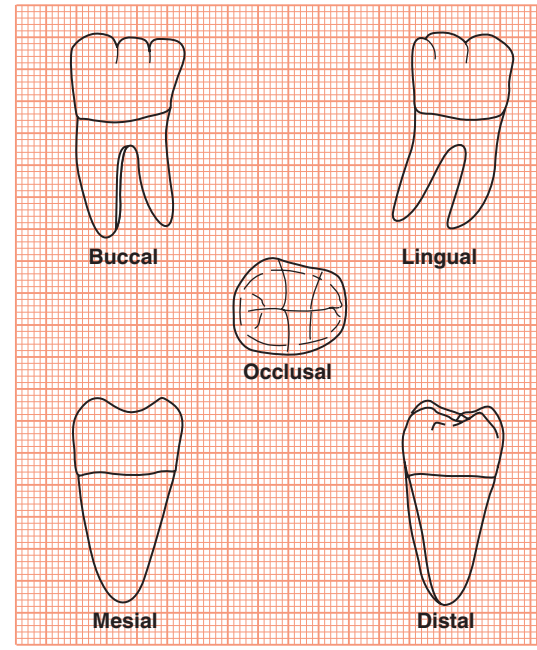


Graphical representation of mandibular left first premolar

SKETCHING A MANDIBULAR LEFT FIRST MOLAR

The dimensions of mandibular first molars are as follows:

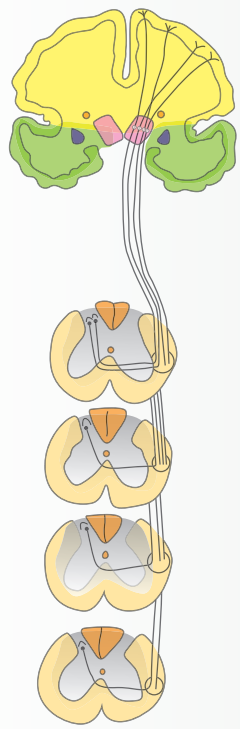
1. Length of the crown: 7.5 mm
2. Length of the root: 14 mm
3. Mesiodistal width of the crown: 11 mm
4. Mesiodistal width of the crown at cervix: 9 mm
5. Labiolingual width of the crown: 10.5 mm
6. Labiolingual width of the crown at cervix: 9 mm
7. Depth of curvature at the mesial aspect: 1.0 mm
8. Depth of curvature at the distal aspect: 0 mm



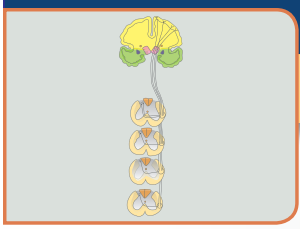
Graphical representation of mandibular left first molar

SECTION III

Oral Physiology



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CHAPTER 22

Somatosensory System

Overview

The somatosensory system is composed of sensory receptors and end organs, peripheral afferent neurons and neurons associated with the central nervous system. The receptors of the somatosensory system can be broadly classified into nociceptors, mechanoceptors and thermoreceptors which respond to pain, mechanical alteration and temperature, respectively. The impulses traverse to the first-order neurons located in the dorsal root ganglion and further reach the second-order neurons in the medulla. Third-order neurons transmit impulses from the ventral posterior lateral (VPL) nucleus and the ventral posterior medial (VPM) nucleus to cortical sensory areas (primary and secondary somatosensory cortex) via the trigeminothalamic tract.

INTRODUCTION

The oral cavity is a compound organ consisting of teeth, muscle, glands, several specialized somatosensory receptors and end organs. This somatosensory system notifies us regarding the substances in the external environment through sensations of touch, position, movement of our body (proprioception) and changes in the temperature of the surroundings. The sensory information transverses through different anatomical pathways in human body to produce a reflex process. This chapter focuses on the somatosensory receptors, pathways and their relevance in the oral cavity.

SENSORY FUNCTION—FACE AND ORAL CAVITY

Somatosensory innervation of the oral cavity is primarily carried by the trigeminal nerve (maxillary and mandibular branches) and glossopharyngeal nerve. The trigeminal nucleus supplying the facial tissues lies at the midpontine level. Neurons with somatosensory function (sensory root) passes into the trigeminal ganglion (semilunar ganglion) located in the middle cranial fossa at the base of the skull near the apex of the petrous portion of the temporal bone. These pseudounipolar neurons send out a single axon that bifurcates into two neurites: one innervating the periphery and the other connecting to the brainstem (**Fig. 22.1**):

1. The *maxillary nerve* arising from foramen rotundum and infraorbital canal of the skull supplies palate *(nasopalatine nerve, greater petrosal nerve* and *lesser petrosal nerve—branches of the maxillary nerve*), vestibular mucosa, teeth and associated periodontium of the maxilla.
2. The *mandibular nerve* arising from foramen ovale supplies cheek mucosa, anterior two-third of the tongue *(lingual nerve—branch of the mandibular nerve)*, vestibular mucosa, teeth and associated periodontium of the mandible.
3. Other nerves include glossopharyngeal nerve (posterior region of the tongue and oropharynx) and chorda tympani nerve (branch of the facial nerve)—special sensation of the anterior two-third of the tongue.

The oral cavity displays greater tactile sensitivity of oral structures in the anterior region than in the posterior region with fine discriminative ability. The tearing and piercing functions of the anterior teeth require greater sensory control than the crushing or grinding function associated with the posterior teeth.

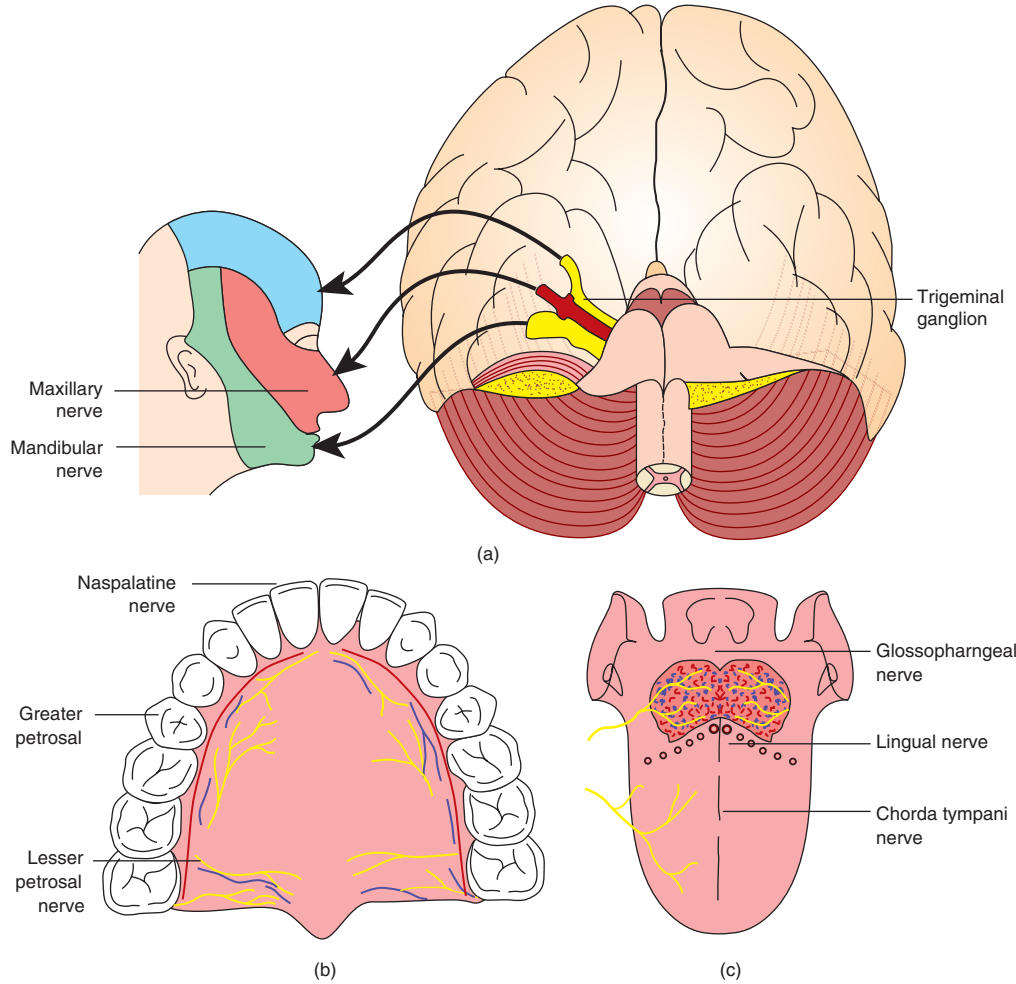


Figure 22.1 Somatosensory innervation of the face and mouth.

SOMATOSENSORY SYSTEM

The somatosensory system is a multifaceted system of nerve cells that responds to changes on the surface or internal state of the body. This system is concerned with the sensitivity of pressure, pain, temperature, touch, position, movement and vibrations which arise from stimuli evoking the muscles, joints, skin and mucosal tissues. Nerve cells (sensory receptors) send impulses along a chain of neurons connecting to the spinal cord where they may be processed by other nerve cells and transmitted to the sensory cortex for further processing. These specialized receptors are present in various parts of the body including the skin, skeletal muscles, bones, joints and internal organs.

Structure of the Somatosensory System

The somatosensory system is composed of sensory receptors and end organs, peripheral afferent neurons and neurons associated with the central nervous system. The general somatosensory pathway exhibits a three-neuron system—primary, secondary and tertiary (or first, second and third)—that relays peripheral sensations via pathways through the spinal cord, brainstem, thalamus and sensory cortex.

Mechanism of Somatosensation

Activation of a specific receptor by a stimulus

↓

Alteration in the ionic permeability—receptor potential of the nerve endings resulting in action potential (transformation of stimulus to electric signal—sensory transduction)

↓

Impulses reach the central nervous system via cranial/spinal nerve fibres (first-, second- and third-order neurons)

↓

Ascending sensory tract (general somatic pathways—touch, pressure, vibration, pain, temperature and position/general visceral afferent pathways—temperature and visceral pain/dorsal column medial lemniscal pathways—discrimination, vibration, position)

↓

Functional integration of sensory impulses via ascending somatosensory pathways, cerebral somatosensory cortex and descending pathways produces reflex response

TYPES OF STIMULI

Stimuli are of the following three types:

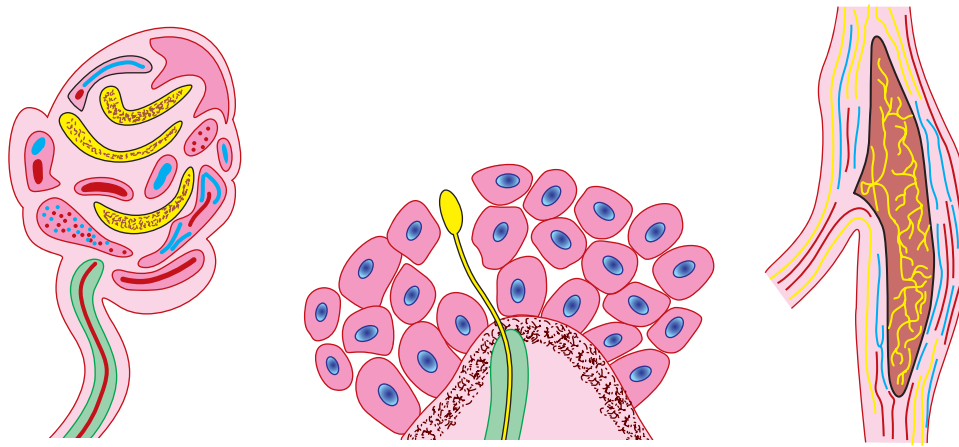
1. **Tactile stimuli**: They are peripheral forces in bodily contact with the skin that give rise to the sensations of touch, vibration or pressure.
2. **Proprioceptive stimuli**: They are internal forces that are generated by the change in position or movement of a body part critical for maintaining posture and balance.
3. **Pain stimuli**: They are tissue-damaging sources of energy that may be external or internal to the body surface. Sharp pain followed by a dull burning pain may follow tissue injury and inflammation.

SOMATOSENSORY RECEPTORS AND END ORGANS

Somatosensory receptors and end organs form the basic component of the somatosensory system of the human body.

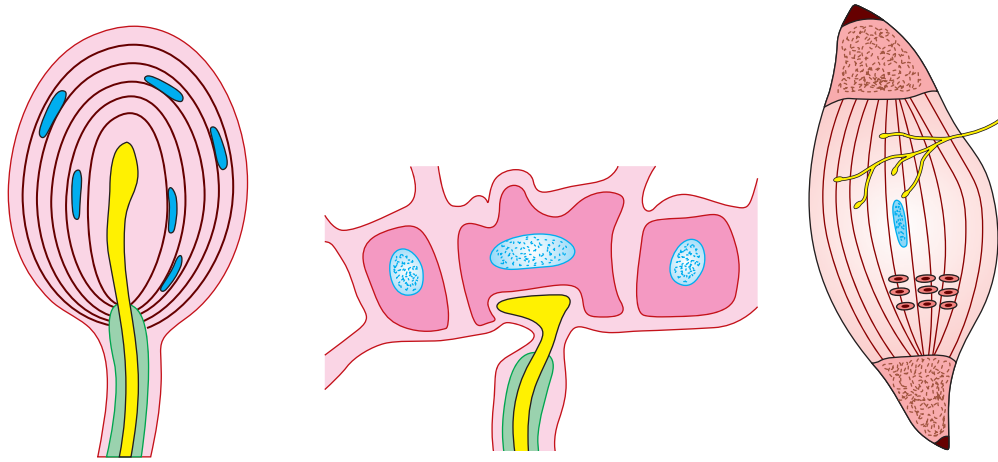
Somatosensory Receptors (Fig. 22.2)

Somatosensory receptors are specific sensory receptor cells (modified neurons/modified epithelial cells) that produce receptor potentials and synapses and helps release neurotransmitters for an effective reflex process to occur. Peripheral axons of the somatosensory primary (1°) afferents end to the surfaces adjoining the somatosensory receptors. This complex of encapsulated tissue with afferent neurons and specific somatosensory receptor plays a crucial role in the receptor transduction process. The sensitivity of the receptors to stimuli is determined by the location of the receptor and the non-neural tissue surrounding the primary afferent terminal.



(a) (b) (c)

Figure 22.2 Somatosensory receptors: (a) Meissner's corpuscle, (b) free nerve ending, (c) Ruffini's corpuscle. (*Continued*)



(d) (e) (f)

Figure 22.2 (*Continued*) Somatosensory receptors: (d) Pacinian corpuscle, (e) Merkel cell receptor, (f) Golgi tendon organs and muscle spindle.

Classification of Somatosensory Receptors (Table 22.1)

Based on the Velocity

1. **Rapidly adapting receptor**: Fast receptor response on discontinuation of the stimulus.
2. **Slowly adapting receptor**: Receptor response only in the presence of stimulus.

Based on the Source of Origin

1. **Exteroceptors**: They transmit sensory impulses from the interface between the body and stimuli from the external environment (e.g. gustatory and tactile sensation)
   (a) *Teloreceptors*: Response of the body to distant stimuli in the absence of physical contact.

Table 22.1 Classification of Somatosensory Receptors Based on the Morphology, Anatomic Location and Function

Types	Morphology	Location	Function
Nociceptors			
Free nerve endings Rapidly adapting receptors	Axon terminals devoid of myelin sheath **Mechanosensitive** (response to pain by A-delta fibres) **Thermosensitive** (response to intense cold/heat by A-delta fibres) **Polymodal C fibres** (sensitive to noxious stimuli)	Epithelium, lamina propria, submucosal connective tissues	Peripheral extensions of myelinated A-delta and C fibres mediate sensation in response to chemical, mechanical and thermal stimuli (temperature, pain and touch)

(*Continued*)

Table 22.1 *(Continued)*

Types	Morphology	Location	Function
Mechanoreceptors			
Non-encapsulated mechanoreceptors (absence of the myelin sheath) *Free nerve endings*: Receptors in epidermis, dermis, pulp, cornea, oral mucosa, muscles, tendon, ligament associated with touch, pain, pressure *Peritrichial nerve endings*: Hair follicle of the sebaceous gland *Tactile receptors*: Merkel cell of the basal layer			
Encapsulated mechanoreceptors (presence of the myelin sheath)			
Meissner's corpuscles • Fast adapting mechanoreceptor (most common mechanoreceptors)	Whirl-like elongated layered cells associated with A-beta fibres encapsulating receptor arising from single central nerve with Schwann cell covering and connective tissue capsule	Dermal papillae of lip, anterior palate, gingiva and connective tissue papilla of dorsum of tongue (fungiform papillae)	Two-point discrimination Transmits information on low-frequency vibration Touch: Flutter and movement
Pacinian corpuscles • Fast adapting mechanoreceptor	Largest mechanoreceptors Encapsulated cells with layered structures related to myelinated A-beta fibres surrounded by an onion-like connective tissue capsule in which the inner core of membrane lamellae is separated from an outer lamella by a fluid-filled space	Dermis and hypodermis of fingers, palms, soles, joint membranes, interosseous membranes, peritoneum	Sensitive to pressure, high frequency vibrations, tickling sensations and sudden displacements of the skin Touch: Vibration
Ruffini corpuscles • Slow adapting mechanoreceptor	Cigar-shaped encapsulated cells with A-beta fibres running at their termination forms branches parallel to collagen fibres and the surrounding lamellated cellular capsule	Temporomandibular joint, periodontal ligament, periosteal tissues, dermis and tendons, hypodermis of skin	Stretching of collagen fibres in skin and mucosa—proprioception Touch: Skin stretch
Proprioceptive receptors (muscles, tendons, joint ligaments and joint capsules)			
Muscle spindles	Encapsulated annulospiral and flower spray endings Extrafusal fibres: Muscle contraction Infrafusal fibres: Possess 2–12 infrafusal fibres with an outer fusiform connective tissue capsule attached to the connective tissue sheath of extrafusal fibres	Striated muscles	Sensory function from the skeletal muscle to spinal cord and cerebellum for monitoring motor function and length (movement, position, orientation of body parts)

(*Continued*)

Table 22.1 *(Continued)*

Types	Morphology	Location	Function
Golgi tendon organs: Fusiform-shaped receptors are located at the junction of muscle tendons that initiate coordination of muscle tension			
Other receptors			
Merkel cell Slow adapting mechanoreceptor	Specialized epidermal cell producing neuroendocrine granules, chromogranin A and neural cell adhesion molecule via several cytoplasmic processes interdigitating with cytoplasm of keratinocytes *(Merkel cell—neurite complex)*	Gingiva, buccal mucosa and hard palate (basal and spinous layers of epithelium)	Sensory function for static discrimination to detect shapes, edges and texture/ size of a particle during mastication and chewing process
Nuclear bag fibres and *nuclear chain fibres* *Hair follicles*: Touch and movement			
Thermoreceptors			
Thermoreceptors	*Cold receptors*: Free nerve endings of myelinated A-delta fibres *Warm receptors*: Free nerve ending of C fibres *Temperature sensitive nociceptors*: Sensitive to extreme changes of heat or cold	Tongue, cheeks and lips	Sensitive to warmth/ cold

(b) *Contact receptors*: Response of the body to direct contact with the stimulus.

2. **Interoceptors**: They relate the body's sensory information regarding the state of the body's internal environment (e.g. stretch function)
3. **Proprioceptive receptors**: They transmit sensory impulses due to a change in the body position.

Meissner's corpuscles, Pacinian corpuscles, Merkel cells and Ruffini's corpuscle receptors are collectively referred to as low-threshold (high-sensitivity) mechanoreceptors because even weak mechanical stimulation of the mucosa induces them to produce action potentials. All low-threshold mechanoreceptors are innervated by relatively large myelinated axons, ensuring the rapid transmission of tactile information.

Somatosensory Receptor End Organ

Somatosensory receptors (**Tables 22.2** and **22.3**) are located on the specialized sensory receptor organs or within a circumscribed portion of the body (taste buds in the mouth/touch on face, muscles and joint act as proprioception receptor organs). These sensory receptor organs 'stock' the somatosensory receptors and transport the impulses to the central nervous system.

Table 22.2 Mechanism of the Action of Somatosensory Receptors

Nociceptors	• Activation of A-delta (fast pain) or C fibres (slow diffuse pain) in response to stimuli with activation of nociceptors and central nervous system results in release of neurotransmitter and associated inflammation
Mechanoreceptors	• Mechanical displacement of epithelium (touch, pressure, stretch vibration) with amplification of cytoplasmic process discharges neurotransmitter granules resulting in activation of nerve endings and simultaneous excitation of muscles of mastication • Response to kinaesthetic changes in facial muscles (muscle contractions) on application of slow pressure leads to excitation of muscles • Alternate slow and fast adapting receptors
Thermoreceptors	• Activation of A-delta (fast pain) or C fibres (slow diffuse pain) in response to thermal stimuli with activation of thermoreceptors and central nervous system result in release of neurotransmitter and reflex response

Table 22.3 Classification of Peripheral Nerve Fibres Associated with Somatosensory Receptors Based on Anatomic Location and Electrophysiological Properties

Types	Location/Function				
Type I A-alpha fibres	Muscle spindles Golgi tendon organs Motor neurons to muscle spindles				
Type II A-beta and A-gamma fibres	Muscle spindles Low adaptation receptors to muscle spindles				
	Type 1	Rapidly adapting receptor II (RA II)	Rapid detector of vibration and deformation	Pacinian corpuscle	Large receptive field with an ill-defined boundary
	Type 2	Rapidly adapting receptor I (RA I)	Slow movements	Meissner corpuscle	Encapsulated nerve ending with a small receptive field
	Type 3	Slow adapting receptor I (SA I)	Two-point discrimination and spatial orientation	Merkel cell	Small receptive field
	Type 4	Slow adapting receptor II (SA II)	Proprioception—static and stretch displacement	Ruffini corpuscle	Large receptive field with an ill-defined boundary—skin over the joints and ligaments
Type III A-delta fibres	Response to mechanical, thermal and chemical stimuli				
Type IV B and C fibres	C nociceptors—high response to mechanical, thermal and chemical stimuli C mechanoreceptors—slow brushing, scratching and stretching movements of skin				

Note: Among the following types of fibres, 'A' has the largest and fastest axons while 'C' has the smallest and slowest axons.

NEURAL PATHWAYS

The mechanism of neural pathways is described in the following text.

Dorsal Root Ganglion

The somatosensory innervations are transmitted via the peripheral nerves to the dorsal root ganglion, which houses cell bodies of the first-order neuron (primary afferent neurons) for the somatosensory system. The fibres split into two functional groups: (i) lateral set (or the anterolateral system) and (ii) medial set (or the dorsal column-medial lemniscal system). This cell body gives rise to a single process that divides to form a peripheral axon (peripheral tissues) and a central axon (central nervous system). The lateral group mainly carries unmyelinated fibres that subserve pain and temperature sensations, whereas the medial group mainly carries myelinated fibres that convey proprioceptive impulses. The sensation of touch is mediated by both systems.

The tissue immediate to the somatosensory primary afferent helps to concentrate and deliver the stimulus onto the primary afferent terminal membrane. These receptors transduce the applied force/stimuli into an electrical potential in the primary afferent neuron. The mechanoreceptor of primary afferent terminal membrane contains ion channels that react to mechanical deformation by increasing sodium and potassium conductance through voltage-sensitive channels. Generator potentials are produced as sodium and potassium flow down their electrochemical gradients to depolarize the terminal ending.

SOMATOSENSORY PATHWAYS

Somatosensory pathways for the head and neck region are described in the following text.

Sensory Transduction

The somatosensory system sends information from each side of the body to the cortex along two major pathways: (i) *dorsal-column medial-lemniscus system* (touch and proprioception with the first synapse in the dorsal column nuclei of the medulla) and (ii) *anterolateral system* (ALS). Pain and temperature are sensed following the synapse in the spinal cord via three tracts:

1. Spinal cord to thalamus (spinothalamic)
2. Spinal cord to reticular formation (spinoreticular) and spinal cord to midbrain
3. Spinotectal pathways

The anterior trigeminothalamic pathway carries similar signals that originate from the receptors on the structures of the oral cavity, teeth and facial region. These are relayed through brainstem and thalamic nuclei to face areas of the sensory cortex (**Fig. 22.3**).

Note: The neospinothalamic pathway carries impulses from the spinal cord across lateral thalamus to the somatosensory cortex. The paleospinothalamic pathway carries impulses across the spinal cord to reticular formation, medial thalamus and finally cingulate, frontal and limbic cortices of the brain. The various levels of neurons positioned within the central nervous system are as follows:

1. **First-order neurons:** The cell bodies of the first-order neurons housed in dorsal root ganglia (trigeminal ganglion) transmit impulses through the spinal nerve in an ipsilateral/contralateral manner after receiving the signal from somatosensory receptors via the sensory afferents.
2. **Second-order neurons:** The cell bodies of the second-order neurons present in the medulla (gracile and cuneate nuclei) transfer impulses received from various anatomic locations of the spinal cord for the fibres carrying pain, touch and temperature sensations to the thalamus or cerebellum.
3. **Third-order neurons:** The cell bodies of third-order neurons transmit impulses from the ventral posterior lateral (VPL) nucleus and the ventral posterior medial (VPM) nucleus (trigeminal lemniscus) to cortical sensory areas (primary and secondary somatosensory cortices) via the trigeminothalamic tract.

Note: The somatosensory cortex is organized in a sensory homunculus depicting genital and leg fibres medially and arm, hand, face, tongue fibres on the lateral surface of the somatosensory area. The trigeminal complex has two components: (i) principal

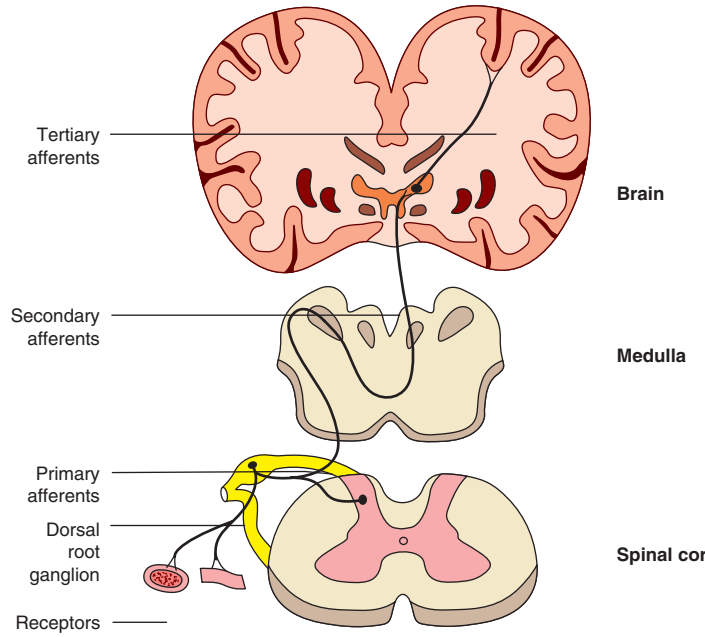


Figure 22.3 Signal transduction—somatosensory system.

nucleus (mechanosensory stimuli) and (ii) spinal nucleus (painful and thermal stimuli):

1. **Primary somatosensory cortex (S1)**: Postcentral gyrus (Brodmann area 3)—crude touch, pain and temperature
2. **Secondary somatosensory cortex (S2)**: Amygdala and hippocampus parietal ventral area—touch, pain, visceral sensation and tactile sensation

SOMATOSENSORY REFLEXES—ORAL CAVITY

Masticatory Reflex

The process of mastication and deglutition involves a high degree of coordination between numerous oral sensory and motor systems. A varied group of highly specialized sensory systems in conjunction with masticatory muscles guides these complex oromotor responses. Masticatory reflex refers to a cyclic process of jaw-closing reflex alternating with jaw-opening reflex.

Stages of Mastication

The stages of mastication are as follows:

1. **First stage:** Placement of food into the mouth (ingestion)
2. **Second stage:** Intraoral transport and the positioning of food between the molars
3. **Third stage:** Mastication
4. **Fourth stage:** Intraoral transport to the back of the tongue
5. **Fifth stage:** Deglutition (caudal region of the nucleus of the solitary tract and the medullary reticular formation)

Jaw-Closing Reflex

Stretching of muscle spindle afferents located on jaw-closing muscles (masseter, temporalis and medial pterygoid)

↓

Excitation of associated ipsilateral motoneurons

Impulses reach the central nervous system—mesencephalic trigeminal nucleus

↓

Functional integration of the impulses from the central nervous system—reflex response

Jaw-Opening Reflex

Presence of non-painful stimuli results in stimulation of mechanoreceptors located in the periodontal ligament, tongue and soft tissues of the mouth

↓

Impulses reach the central nervous system—mesencephalic trigeminal nucleus and trigeminal ganglion via central processes of primary afferent fibres

↓

Inhibition of jaw-closer motoneurons and excitation of jaw-openers muscles (anterior digastric muscles and the inferior head of the lateral pterygoid muscle)—reflex response

Lingual Reflex

Lingual reflex is elicited by stimulation of several afferent nerves (hypoglossal nerve) producing either protrusive or retrusive movements of the tongue using extrinsic and intrinsic muscles. This process provides protection to the tongue during mastication. Impulses are transmitted via these afferents to the trigeminal complex or nucleus of the solitary tract in the central nervous system.

Retrusive Movement

Electrical stimulation of the lingual nerve and glossopharyngeal nerves causes excitation of protruder and retractor motoneurons. Stimulation of lingual receptors innervated by the glossopharyngeal nerve elicits retrusive movements of the tongue.

Protrusive Movement

Contractions of extrinsic genioglossus, geniohyoid, intrinsic vertical and horizontal muscles produce tongue protrusion. Electrical stimulation of the superior laryngeal nerve innervating laryngeal mechanoreceptors results in excitation of protruder and retractor motoneurons. Stimulation of lingual receptors innervated by the superior laryngeal nerve on the pharyngeal regions also elicits protrusive movement of the tongue.

TASTE PATHWAYS

Taste pathways (gustatory system) possess several receptors (taste buds) arranged in clusters on the tongue that detect chemicals in the mouth. These taste buds are located around small protuberances termed 'papillae' to produce the following types of taste: sweet, sour, salty, bitter and umami. The sense of taste serves in both food selection and protection from noxious substances:

1. **Common chemical sensation**: Stimulation of the oral cavity by salts, acids, alkaloids and other compounds result in burning/painful sensation mediated by non-specialized free nerve endings. Responses to salivation and coughing remove offending stimuli from the mouth.
2. **Specialized taste sensations**: Sensations are induced by relatively low concentrations of chemical stimuli when applied to the specialized gustatory receptor cells.

Sweet taste—energy-rich nutrients, umami—amino acids and salty—electrolyte balance.

CLINICAL SIGNIFICANCE

1. **Peripheral neuropathy:** Deficiency of peripheral nerves of the somatosensory system resulting in paraesthesia, seizures and failure to identify thermal or pain sensation
2. **Aura:** Thermal and pain sensations precede the onset of an epileptic seizure.
3. **Jacksonian seizure:** An abnormal, localizable, cutaneous sensation in the absence of stimulus.
4. **Allodynia:** Improper activation of nociceptors results in acute, pathological pain.
5. **Astereognosia:** Inability to recognize objects by touch.
6. **Asomatognosia:** Failure to recognize the parts of one's own body
7. **Aguesia:** Loss of taste sensation
8. Injury to primary somatosensory cortex results in failure of proprioception or two-point tactile discrimination, and disruption of the anterolateral system can produce symptoms ranging from reduced sensibility

(hypaesthesia), numbness, tingling and prickling (paraesthesia) to complete loss of sensibility (anaesthesia).

ADDITIONAL READING

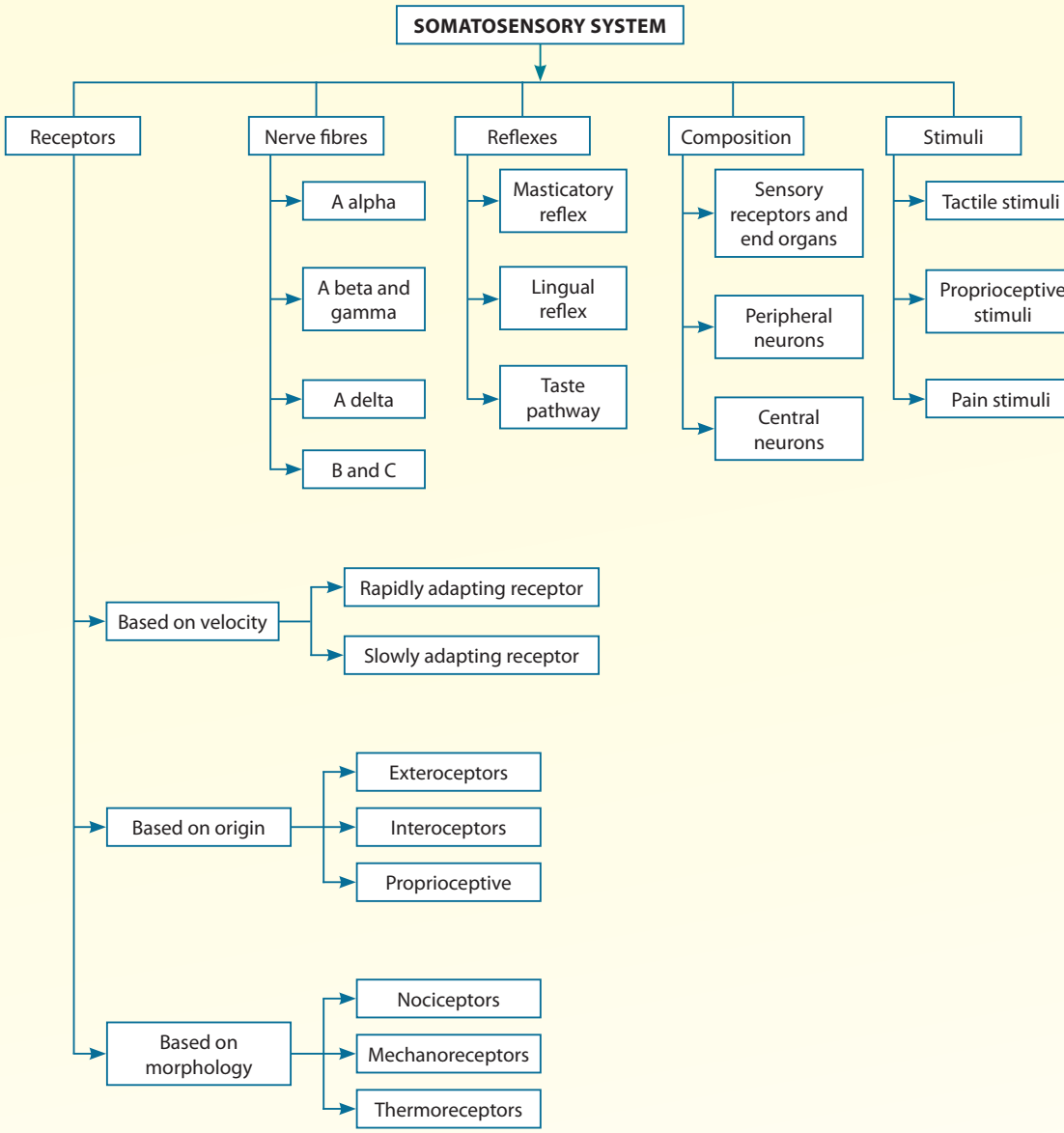
Quantitative Sensory Testing

Quantitative sensory testing (QST) is a valuable method for diagnosing peripheral nervous system disorders, including chronic pain and pain related to various diseases, such as diabetes. QST tests the function of large myelinated, thin myelinated and unmyelinated nerve fibres (and the corresponding central pathways), including the nociceptive fibres and the function of the spinothalamic tract, by application of thermal and mechanical stimuli of different qualities and intensities. QST represents a non-invasive method for quantitative assessment of the sensory perception in response to external stimuli of controlled intensity. Changes in pain sensitivity and somatosensory function can be characterized by QST. QST engages different innocuous and noxious stimuli producing distinct sensory perceptions in different somatosensory submodalities. Stimuli used in QST include touch, pressure, pinprick, thermal or vibratory stimuli. QST has been applied to a variety of conditions accompanied by somatosensory dysfunction such as peripheral neuropathies, complex regional pain syndromes or temporomandibular joint dysfunction.

Key Points

1. The somatosensory system notifies us regarding the substances in the external environment through sensations of touch, temperature, pressure, pain and proprioception through anatomical pathways.
2. Sensations of the head and neck are carried primarily by the trigeminal nerve (maxillary and mandibular branches) and glossopharyngeal nerve via ascending nerve pathways to higher centres of the central nervous system.
3. The somatosensory system is composed of (i) sensory receptors and end organs, (ii) peripheral afferent neurons and (iii) neurons associated with the central nervous system.
4. Nociceptors, mechanoreceptors and thermoreceptors serve the role to mediate various sensations in the human body.
5. Coordination of sensory and motor activity is essential for masticatory reflex, lingual reflex, pain reflex and taste pathways in the oral cavity.

Mind Map


SOMATOSENSORY SYSTEM
Receptors
Nerve fibres
Reflexes
Composition
Stimuli
A alpha
A beta and gamma
A delta
B and C
Masticatory reflex
Lingual reflex
Taste pathway
Sensory receptors and end organs
Peripheral neurons
Central neurons
Tactile stimuli
Proprioceptive stimuli
Pain stimuli
Based on velocity
Rapidly adapting receptor
Slowly adapting receptor
Based on origin
Exteroceptors
Interoceptors
Proprioceptive
Based on morphology
Nociceptors
Mechanoreceptors
Thermoreceptors

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Multiple Choice Questions

1. The chief sensory nerve supply of the face is the
   (a) Trochlear nerve
   (b) Trigeminal nerve
   (c) Facial nerve
   (d) Hypoglossal nerve
2. The following sensory receptors carry sensation of temperature only:
   (a) Mechanoreceptors
   (b) Nociceptors
   (c) Thermoreceptors
   (d) Periodontal receptors
3. All are encapsulated somatosensory receptors except
   (a) Meissner corpuscle
   (b) Ruffini corpuscle
   (c) Pacinian corpuscle
   (d) Free nerve endings
4. _____ nerve provides special sensation to the anterior two-third of the tongue.
   (a) Glossopharyngeal nerve
   (b) Hypoglossal nerve
   (c) Chorda tympani nerve
   (d) Lingual nerve
5. _____ papillae are non-gustatory.
   (a) Filiform
   (b) Fungiform
   (c) Circumvallate
   (d) Foliate

CHAPTER 23



Pain

Overview

The feeling of distress or suffering or agony caused by the stimulation of receptors is called pain. Free nerve endings are the receptors for pain which are connected to the pain fibres such as A-delta and C fibres that carry the pain impulses to the higher centres. Any noxious stimuli elaborate chemicals such as pain-producing substances, bradykinin and others which can stimulate the pain receptors and initiate pain.

INTRODUCTION

Pain can be defined as the feeling of distress or suffering or agony caused by the stimulation of receptors for pain. It is an unpleasant sensation.

Pain is a protective mechanism of the body. It occurs whenever any tissue is being damaged, and it causes the individual to react to remove the pain stimulus.

RECEPTORS

Free nerve endings are the receptors for pain. Receptors are connected to A-delta pain fibres and C fibres. These A and C fibres carry the pain sensation to the central nervous system. The A fibres are fast conductors and are responsible for acute pain, while the C fibres are slow conductors and are responsible for chronic pain.

INITIATION OF PAIN

The adequate stimuli for pain are the noxious tissue-damaging stimuli which may be mechanical, chemical, thermal or electrical. These stimuli lead to the release of some chemicals from the damaged tissues. These chemicals initiate pain through the stimulation of pain receptors.

The chemicals which are thought to stimulate pain receptors are as follows:

1. **Pain-producing substance (PPS):** It is a polypeptide produced from plasma proteins by the action of proteolytic enzymes released from the damaged tissue.
2. **Other chemicals** such as bradykinin, prostaglandins and cyclic AMP (adenosine monophosphate) also act as PPS.

PATHWAY OF PAIN

A-delta and C fibres carry the pain sensation from the receptors to the spinal cord via the dorsal root. First-order neurons are the cells in the dorsal nerve root ganglia. These neurons receive impulses of pain sensation from the pain receptors through their dendrites, and their axons reach the spinal cord.

A-delta fibres, after reaching the spinal cord, synapse with marginal cells in the grey horn, whereas C fibres synapse with the substantia gelatinosa of Rolando (SGR) in the posterior grey horn (**Figs 23.1** and **23.2**).

The marginal cells of the posterior grey horn and the cells of SGR form the second-order neurons. The fibres of second-order neurons cross to the opposite side in the anterior grey commissure, just in front of the central canal, and rise up in the opposite lateral white column as lateral spinothalamic tract. When more and more fibres join the tract from successive segments of spinal cord, fibres from lower segments are pushed laterally.

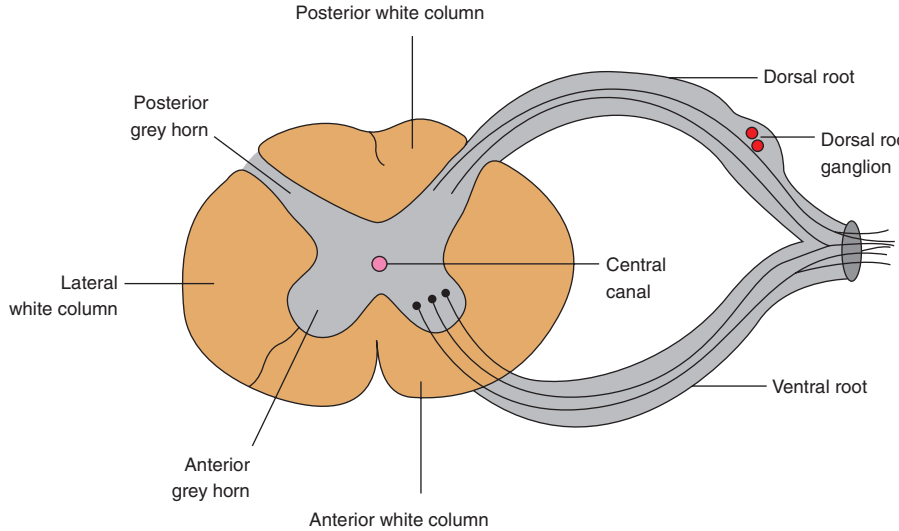


Figure 23.1 Cross-section of the spinal cord.

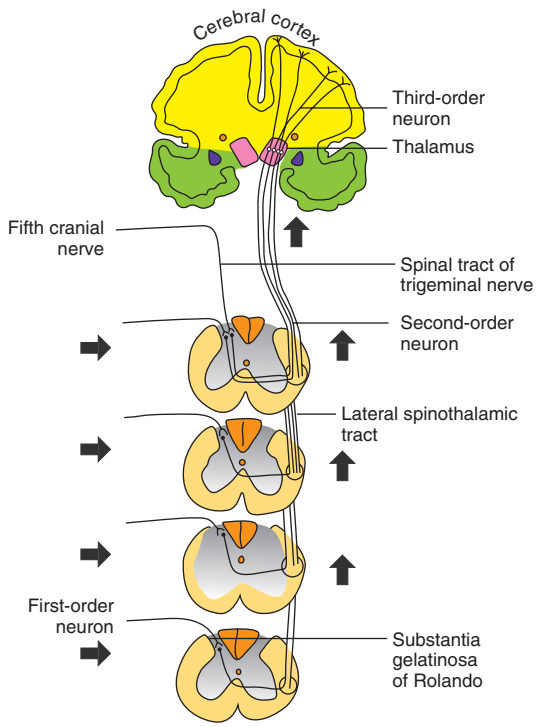


Figure 23.2 Pathway of pain.

Lateral spinothalamic tract continues as spinal lemniscus in the brain stem and ends in the ventral posterolateral (VPL) nucleus of the thalamus.

The third-order neurons start at the thalamus and via the internal capsule reach areas 3, 1 and 2 of the primary sensory cortex.

Orofacial Pain

Pain sensation from the face, oral cavity and nose is carried by the trigeminal nerve.

The tooth pulp is innervated by neurons with cell bodies in the trigeminal ganglion and central terminations in the trigeminal primary sensory and spinal nuclei. The primary sensory nucleus is situated in the pons and the spinal nucleus is situated below primary sensory nucleus and extends up to the upper segments of spinal cord. The axons of these nerves reach the teeth in the maxillary and mandibular branches of the trigeminal nerve.

The fibres carrying the pain sensation from tooth, oral cavity, ear and nose to the spinal cord form the spinal tract of the trigeminal nerve. This tract reaches the first two segments of the spinal cord to end in the spinal nucleus of the trigeminal nerve in posterior grey horn. The second-order neurons start from the spinal nucleus and end in the ventral posterior medial nucleus of the thalamus. The third-order neurons start from the thalamus and reach areas 3, 1 and 2 of the sensory cortex (**Fig. 23.3**).

Applied Physiology

Acute Pain

It is a protective mechanism that alerts the individual to a condition or experience that is immediately harmful to the body.

Chronic Pain

It is persistent or intermittent and usually lasts for at least 6 months.

Hyperalgesia

Excessive sensitiveness to pain is called hyperalgesia. It is noticed around an injury or inflammation due to the release of certain chemicals which decrease the threshold of pain receptors and increase pain sensitivity.

Pain in Thalamic Syndrome

A patient suffers from acute attacks of pain without any obvious stimulus. This type of pain is due to lesions anywhere in the pathway of pain.

Phantom Pain

Pain in the area of non-existing tissue or organ.

Allodynia

Painful sensations provoked by non-noxious stimuli is known as allodynia.

Referred Pain

Pain in the area remote from the region of origin of pain. This occurs since the area of referred pain is supplied by the same spinal segment as the region of origin of pain. For example, myocardial pain can be referred to the lower jaw.

Somatic Pain

Pain arising from the skin or in areas which are in proximity to the surface of the body.

Visceral Pain

Pain arising in the internal organs.

Hemiagnosia

Inability to perceive pain in one side of the body. This is commonly associated with stroke.

Trigeminal Neuralgia

It is one-sided facial pain occurring along the distribution of any one of the branches of trigeminal nerve.

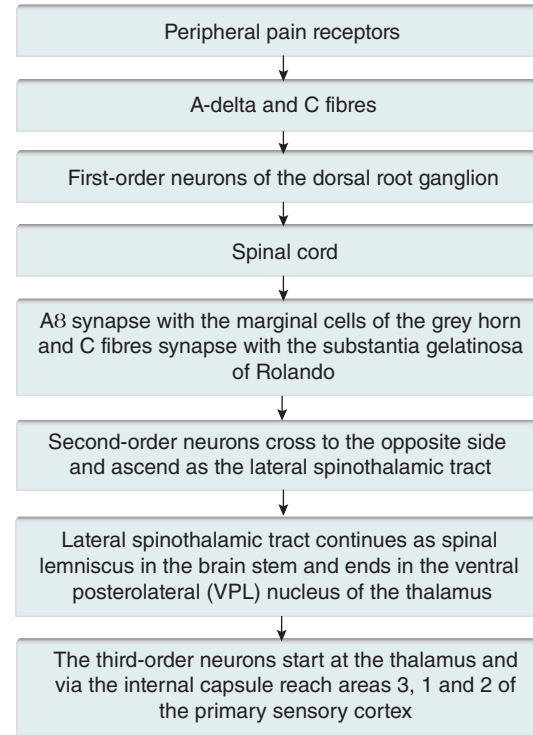


Figure 23.3 Flowchart for pain pathway.

ADDITIONAL READING

Role of Pain Producing Chemicals in Inflamed Tissues

The following are the effects of pain-producing chemicals in inflamed tissue apart from sensitization of nociceptors:

1. Vasodilatatory response
2. Histamine release
3. Increase in blood flow
4. Increase in vascular permeability
5. Increase in blood pressure
6. Synthesis of pro-inflammatory cytokines
7. Chemotaxis of inflammatory cells

Dental Conditions Associated with Increased Release of Pain-Producing Chemicals

1. Dental caries
2. Dental pulpitis
3. Granuloma

Dental Care or Orthodontic Procedures Associated with Increased Release of Pain-Producing Chemicals

1. Cavity preparation
2. Tooth movement
3. Tooth bleaching

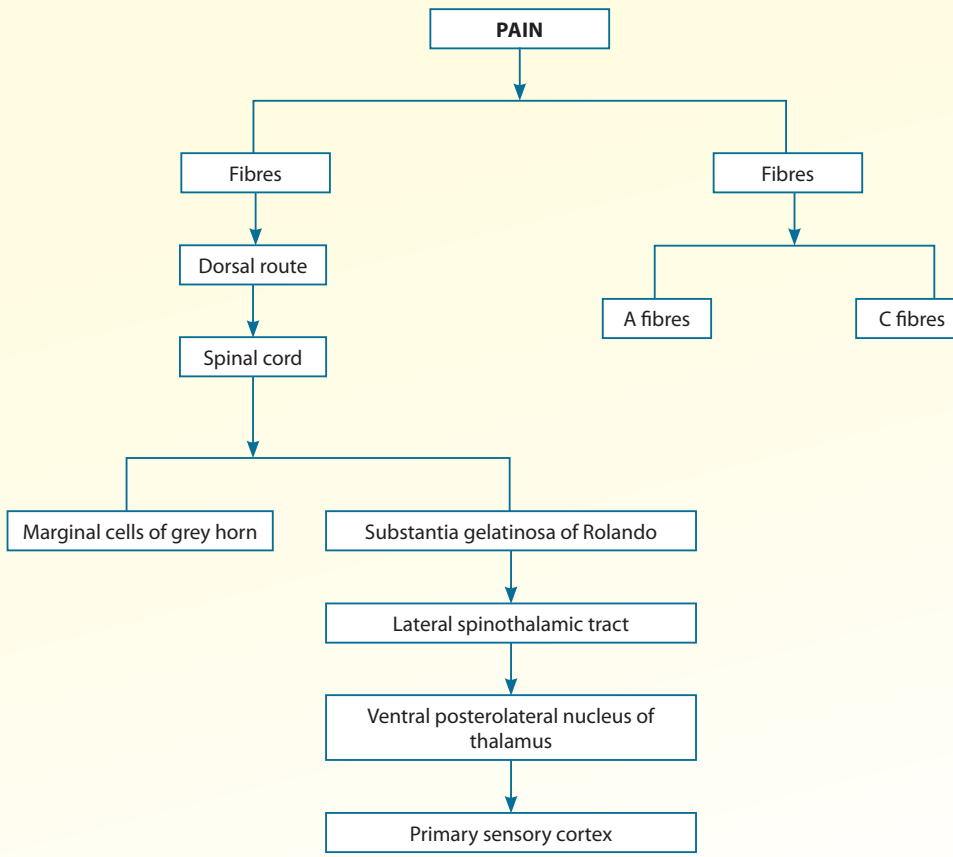
Future Directions

Evidences from current researches abundantly support the view that pain-producing substances are involved in dental pain and inflammation. With respect to various dental procedures, evidences are accumulating that the elaboration of these chemicals varies with different procedures and hence as a future scope it would be ideal to identify procedures that elaborate lesser amount of these chemicals which would ensure enhanced patient compliance.

Key Points

1. Free nerve endings are the receptors of pain.
2. Pain sensation from the face, oral cavity and nose is carried by the trigeminal nerve.
3. Pain is transmitted by the A and C fibres.

Mind Map

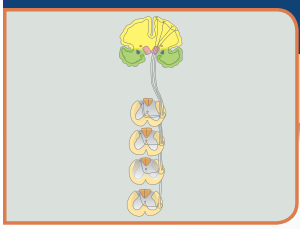


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Multiple Choice Questions

1. Acute pain is carried by
   (a) C fibres
   (b) A-delta fibres
   (c) Both a and b
   (d) Fibres of the hypoglossal nerve
2. Injured tissue releases the following mediators of pain:
   (a) Substance P
   (b) PPS
   (c) Bradykinin
   (d) All of the above
3. The substantia gelatinosa of Rolando is situated in the
   (a) Posterior white column
   (b) Anterior white column
   (c) Anterior grey horn
   (d) Posterior grey horn
4. The tract concerned with pain sensation is the
   (a) Lateral spinothalamic tract
   (b) Descending tract
   (c) Ascending tract
   (d) Both a and c
5. Pain sensation from a tooth is carried by fibres of the following cranial nerve:
   (a) V
   (b) VII
   (c) IX
   (d) XII



CHAPTER 24

Taste

Overview

Chemicals in solution are brought into contact with the chemoreceptors and thus taste is perceived. Taste buds act as these chemoreceptors. These are situated in the dorsum of the tongue, soft palate, epiglottis, oropharynx and larynx. Most of the lingual taste buds are associated with papillae of the tongue. Sweet, salt, sour, bitter and umami are the taste sensations which are perceived by humans. First-order neurons from the various regions of the oral cavity travel to nucleus tractus solitarius (NTS), second-order neurons start at NTS and cross to the opposite side and join the medial lemniscus to end in the posteroventral nucleus of thalamus. From the thalamus, the third-order neurons start and end in the cortex and thus taste sensation is perceived.

INTRODUCTION

Chemosensitivity in most air-breathing vertebrates is divided into a contact chemical sense called taste (gustation) and a distance chemical sense called smell (olfaction). In taste, chemicals in solution are brought into contact with the chemoreceptors; in olfaction, the chemicals are carried to the chemoreceptors as vapour in the inspired air.

TASTE RECEPTORS

The mammalian taste system consists of taste buds as its chemoreceptors. These are situated in the dorsum of the tongue, soft palate, epiglottis, oropharynx and larynx. The afferent fibres from the taste buds relay in the nucleus present in the medulla, pons and thalamus.

Most lingual taste buds are confined to the dorsal and lateral borders of the tongue and are associated with specialized structures called papillae. There are four types of papillae: (i) filiform, (ii) fungiform, (iii) circumvallate and (iv) foliate.

1. **Filiform papillae:** These are the most numerous papillae, located over the dorsum of the tongue in the anterior region. These do not contain taste buds.
2. **Fungiform papillae:** The fungiform papillae contain one or more taste buds on their upper surface and are confined to the anterior dorsum. There are about 200 fungiform papillae in humans (**Fig. 24.1**).
3. **Circumvallate papillae:** The circumvallate papillae are the largest papillae, arranged in front of sulcus terminalis. They are about 8–12 in number in humans. Taste buds are located on the sides of these papillae.
4. **Foliate papillae:** The foliate papillae are found on the posterior, lateral border of tongue and contain taste buds. Some mammals have foliate papillae, but these are not seen in human beings.

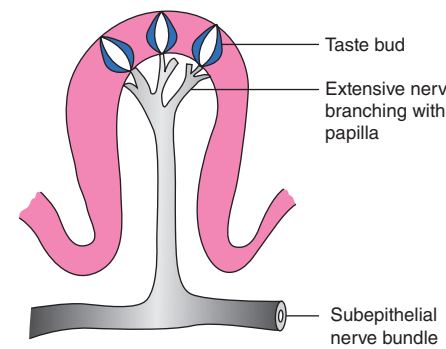


Figure 24.1 Fungiform papilla.

STRUCTURE OF THE TASTE BUD (Fig. 24.2)

Taste buds are goblet-shaped structures present within the epithelium. Each bud consists of about 50 spindle-shaped, modified epithelial cells that extend from the basement membrane to the epithelial surface. At the epithelial surface, the tapered ends of the taste buds are in contact with the fluid environment of the oral cavity through a narrow channel called taste pore. The terminal branches of gustatory nerve fibres enter the taste bud at its base and distribute among taste cells.

Ultrastructural examination of taste buds has revealed that they contain a number of different cell types based on morphological features. There are four types of taste bud cells:

1. **Type I:** The most frequently encountered taste bud cells are the type I cells. They are long and narrow, extending from the base of the taste bud to the taste pore, and occupy approximately 60% of the total cell population. These electron dense cells (dark cells) contain large vesicles with dense cores in the apical cytoplasm as well as deeply indented irregularly shaped nuclei.
2. **Type II:** Type II cells (light cells) extend from the basement membrane to the taste pore, but they are characterized by electron-lucent cytoplasm having large, round or oval nuclei. These cells occupy 30% of the cell population.
3. **Type III:** Type III cells have apical specializations that extend into the taste pore and are similar in morphology to type II cells. They contain vesicles with dense cores in basal cytoplasm. These cells are rarely seen in taste buds.
4. **Type IV:** Type IV cells are in contact with the basement membrane, but unlike the other cells in the taste buds, these do not extend to the taste pore; these are most often called basal cells.

The initial contact between the taste stimuli and the taste receptors takes place in the taste pore. A tight junction joins the apices of the taste bud cells at the base of the pore. Each of the three types of taste bud cells that extend into the taste pore has a different apical structure that contains taste receptors; type I cells have long finger-like microvilli, type II cells have short microvilli and type III cells end as blunt, club-shaped structures.

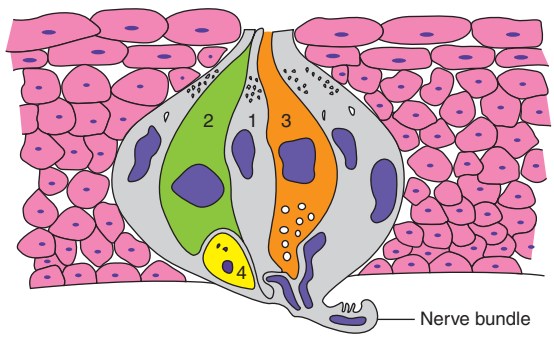


Figure 24.2 Ultra structure of taste bud. 1, type I cell; 2, type II cell; 3, type III cell; 4, type IV cell.

MECHANISM OF TASTE SENSATION

The substance to be tasted must be in solution, for example, in saliva. The dissolved substance probably attaches itself to its specific receptors on the microvilli of the taste receptor cells. This combination ultimately leads to changes in the membrane potential of the receptors cells which is then converted into action potential in the afferent nerves.

There are four basic or primary taste sensations:

1. **Sweet:** Sweet substances have two radicals—glucophore and oxoglu—which are necessary for sweet taste (sucrose, glucose, etc.).
2. **Sour:** Sour taste is produced by agents that liberate H^+ (organic acids like acetic acid, citric acid, etc.).
3. **Salty:** Salty taste is produced by substances such as NaCl, Na_2SO_4 and NaBr.
4. **Bitter:** Bitter taste is produced by alkaloids such as quinine, bile salts, magnesium salts and ammonium salts.

These sensations are felt by different papillae of the tongue as follows:

1. **Sweet and salt:** Fungiform papillae
2. **Sour:** Foliate papillae
3. **Bitter:** Circumvallate papillae

Umami Taste Modality

In the early 20th century, a new taste modality was suggested called umami. This taste sensation was

associated with the amino acid glutamate. Glutamate is commonly combined with sodium to make monosodium glutamate (MSG) and is used to flavour foods. Some people may develop allergy to MSG, and it is also not recommended for young children.

TASTE PATHWAY (Fig. 24.3)

The first-order neurons of the taste pathway are in the nuclei of three different cranial nerves: facial, glossopharyngeal and vagus. The dendrites of the neurons are distributed in the taste buds. After arising from the taste buds, the fibres run in the following nerves:

1. **Chorda tympani branch of the facial nerve:** From the anterior two-third of the tongue
2. **Glossopharyngeal nerve:** From the circumvallate papillae and from other posterior regions of the tongue
3. **Vagal fibres:** From taste buds in other regions

The axons of the first-order neurons together enter into the medulla and end in the NTS.

The second-order neurons start at NTS and cross to the opposite side and join the medial lemniscus to end in the posteroventral nucleus of thalamus. From the thalamus, the third-order neurons start and end in the cortex.

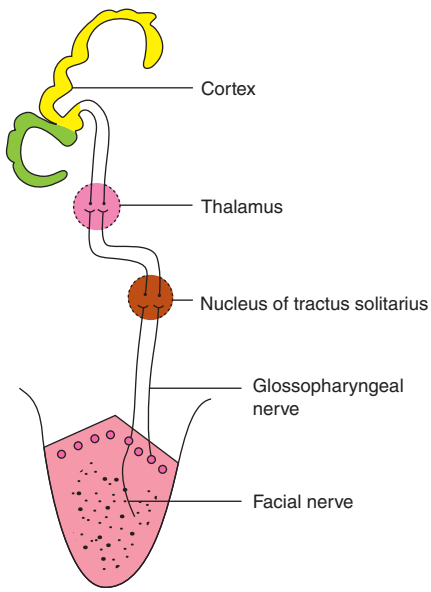


Figure 24.3 Taste pathway.

Applied Physiology

Ageusia

Ageusia is absence of taste sensation.

Hypogeusia

Hypogeusia is decreased taste sensation.

Dysgeusia

Dysgeusia is disturbed taste sensation.

Various Chemosensory Disorders, Malignancies, Drugs, Radiation and Head Injury

They can affect the taste sensations.

ADDITIONAL READING

Extraoral Bitter Taste Receptors

Taste is perceived through sensors in the receptors. Sensors for bitter substances have been identified T2Rs or TAS2Rs, which belong to the class of G protein–coupled receptors (GPCRs). G protein–coupled receptors were originally identified in type II taste receptor cells in the taste bud. The numbers of the sensors vary with the need of food selection. Interspecies variation is seen in the number of T2Rs. About 25 were found in humans and 35 in mice. T2Rs have also been identified in extraoral locations such as digestive, respiratory, and genitourinary systems, brain and immune cells. T2Rs carry out different biological functions in their varied locations. These findings suggest that the evolution of T2Rs could be influenced by the biological functions mediated by these receptors in the extraoral cells and tissues. Extraoral T2Rs could be attractive targets for new therapies, and that currently used bitter medications may also exert their pharmacological functions by acting on these extraoral receptors (excerpts from Lu et al. 2017).

Taste Receptors Mediate Sinonasal Immunity and Respiratory Disease

The bitter taste receptor T2R38 also plays a role in the pathogenesis of chronic rhinosinusitis (CRS). It aids to enhance upper respiratory innate immunity through a triad of beneficial immune responses. The presence of a functional version of T2R38

aids in better perception of the bitter compound phenylthiocarbamide (PTC) and exhibits an antimicrobial response in the upper airway to certain invading pathogens; however, a non-functional version of the receptor which does not perceive the taste of the compound lacks the beneficial response. The non-taster genotype could present with an independent risk factor for CRS and may require surgery, poor quality-of-life (QOL) improvements post-operatively, and decreased rhinologic QOL in patients with cystic fibrosis. They also have a larger burden of biofilm formation. These findings may influence the clinical management of patients with infectious conditions affecting the upper respiratory tract and possibly at other mucosal sites throughout the body (excerpts from Douglas and Cohen 2017).

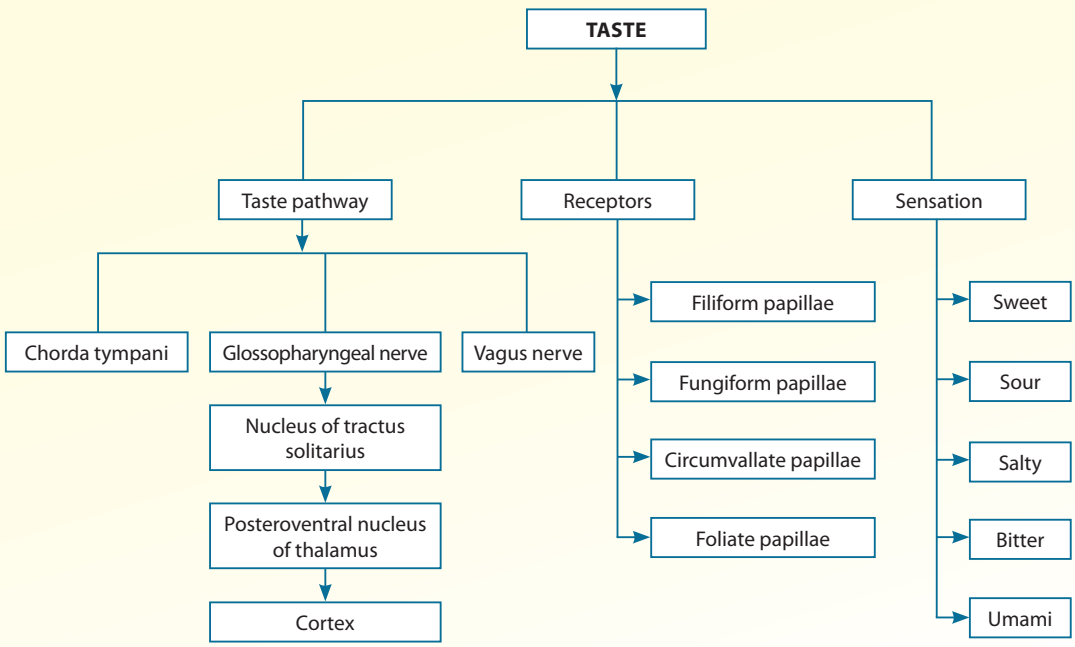
Impact of Ageing and Medical Status on Dysgeusia

Alterations of taste and smell can cause an aversion to food in a sick patient and therefore affect his/her ability to maintain optimal nutrition. Reduced nutrition can lead to a compromised level of strength, muscle mass, function and quality of life. Disorders in differentiation of intensities or concentrations of a tastant can result in increased intake of salt and sugar and exacerbation of chronic diseases such as heart failure and diabetes. These implications are more severe in the elderly, who are particularly frail and are challenged by polypharmacy and multiple comorbid conditions (excerpts from Syed et al. 2016).

Key Points

1. Taste buds are the receptors of taste sensation.
2. Taste bud cells are modified epithelial cells.
3. Sweet, sour, salty and bitter are the four basic or primary taste sensations.
4. Nucleus of tractus solitarius, located in the medulla, is the first relay centre for taste sensation.

Mind Map



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Multiple Choice Questions

1. Taste buds are seen in the following areas except the
   (a) Ventral surface of tongue
   (b) Dorsum of tongue
   (c) Epiglottis
   (d) Soft palate
2. Taste buds are not present in the following papillae:
   (a) Circumvallate
   (b) Filiform
   (c) Fungiform
   (d) Both a and c
3. The circumvallate papilla is located
   (a) Behind the sulcus terminalis
   (b) In front of the sulcus terminalis
   (c) Inside the sulcus terminalis
   (d) Both a and b
4. The predominant type of taste bud cells is
   (a) Type II
   (b) Type III
   (c) Type IV
   (d) Type I
5. The taste sensation from circumvallate papillae is carried by the following nerve:
   (a) Glossopharyngeal
   (b) Facial
   (c) Hypoglossal
   (d) Mandibular

CHAPTER 25



Smell

Overview

Olfaction is the sense of smell that belong to the category of chemosenses. The receptors meant for olfaction are located in the nasal cavity. The substances that cause smell are called odorous substances. To be smelt, these substances should be volatile and need to be dissolved in the olfactory mucosa. The olfactory mucosa consists of an olfactory epithelium that lies over the lamina propria. The olfactory epithelium is a pseudostratified columnar epithelium which is sensory in function and contains olfactory receptors, sustentacular (supporting) cells and basal cells. The olfactory receptors are the primary sensory neurons. The axons of these neurons aggregate into bundles and pass through the foramina in the cribriform plate of the ethmoid bone. The axons then distribute over the surface of the olfactory bulb and transmitted to the olfactory cortex through the olfactory tract. In food recognition and in detection of predators, the sense of smell (olfaction) is important. It also plays an essential role in reproductive behaviour.

INTRODUCTION

The sense of smell (olfaction) and the sense of taste (gustation) together belong to the category of chemosenses. The receptors meant for olfaction are located in the nasal cavity.

The substances that cause smell are called odorous substances. To be smelt, these substances should be volatile and need to be dissolved in the olfactory mucosa.

The sense of smell is important in food recognition and in the detection of predators. It also plays an essential role in reproductive behaviour. Many animals communicate with each other through a specialized olfactory system in which females release chemicals called pheromones that are detected by the males. These pheromones are often species specific and aid in species identification as well. Olfactory receptors are sensitive molecular detectors, capable of responding to more than 10,000 different odour molecules at very low concentrations.

In addition to the olfactory system, the nasal cavity of many vertebrates contains neuroepithelium of the vomeronasal and septal organs, which are innervated with trigeminal endings that respond to chemicals in inspired air.

STRUCTURE OF THE OLFACTORY MUCOSA

The olfactory mucosa is 100–200 μm thick and consists of an olfactory epithelium that lies over the lamina propria. The olfactory epithelium is a pseudostratified columnar epithelium which is sensory in function and contains olfactory receptors, sustentacular (supporting) cells and basal cells (**Fig. 25.1**).

Epithelium

The olfactory epithelium is a pseudostratified columnar epithelium which is sensory in function and contains olfactory receptors, sustentacular (supporting) cells and basal cells (**Fig. 25.1**).

Olfactory Receptor Cells

Olfactory receptor cells are bipolar neurons with cell bodies in the olfactory epithelium. Bipolar neuron cells are a type of neurons that have two extensions. These are specialized sensory neurons for the transmission of special senses. Bipolar cells in the nasal mucosa give rise to axons that enter

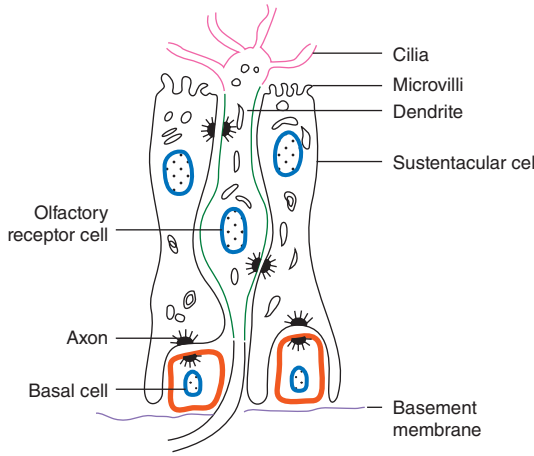


Figure 25.1 Olfactory epithelium.

the cranial cavity through the foramina in the cribriform plate of the ethmoid bone. These cells and their axons, totalling about 20–24 in number, make up the olfactory nerve. A single dendrite extends from the apical end of the soma to the epithelial surface, terminating in an apical dendritic knob. Several motile cilia arise from the knob and extend into the overlying mucous layer.

The area of olfactory mucosa is relatively small but has a large number of receptors, ranging from 60 to 100 million. The olfactory receptive apparatus is present on olfactory cilia.

Sustentacular Cells

Olfactory receptor cells are separated from each other by columnar sustentacular cells that extend from the basal lamina of the epithelium to the epithelial surface. The sustentacular cells have irregular microvilli on their apical surface. The sustentacular cells give out secretions and provide mechanical support to the slender receptor neurons. The supranuclear part of the cell contains mucopolysaccharides that are released into the overlying mucous layer.

Basal Cells

Basal cells are progenitor cells that give rise to new cells. They are located near the basal lamina, between the basal ends of the sustentacular cells.

Lamina Propria

The lamina propria contains bundles of olfactory receptor cell axons and Bowman's glands. Secretions from Bowman's glands and sustentacular cells continuously line the olfactory mucosa.

PROPERTIES OF OLFACTORY NEURONS

Olfactory receptor neurons undergo continuous renewal and are the only neurons in the body to undergo renewal. After mitosis, migration and maturation, the cells in the basal region of the epithelium become functionally mature olfactory receptors. Under normal conditions, an olfactory receptor neuron has a lifespan of 4–8 weeks.

PERCEPTION OF SMELL

Olfactory Receptors

Olfactory receptors are located in the olfactory mucous membrane, which is the modified mucous membrane lining the upper part of nostril (**Fig. 25.2**). The olfactory mucous membrane consists of 10–20 million olfactory receptor cells supported by the sustentacular cells.

The receptors are located outside the main nasal air stream in the most superior part of the nasal cavity. Odours reach the mucosa through turbulence in the flow of air within the nasal cavity.

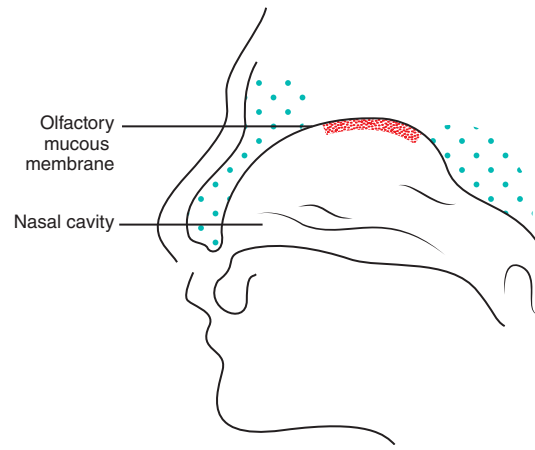


Figure 25.2 Nasal cavity.

SECTION III

Properties of Olfactory Neurons

Olfactory receptor neurons undergo continuous renewal and are the only neurons in the body to undergo renewal. After mitosis, migration and maturation, the cells in the basal region of the epithelium become functionally mature olfactory receptors. Under normal conditions, an olfactory receptor neuron has a lifespan of 4–8 weeks.

RECEPTOR MECHANISM (Fig. 25.3)

The initial perception is the inhalation of a mixture of air and the odour. The odorants have to cross a layer of mucus to reach and interact with the olfactory receptors.

The interaction of an odorant with the chemosensory membrane initiates a series of events associated with sensor transduction and subsequent electrical changes. Odorants bind in a reversible manner to the receptor so that the olfactory stimulation is not continuous and stops when the odorant has been removed.

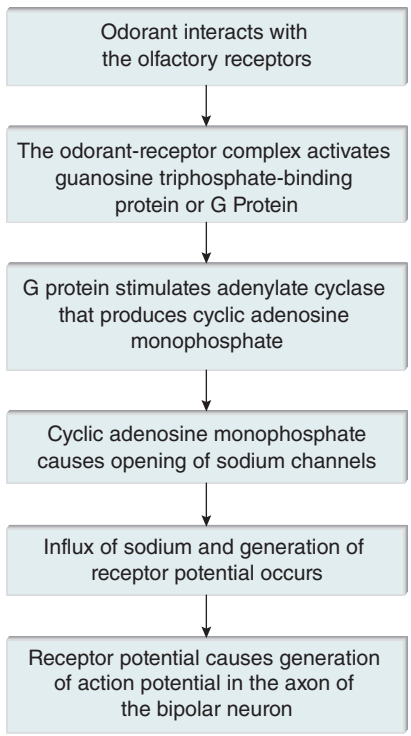


Figure 25.3 Receptor mechanism.

The substance–receptor complex activates guanosine triphosphate (GTP)-binding protein or G protein, which in turn stimulates adenylate cyclase, an enzyme that produces cyclic adenosine monophosphate (cAMP).

This cyclic AMP causes the sodium channels to open, which leads to an influx of sodium and the generation of receptor potential. This receptor potential causes the generation of action potential in the axon of the bipolar neuron.

OLFACTORY PATHWAY (Fig. 25.4)

The olfactory neurons, or the receptor cells, are the primary sensory neurons. The axons of these neurons aggregate into bundles and pass through the foramina in the cribriform plate of ethmoid bone. The axons then distribute over the surface of the olfactory bulb, a layered structure that is the site of the first synaptic interaction in the olfactory pathway.

The olfactory bulb appears layered because of the arrangement of different neuronal types in a layer each. The layers of the bulb are the olfactory nerve layer, the periglomerular region, the glomerular layer, the external plexiform layer and the mitral cell layer. The internal plexiform layer and

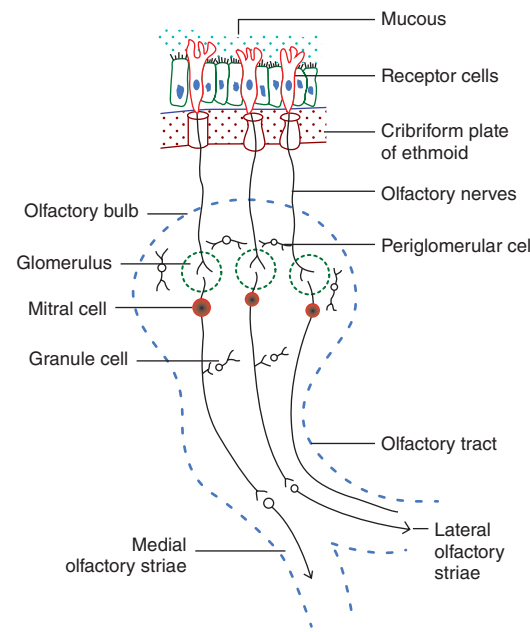


Figure 25.4 Olfactory pathway.

the granule cell layer form the afferent axons of the olfactory nerve which enter the olfactory bulb to form the olfactory nerve layer. Many of these axons connect with the dendritic tree of mitral cells to form spherical structures called glomeruli, which are the most prominent features of the bulb. The granule cell layer contains the output axons from the bulb.

Several different neuron types are distributed within the layers of the olfactory bulb. Neurons with axons that leave the bulb, called principal cells, are mitral and tufted cells. A number of other neuron types are intrinsic to the bulb. These interneurons are scattered throughout the bulb and comprise periglomerular cells, short axon cells and several types of granule cells.

Cell bodies of mitral cells form a single layer within the bulb. Mitral cells send smooth apical dendrites into the glomeruli where they branch and connect with primary afferent axons. The axons of the mitral cells form the olfactory tract, the main output path of the olfactory bulb. The cell bodies of the tufted cells are scattered throughout the external plexiform layer. Tufted cells also send their axons to join the olfactory tract.

The olfactory tract runs backwards through the intermediate and lateral olfactory striae and ends in the olfactory cortex. The olfactory cortex includes the structures which form a part of the limbic system—the anterior olfactory nucleus, prepyriform cortex, olfactory tubercle and amygdala.

Applied Physiology

Anosmia

Anosmia is loss of sensation of smell.

Hyposmia

Hyposmia is reduction in olfactory sensation because of constant exposure to a particular odour (e.g. excessive perfume).

Hyperosmia

Hyperosmia is increased olfactory sensation.

Dysosmia

Dysosmia is altered perception of smell.

Paraosmia

Paraosmia is altered perception of pleasant smell as unpleasant and vice versa, usually unpleasant.

Phantosmia

Phantosmia is perception of smell in the absence of any odour.

Agnosia

Agnosia is the inability to compare or contrast smells.

Age Changes

Olfactory sensation decreases with an increase in age. This may be a significant factor in complaints regarding food in the elderly.

The common causes that lead to primary taste disorders are as follows:

- Smoking
- Radiation treatment
- Chronic diseases of lungs
- Gastroesophageal reflux disease
- Stroke
- Bell's palsy
- Hypothyroidism
- Diabetes
- Intubation during surgeries

CLASSIFICATION OF ODOUR

The different types of odour can be classified as follows:

1. **Aromatic or resinous odour:** Camphor
2. **Ambrosial odour:** Musk and perfumes
3. **Burning odour:** Burning feathers, tobacco, roasted coffee and meat
4. **Ethereal odour:** Fruits, ethers and beeswax
5. **Fragrant/floral/balsamic odour:** Flowers and perfumes
6. **Garlic odour:** Garlic, onion and sulphur
7. **Nauseating/putrid odour:** Decayed vegetables and faeces
8. **Repulsive odour:** Bedbug

Threshold for Olfactory Sensation

1. **Ethyl ether:** 5.8 mg/L of air
2. **Chloroform:** 3.3 mg/L of air
3. **Peppermint oil:** 0.02 mg/L of air

4. **Butyric acid:** 0.009 mg/L of air
5. **Artificial musk:** 0.00004 mg/L of air
6. **Methyl mercaptan:** 0.0000004 mg/L of air

   Thus, methyl mercaptan produces olfactory sensation even at a low concentration of 0.0000004 mg/L of air.

ADDITIONAL READING

Bioelectronic Nose

Variations in the structure of odorous molecules (odorants) causes a significant change of odour. This is due to the fact that every olfactory receptor has a unique code with different genes and usually corresponds to a different type of odour. Identification and characterization of the genes coding the olfactory receptors contribute to the elaboration and development of the electronic smell systems or bioelectronic noses. A bioelectronics nose is constructed by using a primary transducer and secondary transducer. The primary transducer is made of biological materials to improve the selectivity of the sensor and the secondary transducer is made of nanomaterials to increase sensitivity. Bioelectronic noses using various nanomaterials combined with engineered olfactory cells could detect almost all of the smells recognized by human because an engineered olfactory cell is able to express any human olfactory receptor as well as can mimic the human olfactory system. A bioelectronic nose could be used as a potent tool for smell visualization (excerpts from Ko and Park 2016).

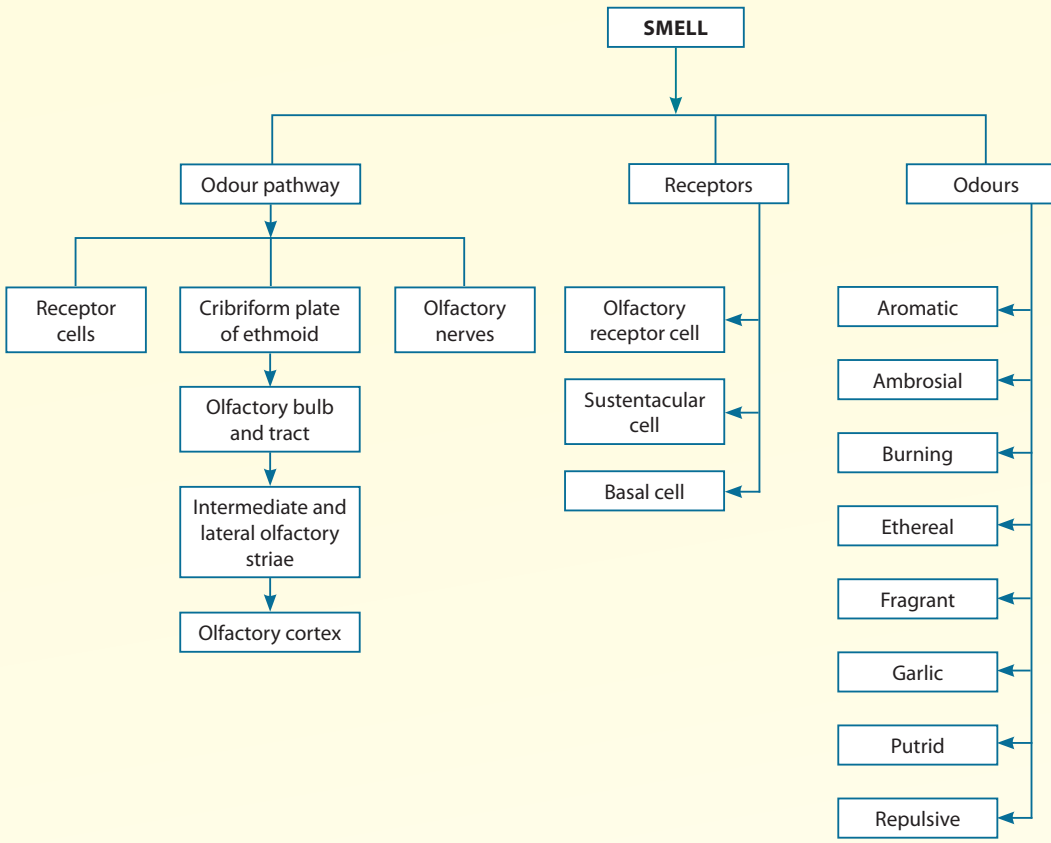
Olfaction as a Marker for Depression

Olfactory and emotion pathways share common anatomical substrates. Mood is affected by alterations in the olfactory function. Olfaction and negative emotions can interact in two ways. The olfactory function in such conditions could be impaired as a consequence of reduced olfactory attention and diminished olfactory receptor turnover rates. The olfactory bulb constitutes as a marker for enhanced vulnerability to depression (excerpts from Croy and Hummel 2017).

Key Points

1. Smell is an important sensation in food recognition and in the detection of predators.
2. The neurons of the olfactory receptor cells are bipolar neurons with their cell bodies in the olfactory epithelium.
3. The lamina propria of the olfactory mucosa contains bundles of olfactory receptor cell axons and Bowman's glands.
4. The interaction of an odorant with the chemosensory membrane of the olfactory mucosa initiates a series of events associated with sensor transduction and subsequent electrical changes.
5. The axons of the mitral cells form the main output path of the olfactory bulb.
6. Methyl mercaptan produces olfactory sensation at a very low concentration of 0.0000004 mg/L of air.

Mind Map

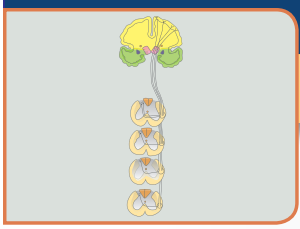


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Multiple Choice Questions

1. The number of olfactory receptor cells present in olfactory mucosa ranges between
   (a) 10 and 20 million
   (b) 1 and 2 million
   (c) 100 and 200 million
   (d) 10,000 and 20,000
2. Olfactory receptors cells are separated by the following cells:
   (a) Sustentacular
   (b) Basal
   (c) Cuboidal
   (d) Polygonal
3. The olfactory mucosa contains the following glands:
   (a) Bowman's
   (b) von Ebner's
   (c) Blandin and Nuhn's
   (d) Lacrimal
4. The axons of the following cells leave the olfactory bulb to form the olfactory tract:
   (a) Mitral
   (b) Granular
   (c) Tuft
   (d) Both a and c
5. Loss of sensation of smell is
   (a) Hyposmia
   (b) Anosmia
   (c) Hyperosmia
   (d) Both a and b



CHAPTER 26

Mastication

Overview

Mastication is the act of chewing food. The masticatory cycle commences with ingestion and ends with swallowing. Masticatory muscles of the jaw, namely masseter, lateral pterygoid, medial pterygoid and temporalis, play a major role in bringing about effective mastication. This process involves transportation of food posteriorly followed by grinding of food and bolus formation. While chewing, the jaw moves rhythmically and the opening and closing of the jaw occur in a series of cyclical movements called the chewing cycle. The masticatory process is controlled by the masticatory centre located in the brainstem.

INTRODUCTION

Mastication is the act of chewing food, and it consists of the coordinated function of various parts of the oral cavity to prepare the food for swallowing and digestion.

STRUCTURES INVOLVED IN MASTICATION

Teeth are the most important structures involved in mastication, but other structures such as lips, cheeks, tongue, palate, gingiva and periodontium, muscles of mastication and the temporomandibular joint, along with the lubricating and enzymatic action of saliva, are important for mastication.

Food taken into the mouth is crushed by the grinding action of the teeth, which makes it suitable for swallowing. Breakdown of food into smaller particles increases the surface area of the food particles. This in turn increases the enzymatic action leading to effective digestion. Mastication also removes the cellulose covering of some food particles.

During chewing, the tongue plays an essential role in controlling the movement of the food and forming the bolus. For food to be broken down, it has to be positioned by the tongue in conjunction with the buccinator muscles of the cheek between the occlusal surfaces of the teeth. The tongue transports solid and liquid foods within the oral cavity.

Jaw Movement During Mastication

In mammals, mastication is characterized by large vertical movements of the lower jaw, usually on one side of the dentition. In most species, this is accompanied by some transverse movements of the mandible, and protrusion and retrusion of the tongue.

Movements of the mandible and tongue begin in utero. Although most mammals are capable of masticatory movements early in life, newborn mammals feed by suckling. As age increases, the motor patterns undergo gradual transition from suckling to mastication. The mechanisms controlling this transition are thought to be multifactorial as maturation of anatomical structures takes place with age.

While chewing, the jaw moves rhythmically and the opening and closing occurs in a series of cyclical movements called the *chewing cycle*. The rate and pattern of jaw movement and jaw muscle activity are typical for a particular species of animal.

Movement of the mandible during the chewing cycle is teardrop shaped, with a duration of 0.8–1.0 second per cycle. In case of sticky and hard food, the cycle time increases.

Although there is a lot of variation in different species, a single chewing cycle is usually divided into four phases. The cycle starts with a

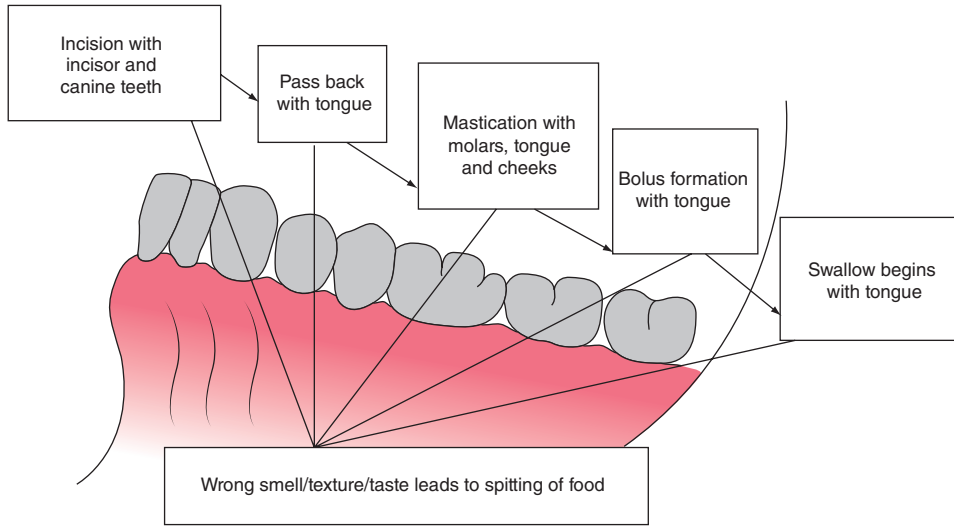


Figure 26.1 Sequence of food intake and processing which leads to swallowing.

minimum-opening phase followed by a faster opening phase. This is followed by a fast-closing phase. The final phase is a slow-closing phase during which the food is crushed between the teeth.

A masticatory sequence consists of many chewing cycles and extends from ingestion to swallowing. The pattern of the individual cycle varies depending on the state of breakdown of the food. The masticatory sequence can be divided into three consecutive periods:

1. **Preparatory** (Fig. 26.1): Initial period where food is transported back to the posterior teeth
2. **Reduction:** Intermediate period where food is ground up
3. **Pre-swallowing:** Final period where bolus is formed for swallowing

Movement of the jaws in these three periods differs depending on the type of foodstuff and the species of animal.

Muscles Involved in Mastication

The muscles which are involved in the process of closing the mouth are masseter, medial pterygoid and temporalis. They are known as elevators.

The muscles involved in the process of opening the mouth (depression) are the lateral pterygoid muscles along with the digastric, mylohyoid and geniohyoid muscles. They are known as depressors.

Medial pterygoid, lateral pterygoid and masseter are helpful in the protrusion of the mandible. Retraction of the mandible is brought about by the temporalis.

Medial and lateral pterygoids of both the sides act alternatively for the side-to-side movement of the mandible.

Muscle Activity

Electromyography (EMG) recordings of jaw muscles during chewing have revealed details of the pattern of activity of muscles.

Masticatory muscles exhibit an asynchronous pattern of activity during contraction, with wide variation in the time of onset, peak activity and rate of decline. The pattern of activity is determined by various factors such as the species, type of food and rate of food breakdown. This pattern of muscle activity is mostly common in mammals. Muscles involved in the opening movement of the mandible are active during the opening. Muscles responsible for the closing of the mandible start showing movement when the jaw begins to close and the teeth begin chewing food.

Applied Physiology

Myofascial Pain

It is characterized by regional pain followed by specific trigger points. The aetiology is still unclear but it is speculated that microtrauma to the muscle fibres due to stretching, contraction or trauma can lead to myofascial pain.

Myositis

Acute inflammation of the muscle leading to pain and swelling. It commonly occurs due to acute overuse or local causes such as impacted third molar pericoronitis or cellulitis.

Muscle Spasm

It is transient involuntary contraction of muscles that leads to pain which can happen due to overstretching of a previously weakened muscle. Lateral pterygoid spasm on one side can lead to shift of occlusion to the contralateral side. Restricted mouth opening is called *trismus*. It occurs due to spasm of the muscles of mastication. Spasm may be due to dental infections or due to bacterial diseases such as tetanus.

Muscle Contraction

Muscle contracture is a chronic condition. It is characterized by muscle shortening. Prolonged hypomobility, trauma, burns, post surgical scar and infections can lead to muscle contracture.

Edentulous Patients

Patients whose posterior jaws are edentulous and patients with completely edentulous condition have difficulty in chewing. They may swallow the food without chewing, which could lead to digestive problems.

Control of Mastication

The movements involved in mastication require the integrated activity of various muscles, controlled by the trigeminal, hypoglossal, facial and possibly other motor nuclei in the brainstem. The coordination of activity in these motor nuclei relies on sensory input from the oral cavity that terminates primarily in the trigeminal nucleus and the solitary tract nucleus. Other brainstem structures, such as the reticular formation, are also involved. Motor and sensory nuclei contained in the brainstem play a pivotal role in the control of mastication.

The basic oscillatory pattern of masticatory movements originates in a neural pattern generator located in the brainstem. Afferent sensory input are sent to these brainstem nuclei; higher brain centres influence the brainstem masticatory coordinating system.

Interconnected neural circuits form a neural oscillatory network that is capable of generating the pattern of masticatory movements. This neural oscillator is called pattern generator or masticatory centre.

Although the presence of a pattern generator is well established, details of the neural circuits and precise anatomical location of the pattern generator have not been fully worked out. However, some of the neural circuitry involved in normal mastication has been revealed by the study of reflex muscle activity initiated by the stimulation of orofacial structures.

A number of reflexes can be elicited from the orofacial area. These include tongue, facial and various jaw reflexes. Because reflex activity of muscles in other body areas has proved useful in understanding neural connections, orofacial reflexes have been studied extensively and have revealed basic neural circuits that connect afferent sensory input with efferent motor output.

MASTICATORY MUSCLES—REFLEX PATTERNS

The mastication process is controlled by a central pattern generator, and the masticatory muscles exhibit specific reflex patterns. The three types of muscle reflexes of the masticatory apparatus are as follows:

1. Jaw-closing reflex (the jaw-jerk reflex)
2. Jaw-opening reflex
3. Unloading reflex

Jaw-Jerk/Jaw-Closing Reflex

The reflex activity of the jaw moving the teeth into occlusion is called the jaw-closing reflex. This is an example of stretch reflex and is

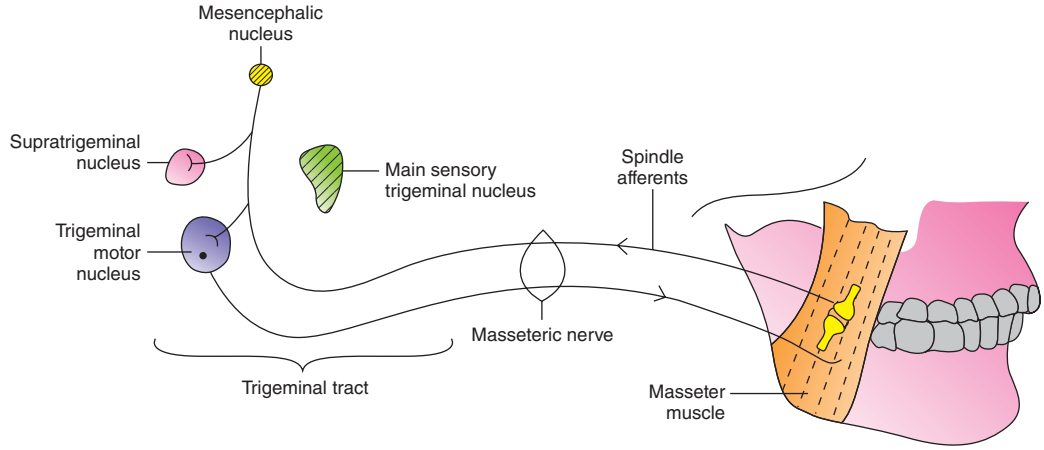


Figure 26.2 Jaw-closing or jaw-jerk reflex.

similar to the knee-jerk reflex. The jaw-closing reflex can be produced by giving a sharp downward tap on the chin when the mandible is out of occlusion in the rest position. The reflex activity of the masseter brings the teeth into occlusion.

The jaw-jerk reflex (**Fig. 26.2**) is a monosynaptic reflex occurring because of the stretching or loading of muscle spindles in the masseter muscle. The reflex lasts for 7–12 milliseconds, after which there is a silent period in the electromyogram which represents spindle unloading.

Depressor muscles relax during jaw-jerk reflex, and their activity is not noticed because of the presence of few muscle spindles.

Jaw-Opening Reflex

The jaw-opening reflex is initiated by mechanical stimulation of the periodontal ligament and mucosal mechanoreceptors. The result is excitation of jaw-opening muscles and inhibition of jaw-closing muscles. This is not a monosynaptic reflex, and at least one interneuron is involved in the reflex pathway (**Fig. 26.3**). Moreover, inhibitory interneurons

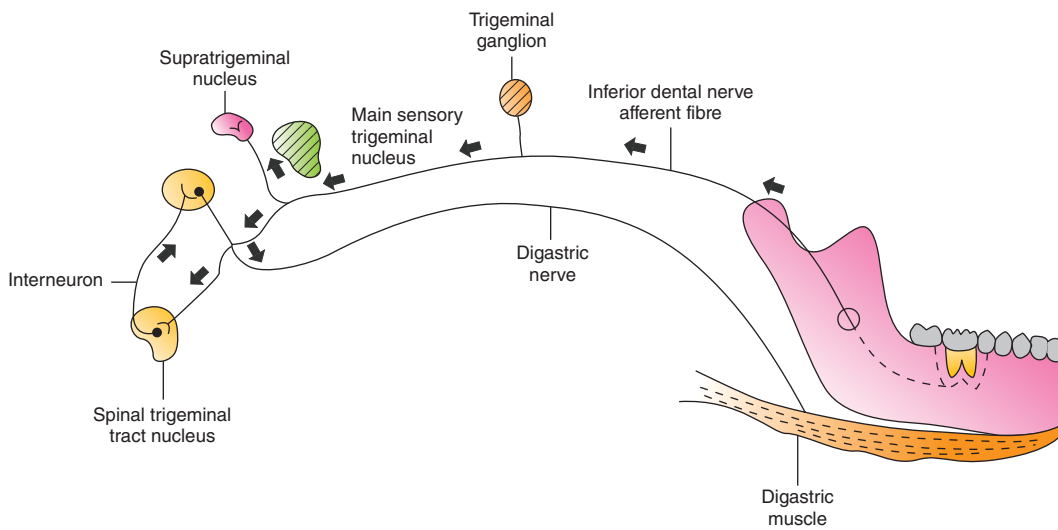


Figure 26.3 Jaw-opening reflex.

may be at work in suppressing the activity of the jaw-closing muscles. A jaw-opening reflex can be initiated by the stimulation of numerous other areas innervated by the trigeminal and other cranial nerves so that there may be a number of reflex pathways involved in this reflex.

Unloading Reflex

The unloading reflex helps to protect the teeth during a heavy occlusal load. This reflex stops mandibular closure by decreasing masseter and digastric muscle activity. This sudden reduction is the result of the inactivation of the muscle spindles.

BITING FORCE

The maximum biting force that can be applied to the teeth varies from individual to individual. Males can exert more force than females. The masticatory force exerted on anterior teeth is 10–15 kg and on molars is around 50 kg. The instrument used to measure bite forces is called gnathodynamometer.

ADDITIONAL READING

Mastication Related to Immunity of the Oral Tissue Barrier

Immunosurveillance networks operate at barrier sites for functional defence mechanisms. They are controlled by local tissue cues to ensure effective immunity. Commensal bacteria which exist in these barrier regions are site specific and evoke key signals ensuring host defence. Oral microbiota and tissue-specific signals regulate immunity at the gingiva, a key oral barrier. Gingiva-resident T helper 17 (Th17) cells contribute to the immune activation through a commensal colonization-independent mechanism. Activation and aggregation of Th17 cells at the gingiva is induced whenever there is a physiological barrier damage during mastication. Th17 cell responses are driven by varied mechanisms; mechanical damage has also been found to define the immune tone in the oral barrier (excerpts from Dutzan et al. 2017).

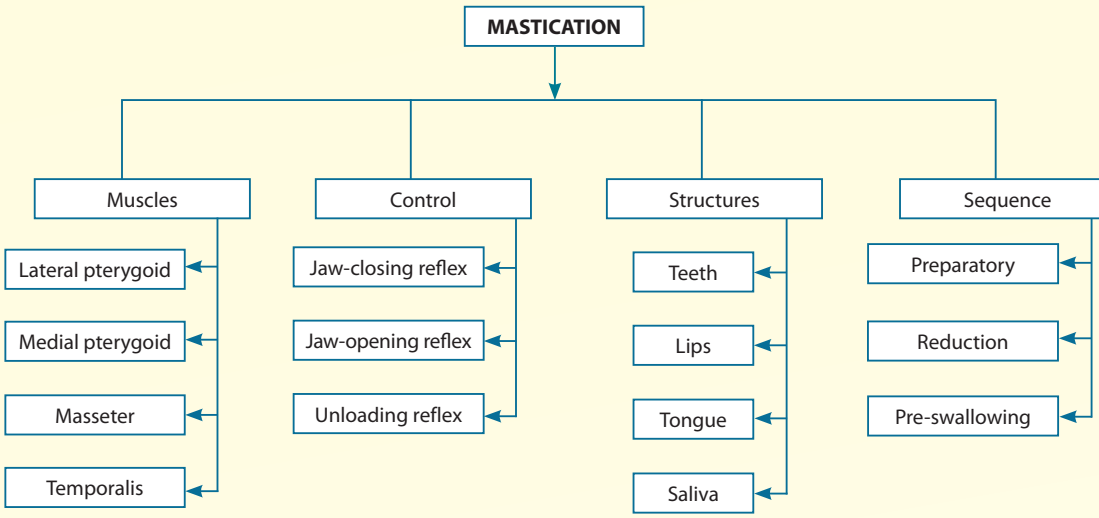
Mastication and Cognitive Status

Cognitive impairment and dementia are common in elderly populations. The risk factors for cognitive impairment and dementia are demographic factors (e.g. increasing age and lower education levels), genetic factors (e.g. APOE*4 allele), medical risk factors (e.g. cardiovascular disease and stroke), psychiatric factors, head injury and lifestyle factors (smoking and heavy consumption of alcohol). Masticatory performance and cognitive status have revealed positive association. Poorer mastication is associated with lower cognitive function and has been found to be one of the significant risk factors for having dementia or mild memory impairment (excerpts from Tada and Miura 2017).

Key Points

1. During chewing, the jaw moves rhythmically, opening and closing in a series of cyclical movements called the chewing cycle.
2. Movement of the mandible during the chewing cycle is teardrop shaped, with a duration of 0.8–1.0 second per cycle. In the case of sticky and hard food, the cycle time increases.
3. The basic oscillatory pattern of masticatory movements originates in a neural pattern generator located in the brainstem.
4. The jaw-jerk reflex (jaw-closing reflex) is a stretch reflex similar to the knee-jerk reflex.
5. The instrument used to measure bite forces is called a gnathodynamometer.

Mind Map



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Multiple Choice Questions

1. The path of movement of the mandible during chewing is in the following shape:
   (a) Circular
   (b) Teardrop shaped
   (c) Oval
   (d) Semicircular
2. Each chewing cycle lasts for approximately
   (a) 0.8–1.0 second
   (b) 3.0–4.0 seconds
   (c) 0.2–0.4 second
   (d) 2.0–3.0 seconds
3. The elevators are
   (a) Masseter
   (b) Temporalis
   (c) Medial pterygoid
   (d) All of the above
4. Muscle activity can be studied by
   (a) Electrocardiography
   (b) Electroencephalography
   (c) Electromyography
   (d) Gnathodynamometer
5. Jaw-jerk reflex is
   (a) Jaw-opening reflex
   (b) Jaw-closing reflex
   (c) Unloading reflex
   (d) Both a and c

CHAPTER 27



Deglutition

Overview

Deglutition (swallowing) is the process by which food is passed into the stomach from the oral cavity. The process of swallowing involves preparatory phase, oral phase, pharyngeal phase and oesophageal phase. Food is made into a mass called bolus and thus the formed bolus is pushed towards the oesophagus and into the stomach in the process of deglutition. Sensory input from the oral cavity, pharynx, larynx and oesophagus terminates in the nucleus tractus solitarius and trigeminal sensory nucleus that are involved in the initiation of swallowing. Motor output of the centre derives from motor neurons within the nucleus ambiguus, facial, trigeminal and hypoglossal motor nuclei as well as motor neurons in the cervical spinal cord. Other neuromuscular activities similar to swallowing are suckling and gagging.

INTRODUCTION

Deglutition (swallowing) is the process by which food is passed into the stomach from the oral cavity.

Swallowing is a reflex activity consisting of muscle contractions and relaxations that help push the ingested food and saliva from the mouth to the stomach. This reflex activity occurs in coordination with numerous motor neurons. The swallowing reflex is pre-programmed as well as initiated in the region of the brainstem known as the swallowing centre. Although swallowing can be initiated voluntarily, much of the swallowing occurs without any conscious effort. The swallowing rate is highest during eating and least during sleep, and swallowing occurs around 600 times per day. The volume of a swallow in drinking, and probably in bolus transport, varies from 5 mL in a child to 10–14 mL in adult women and 15–20 mL in adult men.

Besides helping to move nutrients from the mouth to the stomach, swallowing has many important protective functions. As the respiratory tract and the digestive tract are at the level of the pharynx and larynx, it becomes crucial that solids and liquids do not enter the larynx. Protective mechanisms control or inhibit breathing during swallowing. Vigorous set of reflexes such as coughing or choking are initiated if food or fluid enters the opening of the trachea.

PHASES OF SWALLOWING

Swallowing can be divided into preparatory, oral (buckle), pharyngeal and oesophageal phases.

Preparatory Phase

Formation of food bolus occurs during this phase. Food bolus is a round or oval-shaped mass of food formed in the mouth after thorough chewing. The food bolus is formed as a preparatory event for swallowing.

Oral Phase (Buccal Phase)

Once the bolus is positioned on the tongue dorsum, the oral phase begins. The lips close and the maxillary and mandible incisors come closer together. The anterior two-third of the tongue elevate against the maxillary alveolar ridge and the anterior hard palate, propelling the bolus towards the pharynx. The nasopharynx is shut off by the upward movement of the soft palate and the forward movement of the posterior pharyngeal wall to prevent regurgitation of food through the nose. This is a voluntary phase and respiration is stopped for a while in this phase (**Fig. 27.1a**).

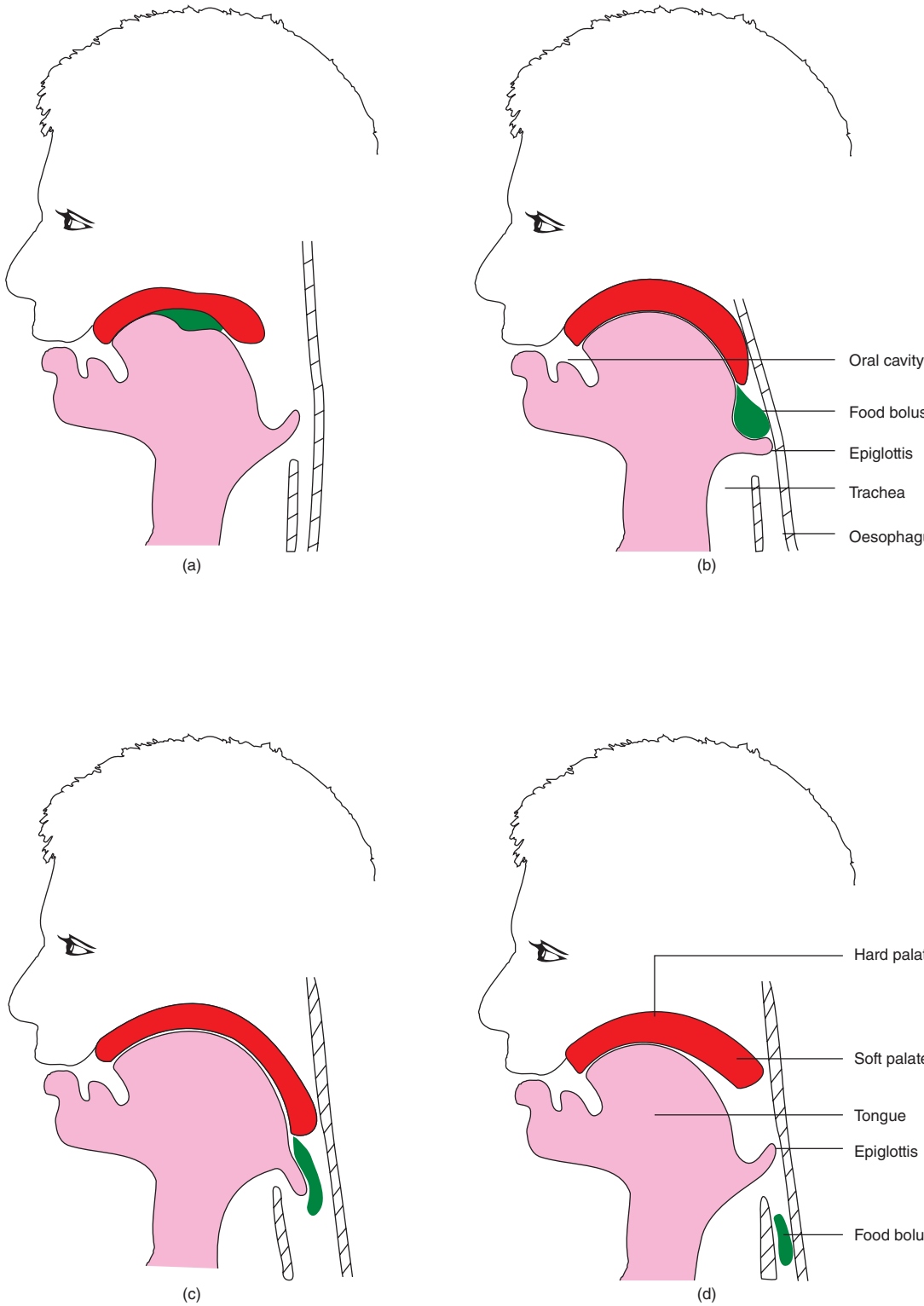


Figure 27.1 Movement of the food bolus in different phases of deglutition.

Pharyngeal Phase

At the beginning of the pharyngeal phase, the posterior part of the tongue makes a rapid piston-like movement to propel the bolus through the oropharynx into the hypopharynx. The pharyngeal constrictors move upwards and forwards and begin propelling the bolus through the pharynx by sequential contractions. The upper oesophageal sphincter opens, and the bolus enters the oesophagus.

During the pharyngeal phase, the laryngeal vestibule closes because of the movement of the epiglottis. The epiglottis first moves from an upright to a horizontal position (**Fig. 27.1b**) because of the elevation of the hyoid bone and larynx and the contraction of the thyrohyoid muscles. Further muscle contraction causes the tip of the epiglottis to rotate over the laryngeal vestibule. The epiglottis does not have to cover the laryngeal opening to prevent aspiration of food. Aspiration of food generally does not occur in individuals with an excised epiglottis. However, the epiglottis does direct the bolus into the piriform sinuses and, therefore, around the opening of the airway into the oesophagus (**Fig. 27.1c** and **d**).

Several mechanisms operate to prevent aspiration of the bolus into the airway during the pharyngeal phase of swallowing. During this phase, respiration is inhibited. Elevation of the larynx and upper oesophageal sphincter shortens the distance the bolus must travel and hence the time the bolus is present at the entry of the airway. Intrinsic muscles of the glottis forcefully approximate the vocal cords. The piriform sinuses create lateral food channels so that the bolus generally deviates around the laryngeal opening. Any residual bolus material trapped in the piriform sinus after swallowing is normally at a lower level than the laryngeal vestibule, making aspiration of residual material unlikely.

Applied Physiology

Forcing food and liquids into the nasal cavity is known as nasal regurgitation. It can occur in patients with palatal clefts or paralysis of soft palate where the nasal cavity cannot be sealed off from the oropharynx.

Oesophageal Phase

After the food is placed in the upper end of oesophagus, the upper oesophageal sphincter contracts, causing peristaltic contractions (wave-like movements) that can send the bolus to the stomach with the help of gravity. The lower oesophageal sphincter opens to allow the bolus into the stomach.

DRINKING

It is possible to ingest fluids without any oral activity. If the head is tipped back so that the oral cavity and the oesophagus present a straight pathway, fluid may be poured down this pathway.

The ingestion of fluids proceeds as follows:

1. Accumulation of fluid takes place in the anterior part of the oral cavity with the tongue hollowed at the tip but raised posteriorly.
2. Tip of the tongue raises to touch the palate behind the upper incisors.
3. The muscles of the tongue contract progressively to bring it back along the palate. The posterior part of the tongue drops down.
4. The pharyngeal phase of fluid intake is mostly similar to the pharyngeal phase of swallowing of food bolus produced by mastication.

Fluid can pass down the oesophagus under the influence of gravity when a person is in an upright position; even then, there is contraction of the superior pharyngeal constrictor and initiation of peristaltic waves in the oesophagus.

MUSCLE ACTIVITY

1. Thirty-one paired muscles are involved in the various phases of swallowing. Muscle patterns differ with the type of food that is swallowed.
2. Muscle activity in the preparatory and oral phases involves various muscles controlling the face and mandible. The medial pterygoid, masseter and temporalis muscles are actively involved in these phases. Facial muscles that control the lips and the cheeks contribute to the development of an oral seal and stabilization of the mandible.
3. The pharyngeal phase of swallowing is complex, and once it begins, the muscles controlling

the hyoid bone, tongue, pharynx and larynx exhibit a series of contractions, relaxations and inhibitions. The mylohyoid, geniohyoid, palatopharyngeus, palatoglossus, superior constrictor, styloglossus and stylohyoid lead the activity at the beginning of a swallow.

4. The pharyngeal constrictors act in an overlapping sequence. The leading complex is activated and consists of a set of muscles including the mylohyoid, geniohyoid, posterior tongue, palatopharyngeus, palatoglossus, superior constrictor, styloglossus and stylohyoid. They are so called because they show activity at the initiation of a swallow.
5. After the activation of the leading complex, the middle and the inferior constrictor become active in a sequential order.
6. The thyrohyoid, thyroarytenoid and the cricothyroid muscles begin to contract after the activity in the leading complex begins to subside.

Applied Physiology

The muscles used for swallowing are different before teeth eruption. In the infantile swallow, the orbicularis oris and buccinator muscles are very active, and the levator muscles of the mandible do not participate in swallowing. After eruption of teeth, this pattern is altered and the activity in the labial and buccinator muscles decreases. Retained infantile pattern causes malocclusion in adults.

CONTROL OF SWALLOWING

Swallowing can be initiated either voluntarily or by stimulation of various areas in the oropharynx. The preparatory and oral phases of swallowing are voluntary, whereas the pharyngeal and oesophageal phases are involuntary. The swallowing motor sequence, including the motility of the smooth muscles of the oesophagus, depends on the swallowing centre. The interneurons in this centre organize the whole sequence of muscle contractions of swallowing so that the control of swallowing is the property of a precisely interconnected set of neurons.

The swallowing centre comprises three components:

1. Sensory input from the oral cavity, pharynx, larynx and oesophagus terminates in the nucleus tractus solitarius and trigeminal sensory nucleus that are involved in the initiation of swallowing, especially the afferent activity in the glossopharyngeal and the superior laryngeal branch of the vagus nerves.
2. Motor output of the centre derives from motor neurons within the nucleus ambiguus, facial, trigeminal and hypoglossal motor nuclei as well as motor neurons in the cervical spinal cord.
3. Between the sensory input and motor output of the centre is an interneuronal network that programs the entire sequence of events in a swallow through excitatory and inhibitory connections.

The swallowing centre, therefore, is a not a discrete anatomical entity but consists of brainstem sensory and motor nuclei interconnected by a neuronal network.

Applied Physiology

Dysphagia (difficulty in swallowing) can occur when the oral cavity, pharynx and oesophagus are affected by any inflammation, infection or nutritional deficiency (iron deficiency anaemia). Occurrence of tumour can also lead to dysphagia. Further stenosis and strictures in the oesophageal lumen can also cause difficulty in swallowing. The common causes of dysphagia are as follows:

1. Oropharyngeal disorders
   - (a) Scarlet fever
   - (b) Mumps
   - (c) Periotonsillar abscess
   - (d) Carcinoma
   - (e) Syphilis
   - (f) Intubation during surgeries
2. Neurological disorders
   - (a) Paralysis of one or both vocal cords
   - (b) Disorders of basal ganglia, cerebellum
   - (c) Any infections of brainstem
   - (d) Stroke
   - (e) Parkinsonism
   - (f) Tetanus
   - (g) Cerebral palsy
3. Mechanical disorders
   - (a) Surgical reconstruction of structures after carcinoma
   - (b) Loose dentures
   - (c) Macroglossia

OTHER NEUROMUSCULAR ACTIVITY RELATED TO SWALLOWING

Suckling

The process by which newborns and infants feed is called suckling; in this process, the intake is that of fluids. Suckling consists of development of negative pressure or suction in the oral cavity combined with jaw movements to express milk from the nipple. Suckling activity in infants and small children is produced by suction and lowering the jaw while the lips are sealed around the nipple to prevent entry of air into the oral cavity.

The infant first forms a teat from its mother's breast by sucking the nipple deep into the posterior part of the mouth to the junction of the hard and soft palates. By elevating the jaw and tongue, the infant compresses, lengthens and shortens the teat to express milk for swallowing.

Swallowing in the newborn is a liquid swallow and is related to suckling. No teeth are present, masticatory movements do not occur and semisolid bolus is not formed. The anatomies of the pharynx and larynx are also different from those of the adult. In the neonate, the soft palate occupies much of the volume of the upper pharynx, which is more compact than in the adult. The epiglottis guides the larynx upwards behind the soft palate and remains there during respiration. During development, the epiglottis descends and assumes its mature functional role during swallowing.

Because of the anatomical relationships of the pharynx and larynx in the newborn, it has been suggested that infants can swallow without interruption of breathing.

Applied Physiology

Occurrence of cleft palate or cleft lip in infants affects suckling. Cleft lip prevents formation of lip sealing and creation of negative pressure while cleft palate can cause aspiration of fluid along with interference in the development of negative pressure essential for suckling.

Gagging or Retching

When the posterior part of the mouth is stimulated, a swallowing pattern of reflex is set up. Any irritation or noxious stimulation can lead to a vomiting reflex. If the swallowing reflex pattern could *be inhibited, the mouth is held open and the cricopharyngeal sphincter and the nasopharynx are* closed. Attempts are made to expel the stimulating material from the mouth by movements of the tongue, which start at the back of the mouth and move forwards. This is termed *gagging* or *retching*. The retching reaction is the first stage of reflex protection of the digestive tube; it gives way to the more powerful protective reflex pattern of vomiting, if the irritant material cannot be removed by retching.

Applied Physiology

The materials used in taking impressions for denture construction, particularly in the upper jaw, can stimulate the back of the mouth and cause a gagging reflex. Very sensitive patients may require anaesthesia of the oral mucosa before denture impressions can be taken.

ADDITIONAL READING

Hyoid Bone Dynamics in Deglutition

In addition to the pharynx, the larynx and hyoid bone are also one of the important factors during swallowing to ensure that food boluses are smoothly carried to the oesophagus without aspiration. Movement of hyoid bone, especially during elevation during deglutition, is a common cause of aspiration in the elderly. Probability of dysphagia increases with age as the hyoid bone lowers in position. Upper oesophageal sphincter opening results due to anterior displacement of the hyoid bone whereas laryngeal closure results in superior displacement. Anterior displacement of the hyoid bone is primarily due to the movement of the geniohyoid, and the anterior belly of the digastric muscle works as auxiliary. Superior displacement of the hyoid bone involves mylohyoid as the primary muscle and the posterior belly of the digastric muscle works as the auxiliary muscle (excerpts from Shinozaki et al. 2017).

Sensory Topography of Oral Structures

Oral cavity and oropharynx sensory innervation is mediated by a variety of receptors that have a

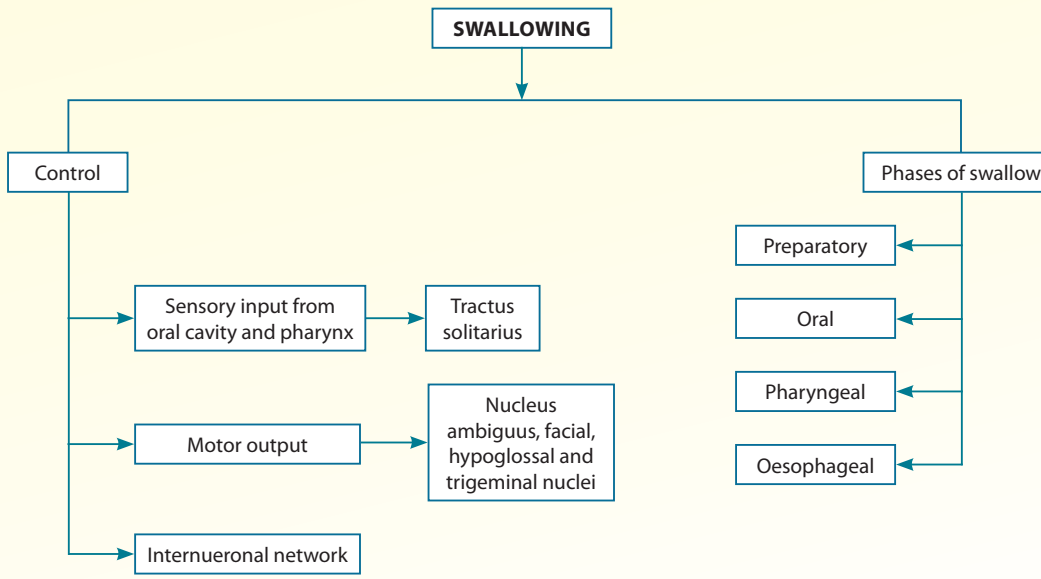
preferential response to touch, pressure, vibration, position, pain, temperature and taste. Tactile sensation plays a critical role than other sensation for safe and effective deglutition.

Specific sensory function is needed in identification of food objects, action selection in mastication, and decision making to trigger a swallow sequence. In addition to deglutition, tactile integrity is involved in precise apposition of the lips, tongue movements and palatal excursions to produce nuanced vocal expressions. The complex synchronicity of oral cavity sensorimotor function can be impaired by primary diseases or secondary treatment effects such as chemotherapeutic, radiotherapeutic or surgical treatment for head and neck malignant conditions. Sensory dysfunction may also occur with snoring and obstructive sleep apnoea disorders (excerpts from Bearelly and Cheung 2017).

Key Points

1. The swallowing rate is highest during eating, least during sleep and occurs around 600 times per day.
2. In the oral phase, the nasopharynx is shut off by the upward movement of the soft palate and the forward movement of the posterior pharyngeal wall to prevent regurgitation of food through the nose.
3. A set of muscles, called the leading complex, show activity at the beginning of a swallow.
4. The swallowing centre is a not a discrete anatomical entity but consists of brainstem sensory and motor nuclei interconnected by a neuronal network.
5. Swallowing in a newborn is a liquid swallow and is related to suckling.
6. When the posterior part of the mouth is stimulated, a swallowing pattern of reflex is set up. In some circumstances, irritation or noxious stimulation can lead to a vomiting reflex.

Mind Map

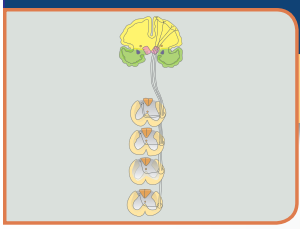


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Multiple Choice Questions

1. The number of times swallowing occurs per day in an individual is approximately
   (a) 600 times
   (b) 60 times
   (c) 6,000 times
   (d) 1,600 times
2. The following stage of deglutition is voluntary:
   (a) Pharyngeal
   (b) Oesophageal
   (c) Oral
   (d) Both a and b
3. Respiration stops for a while in the following phase of swallowing:
   (a) Oesophageal
   (b) Oral
   (c) Pharyngeal
   (d) Both b and c
4. Newborns and infants feed by a process called
   (a) Suckling
   (b) Sucking
   (c) Mastication
   (d) All of the above
5. Irritation or noxious stimulation of the posterior of the oral cavity results in the following reflex:
   (a) Swallowing
   (b) Masticatory
   (c) Suckling
   (d) Vomiting



CHAPTER 28

Speech

Overview

Speech is one of the functions of the upper aerodigestive tract and is an activity that involves nerves, muscles and mechanical factors such as movement of air and hearing. Respiration, phonation, resonance, articulation and suprasegmental characteristics play a pivotal role in production of speech. The sounds produced are classified into bilabial, labiodental, linguodental, linguoalveolar, linguopalatal and linguovelar. At birth, sound production is immature and just initiated but with growth of the corresponding articulators the quality of sound produced is improved. Any pathology associated with any of the articulators or brain development disrupts the sound production.

INTRODUCTION

Speech is a gift given to humans alone. It is one of the functions of the upper aerodigestive tract and is an activity that involves nerves, muscles and mechanical factors such as movement of air and hearing. Speech is produced and modified in the vocal tract, and specific anatomical changes have been incorporated for this purpose. The low position of the larynx in the neck ensures that there is more space in the vocal tract for resonating different sounds—this feature is unique to humans. The disadvantage of such an arrangement is that it causes gagging and choking of food.

When the brain receives suitable stimulation from the environment, it is capable of developing language. Understanding language is a central function of the brain. Speech and hearing are the peripheral processes to produce and receive the spoken language. Most people are right-handed, and in such persons, the left frontal lobe of the brain is more active. In a left-handed person, the right frontal lobe is more active. Speech processing takes place in the left hemisphere for most people. Speech production is controlled by *Broca's area* of the brain, which is in the inferior aspect of the frontal lobe, whereas meaningful or logical speech is controlled by *Wernicke's area,* which is located in the left temporal lobe. If a person has to say something, the words are planned in Wernicke's area and this plan is passed on by the *arcuate fasciculus* to Broca's area, which in turn executes the planned words (**Fig. 28.1**).

The sentence is formulated in Broca's area and transmitted to the motor cortex (pre-central gyrus) for execution. The nerve impulses from the *precentral gyrus* are transmitted to the midbrain and pyramidal system, where speech gestures are fine tuned. The nerve impulses are then transmitted through the cranial nerves to the muscles for the production of sound. The main cranial nerves are as follows:

1. **V (Trigeminal):** Supplies the muscles of mastication for jaw movements
2. **VII (Facial):** Supplies the muscles of facial expression and lip movement

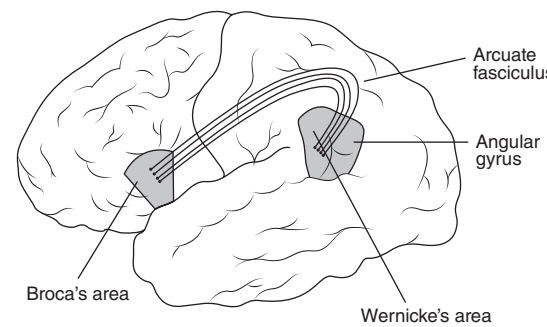


Figure 28.1 Lateral surface of the left hemisphere showing the location of primary areas of language.

3. **X (Vagus):** Supplies the pharyngeal and laryngeal muscles
4. **XII (Hypoglossal):** Supplies the muscles responsible for tongue movements

Thus, the production of sound involves many muscles and needs their coordination. Any structure that vibrates produces sound. Here, the structures that vibrate and produce sound (*phonation*) are the *vocal cords*. The sound produced by vocal cords is reduced, amplified, interrupted or modified by other structures such as the palate and the teeth, which is known as *articulation*. Thus, the exhaled air from the lungs vibrates the vocal cords to produce sound (phonation) which is amplified, reduced or modified (articulation) into its final form. To vibrate the vocal cords, *subglottal pressure* (below the vocal cords) should be a minimum of 7 cm of water (i.e. the minimum pressure for the production of sound). In loud speech or singing, this can increase up to 60 cm of water. Sometimes during singing or shouting, there may be a prolonged and forced expiration without inspiration. Anterior abdominal muscles are also involved during these prolonged expirations.

Sound is different in every individual because the fundamental frequency of human voice is determined by the resting length of the vocal cords, which is different in all people. The fundamental frequency also varies with age and sex. The frequency range in humans is 60–500 Hz, with an average of 120 Hz in males, 200 Hz in females and 270 Hz in children. At puberty, the growth of the thyroid cartilage in males increases the length of vocal cords and reduces the fundamental frequency.

The vocal cords are tensed in panic situations and the cry for help is a high-pitched squeak. The vocal cords can be compared to a rubber band. When the length increases, tension increases but thickness decreases. Vocal cords can be lengthened up to 50% of their resting length.

COMPONENTS OF SPEECH

Speech can be classified under five functional systems:

1. **Respiration:** During respiration, airflow vibrates the larynx to produce speech. During inspiration, when the diaphragm contracts, it creates a negative pressure in the chest, causing the air to flow and fill the lungs. When the diaphragm relaxes, the relaxation of the lungs leads to a reduction in the volume of the thorax, leading to expiration. When inspiration and expiration occur forcefully, other costal and abdominal muscles are also involved. Conversely, respiratory disorders can influence speech production.
2. **Phonation (sound production):** The airstream from the lungs (expired air) vibrates the soft lining of the vocal folds when they are in position, and sound is produced. This raw glottal sound is filtered in the pharynx and modified in the oral cavity to produce speech. The disorders in voice quality are hoarseness, roughness, etc., and in voice quantity are pitch, loudness, etc.
3. **Resonance:** When sound passes from the larynx into the pharynx, the raw sound is amplified and filtered. The modification of sound occurs in the pharynx, which acts as a resonating cavity. The velopharyngeal sphincter, which controls the contraction of the soft palate, also helps in this function. When the nasal sounds 'N or M' are pronounced, the velum or soft palate is lowered and the sound goes through the nose. For most other sounds, the velum is elevated or raised; this prevents the sound from going through the nose.

Applied Physiology

When the nose is blocked in conditions such as the common cold, the normal resonance is affected and diminished nasal airflow can result in the *hyponasality* of sound. The congenital type of hyponasality is seen in cases of cleft lip and palate. When there is damage to the nerve that supplies the velopharyngeal sphincter, the resonance of voice can be affected.

4. **Articulation:** The sound produced in the vocal folds after filtration and amplification in the pharynx is modified by the articulators in the oral cavity. The oral and paraoral structures help in the articulation of speech.
5. **Suprasegmental characteristics:** Depending on the physical and emotional state of

an individual, emphasis is laid on certain words. Such emphases are described as suprasegmental characteristics such as pitch and rhythm of speech. This characteristic is influenced by all other areas of motor speech.

Applied Physiology

The disorders in suprasegmental characteristics are as follows:

1. **Stuttering:** Sudden block in utterance of a word or syllable
2. **Cluttering:** Blended sounds and syllables and silent words that make speech unintelligible

Thus, speech is produced by controlling the airflow that begins in the lungs and passes through the larynx and vocal cords which produce all speech sounds. Subtle adjustments in the airflow contribute to variations in the pitch and intensity of voice. The structures that control different speech sounds are various articulators and valves made in the pharynx, oral and nasal cavities. Each sound is affected by the length, diameter and elasticity of the vocal tracts and by the locations of constrictions along their lengths.

SPEECH ARTICULATORS (Fig. 28.2)

1. **Active articulators:** These are the organs in the oral cavity that move actively during sound production, for example lips, mandible, tongue and soft palate.
2. **Passive articulators:** These are the structures that do not move but support the active articulators, for example front teeth, alveolar ridge and hard palate.

The soft palate serves as an active as well as a passive articulator. It acts as an active articulator in the nasal sounds 'n' and 'm' and a passive articulator for the tongue when pronouncing 'k'.

Classification of English Speech Sounds

1. **Vowels (aeiou):** They increase the resonance frequencies made in the vocal cords. Vowels are continuous, harmonic sounds produced with different degrees of tongue raising, jaw opening and lip rounding.

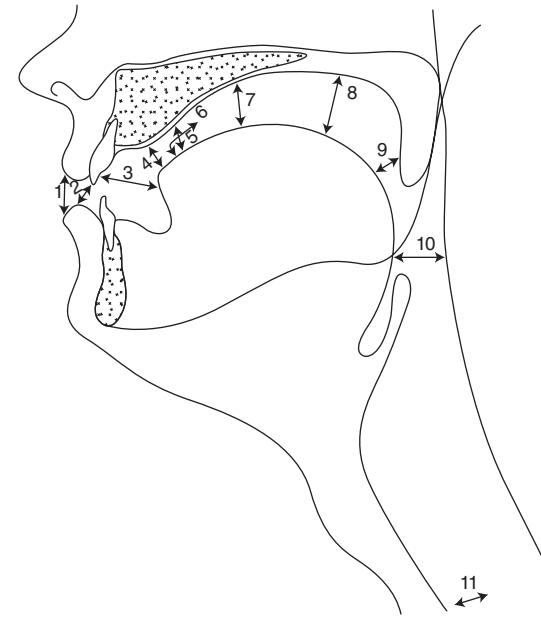


Figure 28.2 Places of articulation. 1, bilabial; 2, labiodental; 3, dental; 4, alveolar; 5, post-alveolar; 6, retroflex; 7, palatal; 8, velar; 9, uvular; 10, pharyngeal; 11, laryngeal.

2. **Consonants:** English consonant sounds are classified by three parameters:
   (a) Manner of articulation
   (b) Place of articulation
   (c) Voiced or not (e.g. sound 'f' is produced by bringing the lower lip close to the upper incisors [non-voiced]. But when sound 'v' is pronounced, vocal folds are involved and hence that is a voiced sound.)

Classification Based on the Manner of Articulation

The classification of English speech sounds on the basis of manner of articulation is elaborated in **Table 28.1**.

Classification Based on the Place of Articulation

1. **Bilabial sounds** (e.g. 'p' [pay], 'b' [bay]): Sounds 'p' and 'b' are made by the contact of lips. Air pressure is built up behind the lips and released without a voiced sound.

Table 28.1 Classification Based on the Manner of Articulation

Name of the Class	How the Sound is Produced	Examples
Plosives	Airflow is blocked and suddenly released with exposure	Bilabial sounds 'p', alveolar sounds 't', velar sounds 'k', voiced counterparts 'v,''d','g'
Fricatives	Friction is caused when airflow is forced through a constriction in the vocal tracts	Labiodental 'f', interdentally voiced and unvoiced 'th', alveolar fricatives 's' and 'z', palatine fricative 'sh'
Nasals	Air goes through the nose	'm' and 'n'
Retroflexes	The tip of the tongue is bent backwards	'r'
Laterals	The body of the tongue is raised and air flows to the right or left of the tongue	'l'
Affricatives	Combination of plosive and fricative sounds	'ts' as in cheese
Approximants	Consonant sounds similar to vowels	'w' and 'j'

Applied Physiology

Incorrect vertical dimension of occlusion hinders proper lip closure, which may affect the pronunciation of these words or sounds.

2. **Labiodentals** (e.g. 'f' [fan], 'v' [van]): They are made between upper incisors and the centre of the posterior third of the lower lip.

Applied Physiology

Importance of Teeth

The most important teeth for speech articulation are the front teeth. They serve as passive articulators. Missing or malaligned anterior teeth can cause lisping. Severe skeletal malocclusion can also cause speech disorders; for example, bilabial sounds such as 'p' and 'b' and labiodental sounds such as 'f' and 'v' are affected. Skeletal malocclusion is usually compensated by alveolar and dental factors, but severe malocclusion will result in speech disorders. Patients with class II malocclusion can compensate better than class III malocclusion. If the movement of tongue is hindered by crossbite or inverted bite, it may also result in speech disorders. Nerve damage due to surgical or dental extraction may affect oral sensation, but usually speech is unaffected unless the anterior teeth are extracted. Lisping is seen in children when their primary tooth is lost, and it continues till permanent teeth erupt. The speech system can adapt to some changes of the passive articulators to a particular physiologic limit. Prosthetic appliances can be used to lift the palate or to close the velopharyngeal opening to aid in proper speech production. Speech modification is one of the main functions of the oral cavity. Dentists play an important role in maintenance and function of teeth and other paraoral structures so that they are well organized for proper speech articulation.

Speech modification is one of the main functions of the oral cavity. Dentists play an important role in maintenance and function of teeth and other paraoral structures so that they are well organized for proper speech articulation.

3. **Linguodentals** (e.g. 'th' [thump]): They are made with the tip of the tongue extending slightly between the upper and lower anterior teeth.

Applied Physiology

In cases of tongue tie/ankyloglossia, difficulty arises with the movement of the tongue and hence production of linguodental sound is affected.

4. **Linguoalveolar** (e.g. 't' [to], 'd' [dot], 's' [so], 'z' [zoo]): They are made with a valve formed by the contact of the tip of the tongue to the most anterior part of the palate or the lingual side of the anterior tooth.

5. **Linguopalatal** (e.g. 'sh' [shoe], 'ch' [chin]): Here, the tongue and the alveolus form the controlling valve. While making these sounds, the upper and lower incisors approach each other but do not touch.

Applied Physiology

Speech disorders can result due to cleft lip and palate. A cleft occurs between the 4th and the 12th weeks of intrauterine life. The cleft may involve the lips, alveolus, hard palate, soft palate or any combination of these structures. All primary repairs of the cleft must be completed within the first year of birth for the proper development of speech. When the velopharyngeal sphincter is affected by cleft, air may escape through nose and that may result in hypernasality of speech. Persons with cleft lip and palate try to make compensatory articulation that has more glottal and pharyngeal speech sounds.

6. **Linguovelar** (e.g. 'k' [black]): Here, the soft palate is the passive articulator and the tongue is slightly raised towards it.

Applied Physiology

Speech Disorders

1. **Aphasia:** Total or partial loss of speech due to brain injury
   (a) *Receptive aphasia*: Difficulty in understanding written words. Speech is muddled and the patients utter wrong words but are not aware of that.
   (b) *Expressive aphasia*: Difficulty in writing and speaking. The patients can understand but cannot speak properly. Speech is jumbled or slurred
2. **Apraxia:** Inability to use the speech muscles to produce understandable speech
3. **Dysarthria:** Paralysis of the speech muscles leading to difficulty in speech

Development of Articulation

At birth, the oral space of the child is filled with the tongue. The initial sounds are glottal, pharyngeal and hypernasal. By 6 months of age, the oral cavity grows in volume, the larynx starts to sink down and the function of velopharyngeal sphincter matures. When the velopharyngeal closure mechanism improves, the child starts producing oral speech sounds with coordinated movements of lips and mandible. Initially, the child speaks in simple repetitive consonant vowel sequences such as mama and papa. Then the child progresses towards more posterior, articulated sounds with the tongue first on the alveolus and then the palate and finally the velum. Children learn easier sounds such as 'm' or 'b' first but more complicated sounds such as 'r' or 's' last. During the development of speech, children may do the following:

1. **Omit** certain sounds which are difficult to pronounce (omission).
2. **Substitute** difficult words with some other words, e.g., bed for red.
3. **Distort** the original sound which is difficult to pronounce.

When the child grows, the *omission*, *substitution* and *distortion* of speech sounds are outgrown.

ADDITIONAL READING

Mechanics of Human Voice Production and Control

Speech is a primary means of communication and voice plays an important role in daily life. The character of the voice depicts many features such as social status, personal traits and the emotional state of the speaker.

Production of voice involves a complex mechanical interaction between fluid structure within the glottis and its control by laryngeal muscle activation. Voice research mainly targets the establishment of causal theory linking voice physiology and biomechanics. Causal theory plays an important role in clinical voice management, voice training and speech technology applications. In addition to the fluid structure–acoustic interaction process, the mechanics of voice production depends on the geometry and material properties of the lungs, larynx and vocal tract. However, the outcome is usually perceived in terms of its acoustics and perception. Meeting the future challenges of developing a causal theory

of voice production and perception depends on the development of mechanical and computational models of voice production (excerpts from Zhang 2016).

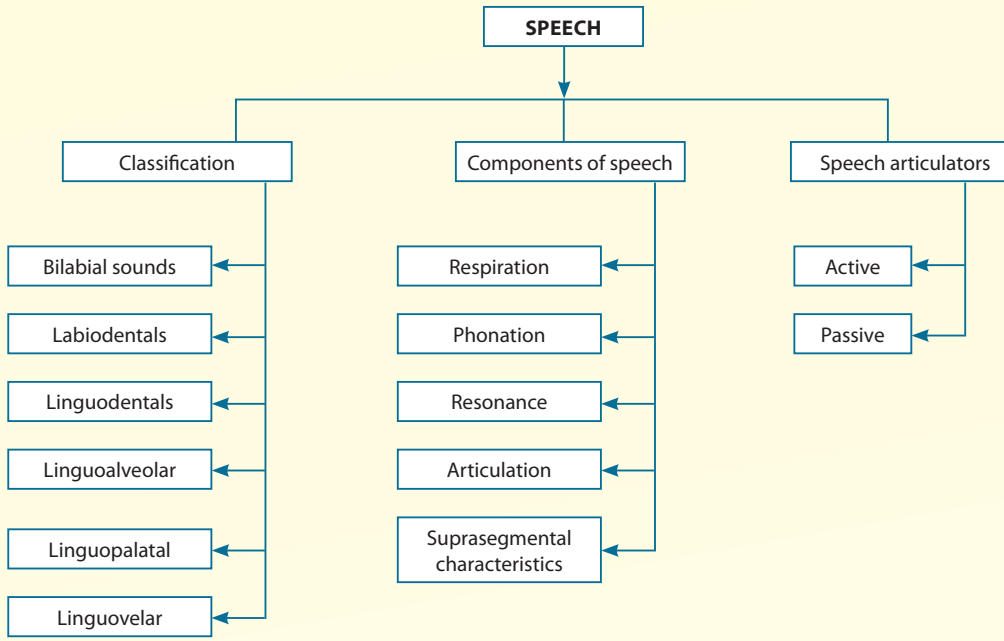
Lingual Kinematics

Speech production is mainly dependent on tongue motion; however, most of the tongue movements are invisible. The methods to analyse lingual kinematics include X-ray cinefluorography, ultrasound imaging, magnetic resonance imaging, wired electromagnetic articulography (EMA) and wireless magnetic localization. The average speed of tongue movements during speech range between 100 and 200 mm/s. The position of the tongue is in relation to the upper and lower jaws which is contributed by the position of the hyoid bone, anterior and posterior suprahyoid muscles. The hyoid and its associated muscles control the angulation and length of the floor of the mouth on which the tongue movement occurs. The inherent shape of the tongue is regulated by the 'extrinsic muscles' acting in coherence with the 'intrinsic' muscles. The intrinsic muscles can also be considered as the 'laminated segmental system' with tightly packed layers of the 'transverse', 'longitudinal' and 'vertical' muscle fibres. Each segmental system receives individual fibres from the hypoglossal nerve. The jaw-hyoid-tongue complex, or the hyomandibular 'kinetic chain', plays a vital role in feeding and consecutive speech (excerpts from Hiiemaee and Palmer 2003 and Lu et al. 2017).

Key Points

1. Speech is made and modified in the vocal tract.
2. Two areas of the cerebral cortex are necessary for speech: Broca's area and Wernicke's area.
3. The cranial nerves involved in speech production are V, VII, X and XII.
4. The organs in the oral cavity that move actively in sound production are called active articulators, and the structures that support the active articulators without movement are called passive articulators.
5. Phonation is the production of sound and articulation is the modification of speech to its final form.
6. Missing or malaligned anterior teeth can cause lisping.

Mind Map

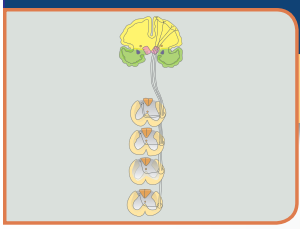


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Multiple Choice Questions

1. Logical speech originates in which part of the brain?
   (a) Broca's area
   (b) Wernicke's area
   (c) Pyramidal tract
   (d) Cranial nerves
2. The cranial nerves involved in speech are
   (a) V, VII, X, XII
   (b) II, IV, VI, VIII
   (c) III, V, VII, VIII
   (d) IV, VI, V, X
3. What are phonation and articulation?
   (a) Phonation is the production of sound and articulation is the modification of speech to its final form
   (b) They are the application of speech
   (c) Phonation is done by tongue and articulation by the larynx, respectively
   (d) Phonation is due to articulation and inspiration
4. For speech, the essential component is
   (a) Inspired air
   (b) Expired air
   (c) Heart beat
   (d) Temperature
5. Frequency of sound is more in
   (a) Ladies
   (b) Men
   (c) Children
   (d) Old people
6. The nasal sounds are
   (a) m and n
   (b) t and k
   (c) w and j
   (d) th and t
7. The sounds that are first pronounced by a child are
   (a) m or b
   (b) r or s
   (c) t or q
   (d) a or y
8. Lisping of speech is commonly because of
   (a) Missing and malaligned anterior teeth
   (b) Missing or malaligned posterior teeth
   (c) Abnormalities of the tongue
   (d) Nerve abnormalities



CHAPTER 29

Calcium and Phosphorus Metabolism

Overview

The important body contents necessary for normal growth and development are calcium and phosphate. Calcium and phosphate in the form of calcium hydroxyapatite crystals are present in bone and teeth. Calcium and phosphate levels are regulated by parathyroid hormone, calcitonin and Vitamin D. Dysregulation of calcium or phosphate metabolism severely hampers normal bone and tooth development as well as causes abnormalities in the developed bone and tooth.

INTRODUCTION

Calcium and phosphorus are important body contents necessary for normal growth and development. Bone and teeth contain the maximum amount of calcium and phosphate in the form of calcium hydroxyapatite crystals.

CALCIUM

The total body content of calcium in an adult is approximately 1.1 kg, of which around 98–99% is present in bone and teeth alone.

Functions of Calcium

1. Helps in the stability of cell membranes
2. Helps in muscle contraction
3. Helps in exocytosis in secretory cells
4. Helps in blood clotting
5. Helps in the development of bone and teeth

Dietary Intake

The daily requirement of calcium is around 300 mg but more has to be consumed because only 60% of what we take is absorbed. Milk, vegetables, cheese and fruits are some of the main sources of calcium.

The recommended dietary allowance (RDA) for calcium is 0.5–0.8 g/day. During pregnancy, the calcium intake should be around 1.5 g/day, and in lactating mothers, it should be 2 g/day for the healthy growth of the infant.

Calcium Absorption

Calcium is absorbed in the duodenum. Phytic acid and oxalic acid decrease absorption by forming insoluble calcium phytate and calcium oxalate. Factors such as vitamin D, fat, citrates, protein diet and low pH in the gastrointestinal tract increase the absorption of calcium.

Calcium enters the cells by passive diffusion and binds to the calcium-binding proteins within the cell. From the cells, the calcium is passed out by active calcium pumps on the cell membrane.

Calcium Excretion

Calcium is excreted in faeces and in urine. In the faeces, it is excreted through the exfoliated gastrointestinal tract cells, and in the urine, it is excreted as calcium phosphate and calcium chloride.

Blood Calcium Concentrations

The normal blood calcium level is maintained between 9 and 11 mg/100 mL. Blood calcium may be in a free state or may be complexed with hydrogen carbonate and citrates and in some cases, bound to plasma proteins.

Calcium Store

The main body store of calcium is bone. An adult contains about 1,000 grams of calcium in

the bone. Of this, 4 grams are readily available for exchange. The bone crystals remain in equilibrium with the tissue fluid and capillary blood. Passive exchange of ions at the crystal surface is not confined to calcium; ions such as strontium and fluoride are taken up by the bone in exchange for calcium. Lead may also be taken up by bone similarly.

Regulation of the Calcium Level

The blood calcium level is maintained by two hormones and vitamin D.

1. **Parathyroid hormone:** Secreted by the chief cells of the parathyroid gland
2. **Calcitonin:** Secreted by the parafollicular cells of the thyroid gland
3. **Vitamin D:** Acts like a third hormone in this regulatory process

Parathyroid Hormone (Parathormone) (Fig. 29.1)

The main function of the parathyroid hormone (PTH) is to increase the blood calcium level. The action of PTH is both by its direct effect on bone and kidney and by its indirect effect on intestine through vitamin D. The secretion of PTH varies inversely with the level of calcium in blood. The parathyroid hormone acts in the following ways:

1. Effect of PTH on kidney
   (a) Increases the reabsorption of calcium
   (b) Increases phosphate excretion
   (c) Increases the conversion of 25-hydroxy-cholecalciferol to its active form *1,25-dihydroxycholecalciferol* (calcitriol) which enhances calcium absorption in the intestine

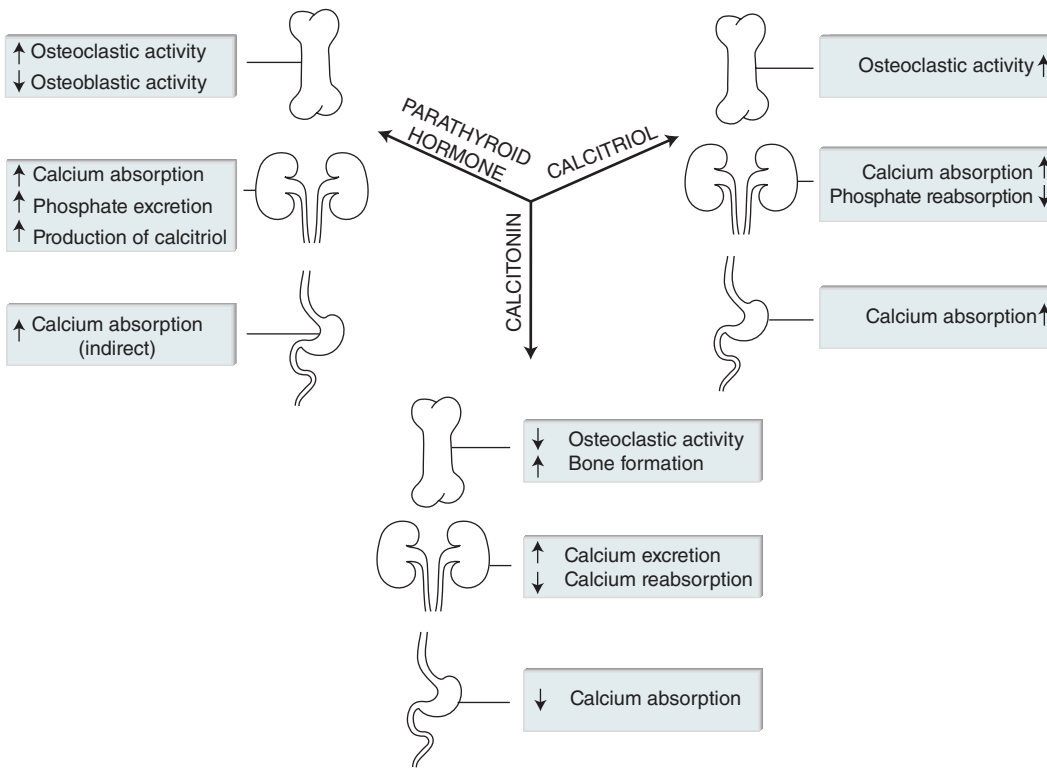


Figure 29.1 Hormonal control of calcium and phosphate.

2. Effect of PTH on bone
   (a) Increases osteoclastic activity on bone, thereby mobilizing calcium from bone to plasma
   (b) Decreases osteoblastic activity and new bone formation, thereby decreasing utilization of blood calcium
3. Effect of PTH on intestine
   (a) Increases the absorption of calcium and phosphorus by indirectly increasing the renal production of 1,25-dihydroxycholecalciferol (calcitriol)

Applied Physiology

Hyperparathyroidism

It is characterized by increased levels of PTH in the body which results in resorption of bone, increased absorption and reabsorption of calcium which eventually ends in increasing the serum calcium levels. This causes severe bone pain, abdominal pain and metastatic calcifications. Though new bone formation commences with induced bone resorption, at some point resorption surpasses the formation of bone. This results in a characteristic pathology commonly affecting the jaw bone called as Brown's tumour of hyperparathyroidism. The term *tumour* is a misnomer since essentially this lesion is composed of granulation tissue and osteoclast-type giant cells. Further, very rarely can hyperparathyroidism be associated with multiple internal resorption of tooth.

Hypoparathyroidism

It results in a reduced serum calcium level (hypocalcaemia). Hypocalcaemia leads to a neuromuscular disorder known as *tetany*. Hypoparathyroidism at a very early stage of life can lead to abnormalities in tooth development which may present as a generalized pitting type of enamel hypoplasia.

Calcitonin (Fig. 29.1)

The modes of action of calcitonin are as follows:

1. When the blood calcium level increases, calcitonin reduces the number of active osteoclasts and inhibits bone resorption, thereby reducing the amount of calcium mobilized to blood.
2. It prevents the distal tubular reabsorption of calcium, thereby increasing the excretion of calcium and reducing the blood calcium level.

Vitamin D (Fig. 29.2)

The most active metabolite of vitamin D is calcitriol, which is formed in the kidney and is considered a hormone.

The active form of vitamin D is formed from vitamin D_2 or ergocalciferol and vitamin D_3 or cholecalciferol. Vitamin D_3 is made in the skin when 7-dehydrocholesterol reacts with ultraviolet light. Ergosterol is derived from diet. Cholecalciferol is hydroxylated in the liver to form 25-hydroxycholecalciferol. This reaction is catalysed by the microsome enzyme present in the liver, hepatic 25-hydroxylase. It is further transported to the proximal tubules of the kidneys, where it is hydroxylated to form calcitriol (1,25-dihydroxycholecalciferol). This product is the active form of vitamin D, which mediates most of the physiologic actions of the vitamin.

Calcitriol is responsible for all the effects of vitamin D on calcium metabolism. Calcitriol increases the blood calcium level by its effect on the intestine, kidneys and bone. The functions of calcitriol are as follows:

1. Calcitriol increases the formation of calcium-binding proteins, which in turn cause increased absorption of calcium from the intestine and also enhance calcium transport.
2. Calcitriol increases osteoclastic activity and increases mobilization of calcium from bone to blood.
3. Calcitriol increases renal reabsorption of calcium and decreases phosphate reabsorption.

Applied Physiology

Rickets

This is a condition which affects children with calcium, phosphate and vitamin D deficiency. Malformed teeth and bone abnormalities are seen in this condition.

Other Hormones Involved in Calcium Metabolism and Bone Turnover

1. **Growth hormone:** It increases absorption of calcium from intestine and also enhances protein synthesis in bone.
2. **Insulin:** It is an anabolic hormone that favours bone formation.

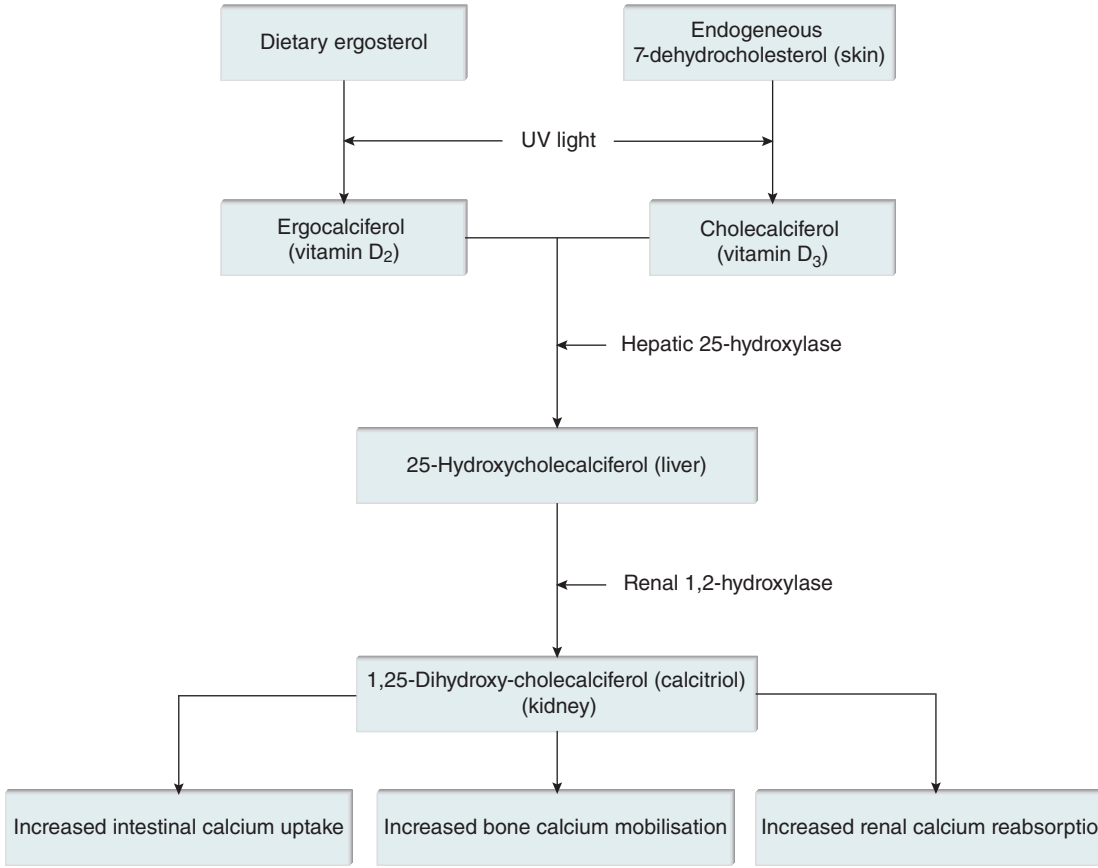


Figure 29.2 Metabolism and actions of vitamin D.

3. **Sex hormones:** They increase calcium absorption, decrease calcium excretion and enhance bone mineralization. Oestrogen has a direct effect in reducing bone resorption.
4. **Prolactin:** It increases calcitriol production, thereby increasing calcium absorption during the lactating period.
5. **Thyroid hormone:** An increase in the levels of thyroid hormone is accompanied by osteoporosis and hypercalciuria.

PHOSPHATE

The total body content of phosphate is 320 mmol/kg. Eighty-five percent of the body's phosphate content is present in the bones and teeth; the rest is widely distributed in the cells.

Functions of Phosphate

1. Helps in the development of bone and teeth
2. Helps in the metabolism of fat and carbohydrate (phosphorylation)
3. Helps in the formation of adenosine triphosphate (ATP)
4. Helps in the formation of nucleic acids

Dietary Intake

The RDA of phosphate is around 550 mg/day but has to be increased in pregnant and lactating females (around 1,000 mg/day). Some of the rich sources of phosphate are milk, meat, fruits and vegetables.

Phosphate Absorption

Phosphate is absorbed in the duodenum. The presence of calcitriol increases phosphate absorption. Excess of iron, calcium and aluminium retards phosphate absorption.

Phosphate Excretion

Phosphorus is mainly excreted in the urine as phosphates of various cations. Faecal phosphates are excreted in the form of calcium phosphate. Ninety percent of phosphates are reabsorbed in the proximal convoluted tubule. Parathormone decreases renal tubular reabsorption of phosphates.

Blood Phosphorus Concentrations

The normal blood level of phosphorus is 2–4 mg/100 mL in adults.

CLINICAL CONSIDERATIONS

1. **Tetany:** When the blood calcium level decreases, it leads to a neuromuscular disorder called tetany.
2. **Rickets:** This is a condition which affects children with calcium, phosphate and vitamin D deficiency. Malformed teeth and bone abnormalities are seen in this condition.

ADDITIONAL READING

Calcium Deficiency and Bone Architecture

Deficiency of dietary calcium often leads to decreased body weight, rate of weight gain skeletal bone growth and serum calcium levels. Serum calcium concentration is controlled by hormones calcitonin and parathyroid hormone, and it plays an important role in the maintenance heart beat bone metabolism. Reduction in calcium concentration leads to alterations in the systemic mineral metabolism which further leads to arteriosclerosis and vascular calcification.

Decrease in serum calcium concentration triggers the release of parathyroid hormone which compensates by increasing resorption of calcium from bone. Calcium deficiency affects jaw bone growth also, especially in the cortical bone region. Deterioration of the cortical bone structure occurs due to inhibition of formation of a mineralized surface in both the maxilla and the mandible. Bone resorption has been observed in microCT in the endosteal surface of both the maxilla and the mandible (excerpts from Fujita et al. 2016).

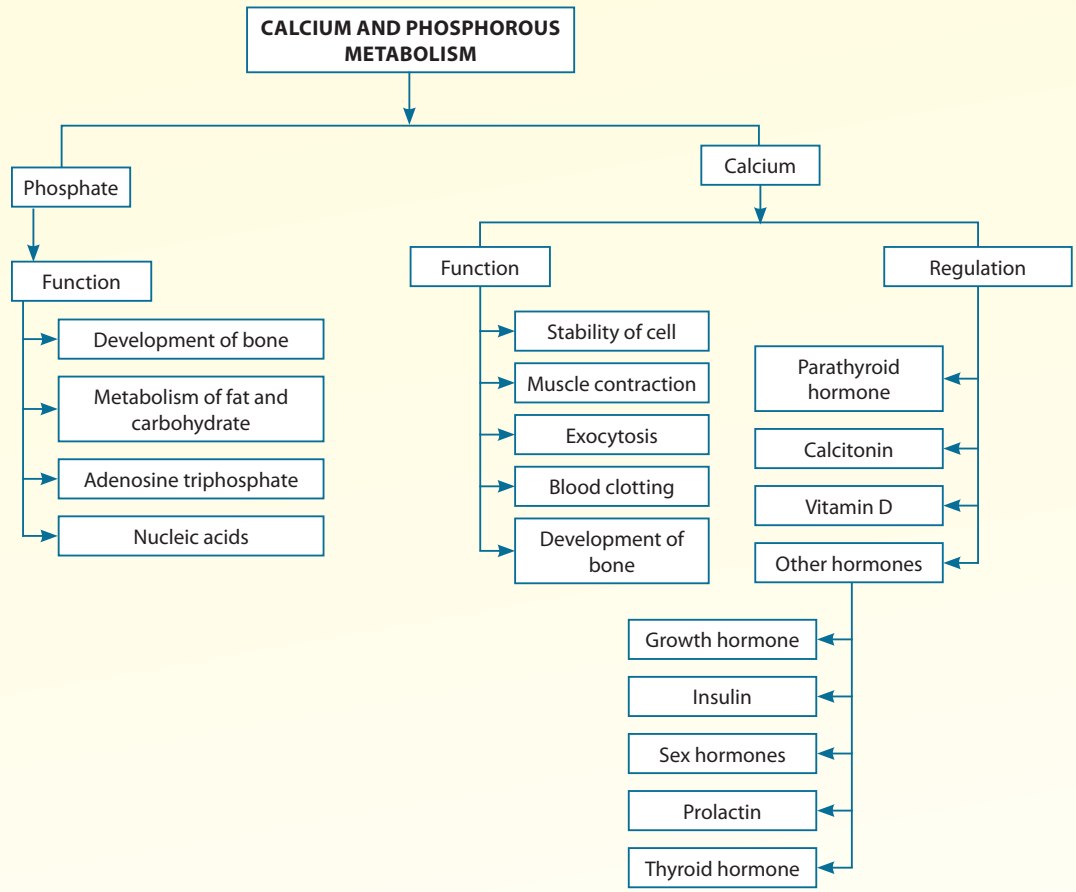
Vitamin D and Calcium Homeostasis

Vitamin D and its' metabolites are a crucial part of the endocrine system that controls whole body calcium homeostasis. The goal of this hormonal control is to regulate serum calcium levels so that they are maintained within a very narrow range. To achieve this goal, regulatory events occur in coordination at multiple tissues, e.g. the intestine, kidney, bone, and parathyroid gland. Production of the vitamin D endocrine hormone, 1,25-dihydroxyvitamin D ($1,25[OH]_2D$) is regulated by habitual dietary calcium intake and physiologic states like growth, aging, and the menopause. The molecular actions of $1,25(OH)_2D$ on calcium regulating target tissues are mediated predominantly by transcription controlled by the vitamin D receptor. A primary role for $1,25(OH)_2D$ during growth is to increase intestinal calcium absorption so that sufficient calcium is available for bone mineralization. Vitamin D also has specific actions on kidney and bone (excerpts from Fleet 2017).

Key Points

1. Bone and teeth contain the maximum amount of calcium and phosphate in the form of calcium hydroxyapatite crystals.
2. The normal blood calcium level is maintained between 9 and 11 mg/100 mL.
3. The parathyroid hormone increases osteoclastic activity of the bone, thereby mobilizing calcium from bone to plasma.
4. The active form of vitamin D is calcitriol. Calcitriol by its effect on the intestine, kidneys and bone increases the blood calcium level.
5. Phosphate helps in the formation of adenosine triphosphate (ATP) and nucleic acids.

Mind Map



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Multiple Choice Questions

1. The amount of calcium present in the body of an adult is approximately
   (a) 1.1 kg
   (b) 3 kg
   (c) 1.1 g
   (d) 4 kg
2. The normal blood calcium level ranges between
   (a) 6 and 7 mg/100 mL
   (b) 9 and 11 g/100 mL
   (c) 9 and 11 mg/100 mL
   (d) 15 and 16 mg/100 Ml
3. The parathyroid hormone has the following effect:
   (a) Reabsorbs calcium
   (b) Excretes phosphate
   (c) Decreases blood calcium
   (d) Both a and b
4. The active form of vitamin D is
   (a) Calcitriol
   (b) 25-hydroxycholecalciferol
   (c) Ergosterol
   (d) 7-dehydrocholesterol
5. The normal blood level of phosphate is
   (a) 7–8 mg/100 mL
   (b) 2–4 mg/100 mL
   (c) 0.5–1 mg/100 mL
   (d) 2–4 g/100 mL

CHAPTER 30



Theories of Mineralization

Overview

The hard tissues of the body are formed by mineralization of bone, enamel, dentin and cementum. The process by which minerals are deposited in the organic matrix, which is capable of accepting the minerals, is called mineralization (calcification). The process of mineralization can be homogeneous or heterogeneous. Proposed theories of mineralization are booster theory, collagen-seeding theory and matrix vesicle theory. Matrix vesicle theory is the widely accepted theory of mineralization.

INTRODUCTION

Mineralization (calcification) is the process by which minerals are deposited in the organic matrix, which is capable of accepting the minerals. Mineralization is one of the important steps in the formation of hard tissues of the body that is bone, enamel, dentin and cementum. The *synthetic cells,* along with the help of the enzyme *alkaline phosphatase,* aid the mineralization process.

The mineral content (inorganic portion) of all the hard tissues of the body is mainly in the form of *calcium hydroxyapatite* crystals, $Ca_{10}(PO_4)_6(OH)_2$. The synthetic cells achieve this property by secreting proteins that stabilize calcium and phosphate in the body fluids and control their deposition onto the extracellular matrix. These proteins are (i) salivary proteins, (ii) enamel matrix protein and (iii) dentin, cementum and bone matrix proteins.

Spontaneous precipitation (crystallization) of calcium phosphate does not occur during the process of formation of hard tissues, even though the tissue fluid contains calcium, phosphate and other minerals. This is because of the presence of substances inhibiting crystal formation and also because of the formation of an unstable, inadequate mass of crystal that cannot initiate the mineralization process.

PROCESS OF MINERALIZATION

Mineralization occurs by aggregation of ions to form crystals. This process is termed as nucleation. Nucleation is of two types:

1. **Homogeneous nucleation:** When local increase in the concentration of minerals allows the formation of sufficient ionic crystals required for mineralization, it is called homogeneous nucleation. Nucleation refers to the first aggregation of ions to form a crystal.
2. **Heterogeneous nucleation:** When the presence of nucleating substances (nucleators), which could act as a template for crystal formation, initiates the process of mineralization even in the absence of an increase in the ionic concentration, it is called heterogeneous nucleation. Collagen and non-collagenous bone proteins may act as nucleators.

The following theories have been put forward to explain mineralization:

1. Booster theory or Robinson's alkaline phosphatase theory
2. Collagen-seeding theory
3. Matrix vesicle theory

Booster Theory or Robinson's Alkaline Phosphatase Theory

According to the Booster theory, the alkaline phosphatase present in the organic matrix of calcifying tissue hydrolyses organic phosphates (pyrophosphates) present in the plasma and calcifying tissue fluid to release phosphate ions. This local increase in phosphate ions is sufficient to cause

precipitation. The phosphate ions combine with the calcium ions present in the tissue fluid to form hydroxyapatite crystals.

This theory is not accepted widely because of the following reasons:

1. It is based on an experimental study conducted on a diseased tissue and not on a normal tissue.
2. Alkaline phosphatase is also seen in other tissues which do not calcify.
3. The organic phosphate present in the tissue fluid of calcifying tissue is not sufficient to produce adequate amount of inorganic phosphate to initiate the calcification process.

Collagen-Seeding Theory

Nucleating substances with spatial arrangement similar to that of hydroxyapatite crystals can act as a template over which crystals can be deposited and thereby the mineralization process can be initiated. One such nucleating substance is collagen (seed). Certain amino acids in collagen have a spatial arrangement similar to that of hydroxyapatite and can act as a template. Calcium and phosphate ions present in the extracellular fluid can bind to these specific sites in the collagen and form hydroxyapatite crystals, which further grow with the addition of ions.

Calcium binds to proteoglycans present in the gap between collagen molecules. Proteoglycans are removed by enzymatic action, and calcium is freed. Once proteoglycans are removed, phosphoproteins are attached to collagen. These phosphoproteins are broken down by alkaline phosphatase to release phosphate ions. The calcium and phosphate ions combine to form apatite crystals at the gap zone of collagen.

Apart from collagen, lipids and protein polysaccharides can also act as nucleators.

This theory fails to explain mineralization in enamel, which does not contain collagen, and mineralization of cartilage that is initiated in the ground substance and not in collagen.

Another important question the theory needs to answer is why the collagen in the soft tissues does not calcify. Possible reasons are as follows:

1. The spatial arrangement of collagen present in the connective tissue that does not calcify may be different from that of the collagen belonging to calcifiable tissue and therefore it cannot act as a suitable template (seed).
2. Some ground substances may mask the ion-binding sites in collagen belonging to soft tissue, which prevents the binding of ions and thereby prevents mineralization. These substances that prevent mineralization are called *crystal poisons* (e.g. pyrophosphate).

Matrix Vesicle Theory (Fig. 30.1)

Matrix vesicles are organelles of cellular origin that are observed in the matrix of cartilage, bone and other hard tissues. Matrix vesicles bud off from the synthetic cells. They have the capacity to induce the mineralization process and contain enzymes that can break down mineralization inhibitors. Matrix vesicles also contain substances such as ATPase, alkaline phosphatase and pyrophosphatase which can initiate mineralization,

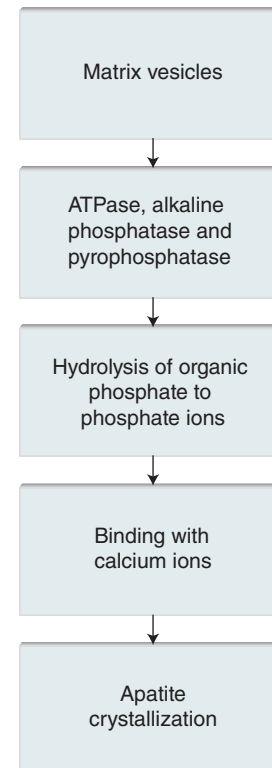


Figure 30.1 Matrix vesicle theory.

thus providing a local environment for the initiation of the mineralization process. Matrix vesicles contain Ca^{2+} ions in large quantities bound to phospholipids, which act as nucleating sites within the vesicle.

Through alkaline phosphatase activity, matrix vesicles hydrolyse organic phosphates to phosphate ions, which in turn bind to calcium and initiate the apatite crystallization. The first crystal is formed within the matrix vesicle. It grows inside the matrix vesicle with the addition of ions. The matrix vesicle finally ruptures, releasing the crystals into the organic matrix, where the crystals grow by using ions in the tissue fluid.

Applied Physiology

1. Substances such as pyrophosphates, nucleotides, citrates and Mg^{2+} act as inhibitors of calcification in the soft tissues.
2. Processes such as inflammation and necrosis can affect the inhibitors and alter the local environment leading to ectopic and extraskeletal calcifications.

ADDITIONAL READING

MATRIX VESICLES—INSIGHT

Formation of the Matrix Vesicle

Matrix vesicles are formed by budding of the cell plasma membrane. This budding has been clearly established with morphological studies. They originate as blebs at surface microvilli, with the retraction of supporting the microfilament network and by working against matrix attachment forces, and promote their release from the cell.

Matrix vesicle formation in cartilage has been established through electron microscopic findings that they form by polarized budding from cell protrusions of the chondrocyte membrane. Cultured osteoblast-like cells exhibited formation of matrix vesicles at the apical membrane. Though the position of the bleb formation could be localized, conditions that facilitate blebbing are poorly understood. A rise in intracellular calcium levels which leads to changes in the localization of membrane phospholipids and proteins (annexins) is being hypothesized to initiate vesiculation.

Mineralization Commencement

Matrix vesicle formation during the endochondral mineralization process has been debated that mineralization is initiated as an intracellular event. Mineral formation is thought to occur first within the cells and not in extracellular particles (matrix vesicles). Apatitic salts or pre-nucleation ion clusters are formed within the endosome; this process is controlled calcium and phosphate metabolism and homeostasis. The mineralized microparticles after their release become embedded or anchored in the dense extracellular tissue as matrix vesicles. Further, after contact with ions of the extracellular fluid, mineral phase transformations and mineral growth occur. The secreted matrix vesicles further serve as a locus for mineral ion and crystal accretion in addition to their involvement with critical mineral nucleation activities.

Matrix Vesicle and Cell-to-Cell Communication

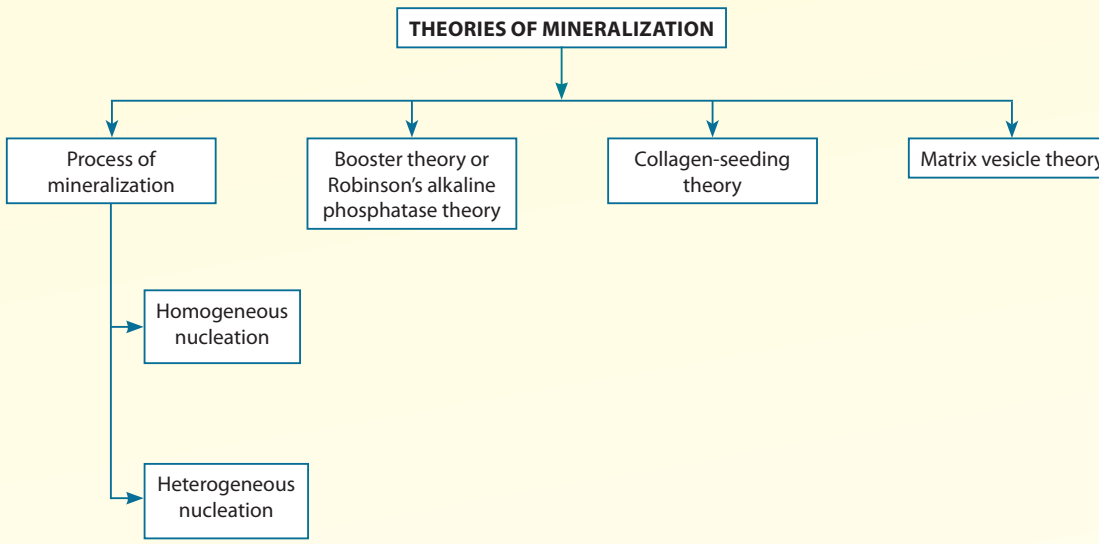
Intracellular components that reflect the composition of the cell of origin are present in matrix vesicles. They include resident cytosolic enzymes, membrane proteins, lipids and ribosomes.

These multiple molecules exert their effects not only on the mineralization properties of the matrix, but also on cell-to-cell communication. The miRNAs regulate post-transcriptional gene expression of differentiating chondrocytes. The expression exerts control over mesenchymal cell-chondrocyte transition influences downstream events involved with chondrocyte-osteoblast interactions and bone formation (excerpts from Shapiro et al. 2015).

Key Points

1. The mineral content (inorganic portion) of all the hard tissues of the body is mainly in the form of calcium hydroxyapatite crystals, $Ca_{10}(PO_4)_6(OH)_2$.
2. Nucleation refers to the first aggregation of ions to form a crystal.
3. Nucleating substances with spatial arrangement similar to that of hydroxyapatite crystals can act as a template over which crystals can be deposited and thereby initiate the mineralization process.
4. Matrix vesicles are organelles of cellular origin that are observed in the matrix of cartilage, bone and other hard tissues. They have the capacity to induce mineralization process.

Mind Map



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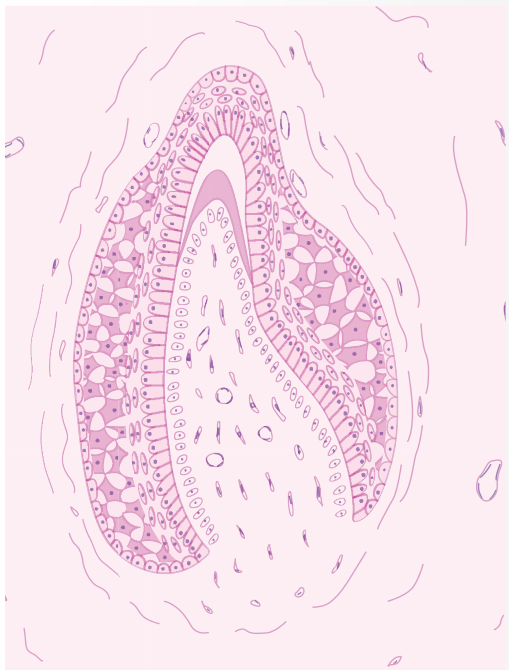
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Multiple Choice Questions

1. The enzyme responsible for mineralization is
   (a) Acid phosphatase
   (b) Alkaline phosphatase
   (c) Collagenase
   (d) Both a and b
2. The following are the functions of alkaline phosphatase:
   (a) Transport ion
   (b) Hydrolyse organic phosphates
   (c) Remove crystal poisons
   (d) All of the above
3. The following can act as a seed for mineralization:
   (a) Collagen
   (b) Nucleotides
   (c) Citrates
   (d) Mg^{2+}
4. Matrix vesicles are derived from
   (a) Synthetic cells
   (b) Resorptive cells
   (c) Inflammatory cells
   (d) Collagen
5. The substances that inhibit mineralization are
   (a) Pyrophosphates
   (b) Nucleotides
   (c) Mg^{2+}
   (d) All of the above

SECTION IV

Oral Histology



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CHAPTER 31

Introduction to Histology

Overview

The chapter outlines the basics of cell biology and tissues. Cell biology deals with the microscopic structure of organelles, interactions, life cycle and division of basic units of organisms. Aggregations of cells organize themselves to form tissues which further form part of larger organ systems. Understanding structure and function aids in correlation in a diseased state.

INTRODUCTION

The study of the microscopic structure of cells and tissue forms the basis of effective understanding of disease process. Cell biology is an important part of histology. Understanding the basics of cell and tissue architecture is vital in understanding the subject of oral histology. Organisms range from being single cellular to multicellular. Unicellular organisms such as bacteria, amoebas and yeasts consist of single cells that are capable of independent self-replication. Highly evolved organisms consist of collections of cells that function in a synchronized manner, with different cells specialized to perform particular tasks. The human body consists of more than 200 types of cells, specific for precise functions. Tissues are made from large groups of cells that group together to complete a shared function. The tissue organizes itself into a particular architecture to form specific organs. Understanding histology enables students to predict and understand organ behaviour and function.

PLASMA MEMBRANE/ CELL MEMBRANE

The plasma membrane (**Fig. 31.1**) is a bilipid membranous layer composed of proteins and carbohydrates. It separates the cell from its external environment and is selectively permeable. It protects the cell and provides stability. Proteins are found embedded within the plasma membrane, with some extending all the way through in order to transport materials. Carbohydrates are attached to proteins and lipids on the outer lipid layer.

Phospholipids (fats) contain a hydrophilic head and a nonpolar hydrophobic tail, which creates a barrier. The cholesterol stiffens the membrane by connecting phospholipids. Glycolipids present in the membrane act as signal molecules.

Proteins embedded in membrane serve different functions. Channel proteins help to form small openings for molecules to diffuse through. Carrier proteins act as gates to provide a binding site on the protein surface and help the movement of certain molecules into the cell. Receptor proteins cause molecular triggers that set off cell responses. Cell recognition proteins helps to identify cells to the body's immune system. Enzymatic proteins play a role in carrying out metabolic reactions.

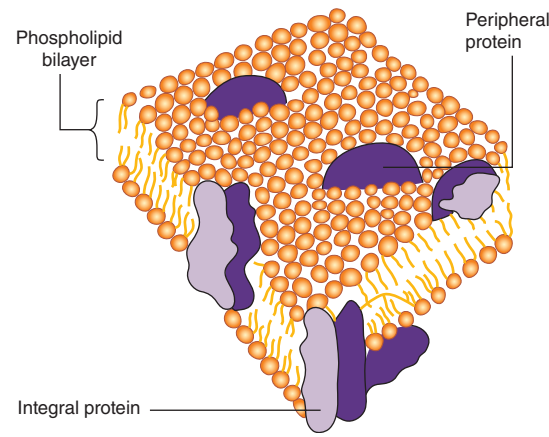


Figure 31.1 Cell membrane. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

CYTOPLASM

Cytoplasm is a semifluid portion thick that fills each cell and is enclosed by the cell membrane. It is mainly composed of water, salts and proteins. The cytoplasm includes all the material inside the cell and outside of the nucleus. All the cell organelles such as the nucleus, endoplasmic reticulum and mitochondria are located in the cytoplasm. The portion of the cytoplasm that is not contained in the organelles is called the cytosol. Cytoplasm is highly organized and consists of a framework of protein scaffolds called the cytoskeleton which gives structural support to the cell.

Organelles

Cell organelles are membrane-bound structures found within a cell. The organelles are bound by a double layer of phospholipids. Each organelle has a specific role to function. The organelles are metabolically active and determine the role of the cell based on its genetic code. The major cell organelles of cell are the nucleus, ribosomes, endoplasmic reticulum, ribosomes, mitochondria, Golgi complex, lysosomes and cytoskeleton. Most of the organelles such as the nucleus, mitochondria, Golgi complex, lysosomes perform similar functions in all the cells; however, some are specialized and are present according to specialization of the cell like the secretory granules in the neuroendocrine cells and melanosomes.

Nucleus

The nucleus is the most vital organelle of the cell. It stores the genetic material DNA. It also controls the cell metabolism and growth.

Nuclear Membrane The nucleus is enclosed by a nuclear membrane. It is made of two phospholipid bilayers. The outer membrane is continuous with that of the rough endoplasmic reticulum which is studded with ribosomes. The inner nuclear membrane is made of lamin proteins which are connected to the nuclear components such as chromatin. The inner membrane proteins that also offer structural support has a role in regulating materials to the nuclear pores for transport. The outer and inner membranes are also joined at nuclear pores which regulate the passage of materials between the nucleus and the cytoplasm. Nuclear pores occur at regions where the inner and the outer membranes of the nuclear envelope fuse. An average of 3000 and 4000 nuclear pores is present in the nuclear membrane and they have a diameter of approximately 600 Å. The space between the two membranes is called perinuclear space.

Nucleolus It is the most distinct suborganelle of the nucleus. It consists of three parts: fibrillar centre, dense fibrillar component and granular component. Nucleolus helps in transcription and processing of ribosomal RNA (rRNA). Transcription of the ribosomal RNA (rRNA) occurs at the boundary of the fibrillar centre and dense fibrillar component. Pre-rRNA processing occurs at the dense fibrillar component and continues in the granular component. Assembly of the rRNA with ribosomal proteins forms partially completed pre-ribosomal subunits which are transported to the cytoplasm.

Chromosomes They are thread-like structures which contain condensed strands of DNA. DNA carries the cell's genetic information. There are 23 pairs of chromosomes in every nucleus. DNA is confined into these 23 pairs of chromosomes. Each chromosome has a central constriction point called the centromere, which divides into two 'arms'. The short arm of the chromosome is referred to as the 'p arm' and the long arm as 'q arm'.

Transcription It is the first step in the process of gene expression during which a segment of DNA is copied into RNA. Transcription happens in the nuclei. The central dogma of cell biology states that the transcribed RNA is further converted to protein. Three types of RNA are formed in the nucleus: mRNA (messenger RNA), rRNA (ribosomal RNA) and tRNA (transfer RNA).

Mitochondria

Mitochondria (**Fig. 31.2**) are cylindrical, rod-like structures which are commonly referred to as power generators of the cell. They consist of two functional membranes which divide the organelle into intermembrane space and internal matrix. The outer membrane acts like a sieve due to the

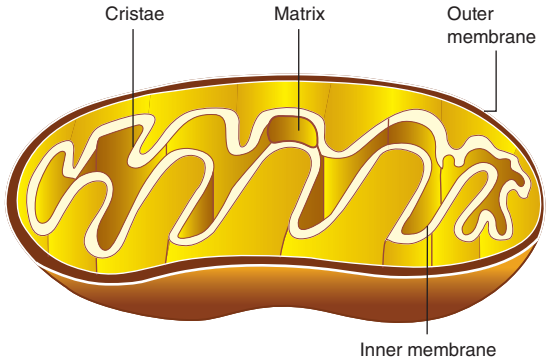


Figure 31.2 Mitochondrion. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

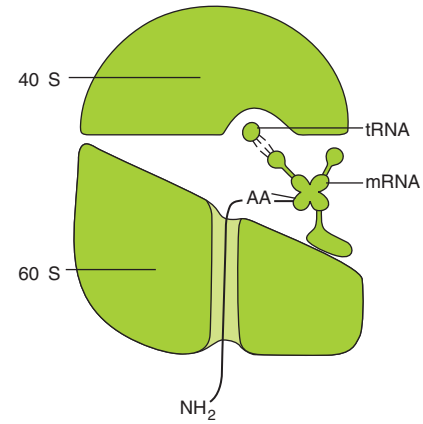


Figure 31.3 Ribosomes.

presence of proteins porin. The inner membrane is highly convoluted with infoldings called cristae. Mitochondria convert oxygen and nutrients into adenosine triphosphate (ATP) through a process called aerobic respiration. ATP plays a potent source of chemical energy that conducts the cell's metabolic activities.

Ribosomes

Ribosomes (**Fig. 31.3**) are minute, sphere-shaped particles which are composed of protein and ribonucleic acid. They serve as the site of protein synthesis. They are abundant in cells that are active in synthesizing proteins. They consist of 60% ribosomal RNA (rRNA) and 40% protein. They are not enclosed by a membrane and are smaller than other organelles. Ribosomes are attached to the endoplasmic reticulum and the nuclear envelope. Some are also freely scattered in the cytoplasm.

Eukaryotic organisms contain rRNA which is organized into four strands. Two ribosomal subunits are created to make a ribosome. These units are referred by their Svedberg(s) values, which are based upon their rate of sedimentation in a centrifuge. Eukaryotes contain ribosomes with a Svedberg value of 80S and are comprised of 40S and 60S sub-units.

Protein synthesis in ribosomes require mRNA and tRNA too. Messenger RNA (mRNA) provides the template of instructions from the cellular DNA for building a specific protein. Transfer RNA (tRNA) brings the protein building blocks, amino acids, to the ribosome. Transfer RNA contains three binding sites on a ribosome: aminoacyl binding site, peptidyl binding site and exit binding site to discharge the used tRNA molecules from the ribosome.

Once the protein backbone amino acids are polymerized, the ribosome releases the protein and it is transported to the cytoplasm in prokaryotes or to the Golgi apparatus in eukaryotes.

Endoplasmic Reticulum

The endoplasmic reticulum (ER; **Fig. 31.4**) consists of parallelly arranged stretched sacs and branching tubules. These sacs and tubules are interconnected to form a large, highly convoluted and complexly arranged lumen. ER acts as a channel between the nucleus and the cytoplasm. ER is of two types:

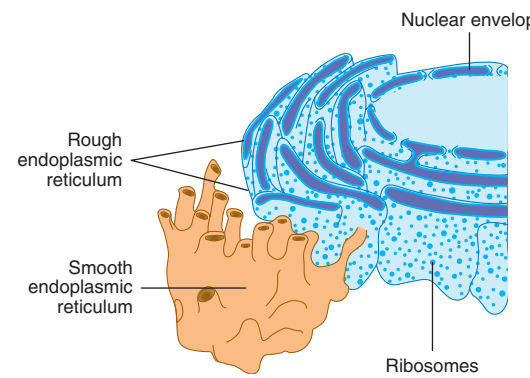


Figure 31.4 Endoplasmic reticulum. (*Source*: Vijaya Joshi, Ashalata Nandedkar and Sadhana Mendhurwar, Anatomy and Physiology for Nursing and Healthcare Students, 3rd edn. Wolters Kluwer India, New Delhi; 2017.)

rough and smooth. Rough endoplasmic reticulum is covered with ribosomes and aids in production and processing of proteins. The ribosomes help in assembling the amino acids into protein units which are further processed in the rough endoplasmic reticulum. The proteins which are formed are either of the transmembrane type or of the water-soluble type. The transmembrane type of proteins becomes embedded in the membrane of the endoplasmic reticulum and water-soluble proteins pass completely through the membrane into the lumen. Proteins which reach the internal lumen undergo post-translational modification by addition of carbohydrates or sugars and are transported as completed proteins to areas of the cell where they are needed or are sent to the Golgi apparatus for further processing and modification.

Lysosomes

Lysosomes (**Fig. 31.5**) are spherical membrane-bound vesicles which function as the digestive system of the cell. They help in degrading the cell's organic material through the process of autophagy. Lysosomes lyse the cellular waste products, fats, carbohydrates, proteins and other macromolecules into simple compounds, which further are transferred back into the cytoplasm.

Cytoskeleton

The cytoskeleton of the cell is responsible for the maintenance of cell shape, motility of the cell as a whole and motility of organelles within a cell. There are three types of filaments in the cytoplasm of most vertebrate cells: microfilaments, microtubules and intermediate filaments.

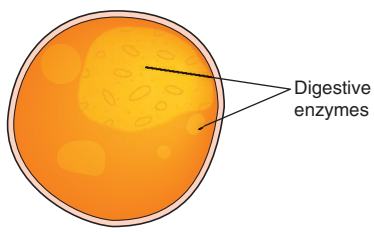


Figure 31.5 Lysosome. (*Source*: Vijaya Joshi, Ashalata Nandedkar and Sadhana Mendhurwar, Anatomy and Physiology for Nursing and Healthcare Students, 3rd edn. Wolters Kluwer India, New Delhi; 2017.)

Microtubules They are the largest type of filament, measuring 25 nm in thickness. They consist of a protein called tubulin. Tubulin is made of two polypeptide subunits, and dimers of these subunits unite to form long strands called protofilaments. Thirteen protofilaments then come together to form the hollow, straw-shaped filaments of microtubules. Microtubules constantly adapt to changes by addition and subtraction of tubulin dimers at both ends of the filament. The end that grows rapidly is called the plus end whereas the other end is known as the minus end. In most cells, microtubules are organized in a radial array extending from a single site termed the microtubule organizing centre (MTOC), generally positioned near the nucleus. The dynamics of microtubules play an important role in vesicle transport, segregation of chromosomes and mitosis. Vesicle transport and chromosome segregation are executed with the help of molecular motors that bind to and move along microtubule tracks. These motors are divided into two families: kinesin and cytoplasmic dynein.

Microfilaments They measure about 8 nm in diameter and are the thinnest of the cytoskeletal filaments. The filament is composed of a protein called actin that measures 42 kilodaltons (kd) in weight. Actin exists in two states: globular actin and filamentous actin. Each microfilament has a fast-growing, or 'plus,' end, and a slow-growing, or 'minus,' end. In most cells, the plus ends of the filaments are oriented towards the edge of the cell. Contraction of microfilaments happens through a process of rapid polymerization of actin monomers onto the plus ends of microfilaments to produce pseudopods on the cell surface. These pseudopods help the cells to move in a particular direction. Microfilaments also mediate cytoplasmic streaming, cytokinesis and muscle contraction. Microfilaments also play a role in cytoplasmic streaming, cytokinesis and muscle contraction.

Intermediate Filaments They have a dimension which is intermediate between the diameters of the other two principal elements of the cytoskeleton (microfilaments and microtubules) and measure about 10 nm. They provide

structural support to cells and tissues. There are about 50 types of intermediate filaments which are composed of a variety of proteins in different types of cells. These are further divided into six groups based on similarities between their amino acid sequences. Types I and II consist of two groups of keratins, each consisting of about 15 different proteins, which are expressed in epithelial cells. Each type of epithelial cell synthesizes at least one type I (acidic) and one type II (neutral/basic) keratin. The type III intermediate filament, vimentin, is found in fibroblasts, smooth muscle cells and white blood cells. Another type III protein—desmin—is specifically expressed in muscle cells, where it connects. A third type III protein is specifically expressed in glial cells and a fourth is expressed in neurons of the peripheral nervous system. The type IV neurofilament (NF) proteins form the major intermediate filaments of many types of mature neurons. Another type IV protein (α-internexin) is expressed at an earlier stage of neuron development, prior to expression of the neurofilament proteins. The type VI intermediate filament protein (nestin) is expressed even earlier during the development of neurons, in stem cells of the central nervous system.

CELL DIVISION

Cell cycle is a complex event and consists of four phases. The four coordinated phases include cell growth, DNA replication, distribution of the duplicated chromosomes to daughter cells, and cell division. Cell cycle is broadly divided into two basic parts: mitosis and interphase. Mitosis involves separation of daughter chromosomes and results in cell division or cytokinesis. However, mitosis last only for an hour; about 95% of the cell cycle is spent in interphase. Interphase involves condensation of chromosomes and distribution in the nucleus. The four distinct phases consist of M, G_1, S and G_2. The M phase of the cycle corresponds to mitosis. This phase is followed by the G_1 phase (gap 1), the gap between mitosis and initiation of DNA replication. G_1 is followed by the S phase (synthesis), during which DNA replication takes place. The completion of DNA synthesis is followed by the G_2 phase (gap 2), during which cell growth continues and proteins are synthesized in preparation for mitosis.

EXTRACELLULAR MATRIX

Extracellular matrix, however, is most abundant in connective tissues and consists of a mixture of proteins, polysaccharides and adhesion proteins that connect components of the matrix to one another and to attached cells. Extracellular matrix provides attachment sites for cells and supports sheets of epithelial cells basal laminae and surround muscle cells, adipose cells and peripheral nerves.

The macromolecules that constitute the extracellular matrix are mainly produced by cells in the matrix. Two main classes of extracellular macromolecules make up the matrix: (i) polysaccharide chains of *glycosaminoglycans* (*GAGs*), which are usually found covalently linked to protein in the form of *proteoglycans,* and (ii) fibrous proteins, including collagen, elastin, fibronectin and laminin, which have both structural and adhesive functions.

The major structural protein of the extracellular matrix is collagen, which is the single-most abundant protein in animal tissues. The collagens contain 19 different members. The defining feature of collagen is a highly structured motif in which three parallel polypeptide strands in a left-handed, polyproline II-type (PPII) helical conformation coil about each other with a one-residue stagger to form a right-handed triple helix. The amino acid sequence of a collagen triple helix domain consists of Gly-X-Y repeats, in which X is frequently proline and Y is frequently hydroxyproline.

INTERCELLULAR JUNCTION (Box 31.1)

Intercellular junctions are structures that provide adhesion and communication between cells. Cell–cell junctions play a key role in the organization of cells in tissues. Several different types of cell–cell junctions are critical to the maintenance and function of epithelium.

Box 31.1 Functional Classification of Cell Junctions *(adapted from Alberts B. Molecular Biology of the Cell)*

Occluding junctions
- Tight junctions

Anchoring junctions
- Actin filament attachment sites
  - Cell–cell junctions (adherens junctions)
  - Cell–matrix junctions (focal adhesions)
- Intermediate filament attachment sites
  - Cell–cell junctions (desmosomes)
  - Cell–matrix junctions (hemidesmosomes)

Communicating junctions
- Gap junctions
- Chemical synapses

Three types of intercellular junctions have been defined based on their function:

1. Tight or occluding junctions
2. Adherent or anchoring junctions
3. Gap junctions

Occluding Juctions

Tight or occluding junctions (**Fig. 31.6**) have very close adaptation of cell membranes of the adjacent cell. These junctions prevent the intercellular exchange of large molecule substances and allow selective passage of small molecules. They provide strength and stability to the tissues. They consist of transmembrane proteins claudin and occludin. They are arranged as parallel rows embedded into the adjacent plasma membrane. The transmembrane proteins associate with the intracellular peripheral membrane proteins called ZO (zonula occludens) proteins which are involved in anchoring the strands to the actin cytoskeleton of the epithelial cell.

Anchoring Junctions

Cell junctions that help to anchor one cell to another and to the components of the extracellular matrix are called anchoring junctions. They assist in keeping the cells together and provide structural cohesion of tissues.

Anchoring or adherens junctions (**Fig. 31.6**) are involved in cell-to-cell contact and help the cells to hold together. They are attached to the cell cytoskeleton by actin filaments. They are composed of cadherins, delta catenin (p120), gamma catenin (plakoglobin) and alpha catenin. They appear as bands encircling the cell (zonula adherens) and are found immediately below the tight junctions or as spots of attachment to the extracellular matrix (adhesion plaques).

Desmosomes help in cell-to-cell contact and use actin filaments as the cytoskeletal anchor. The junction consists of a dense cytoplasmic plaque consisting of intracellular anchor proteins plakoglobin and desmoplakin that are responsible for connecting the cytoskeleton to the transmembrane adhesion proteins desmoglein and desmocollin.

Hemidesmosomes, or half-desmosomes, link a cell to the extracellular matrix and use intermediate filaments as the cytoskeletal anchor. The extracellular domains of the integrins that mediate the adhesion bind to a laminin in the basal lamina, while an intracellular domain binds via an anchor protein plectin to keratin intermediate filaments.

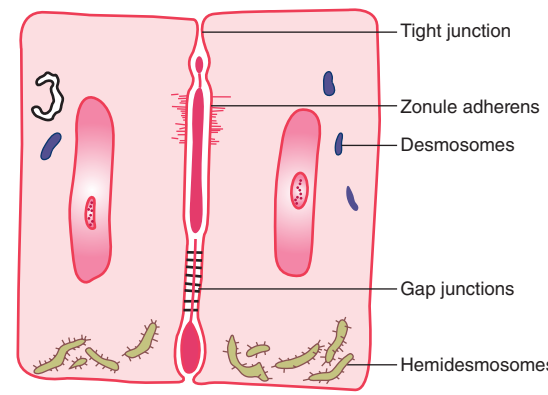


Figure 31.6 Intercellular connections. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

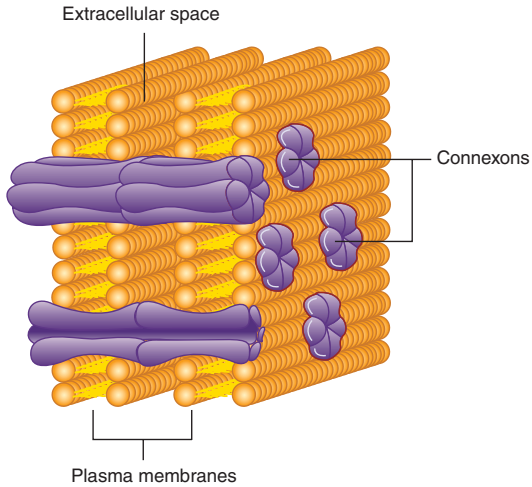


Figure 31.7 Gap junctions. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

Gap Junctions

Gap junctions (**Fig. 31.7**) are the most common of all cell junctions in animal tissues. They enables direct communications between cells. The gap measures about 2–4 nm between two adjacent cells. They respond to changes in calcium levels and pH.

Gap junctions are composed of transmembrane proteins called connexins. Six connexins assemble to form a cylinder-like structure with a central open aqueous pore. Connexins of one cell are aligned with the connexins of the adjacent cell, forming an open channel between the two cytoplasms.

BASIC TISSUES

Epithelial Tissue

Epithelial tissues (**Fig. 31.8**) form the covering of all body surfaces. They line body cavities and hollow organs and are the major tissue of glandular structures. They perform a variety of functions that include protection, secretion, absorption, excretion, filtration and diffusion.

The cells in epithelial tissue are tightly packed together and are arranged in the form of sheets. They are attached to the adjacent cell with intercellular attachment apparatus. These protein connections hold the cells together to form a tightly connected layer that is avascular but innervated in nature.

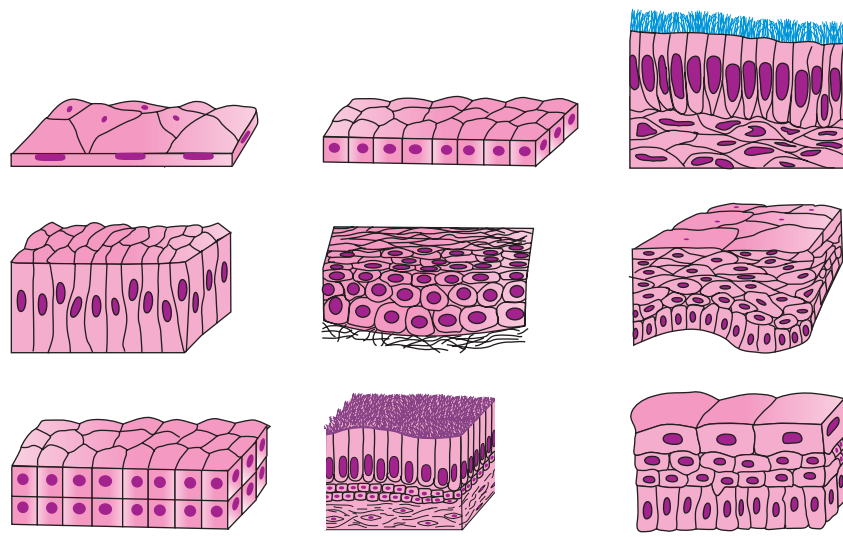


Figure 31.8 Epithelial tissues. (*Source*: DR Singh, Essentials of Anatomy for Dentistry Students, 2nd edn. Wolters Kluwer India, New Delhi; 2017.)

Epithelial cells may be squamous, cuboidal or columnar in shape and may be arranged in single or multiple layers.

Based on the cell shape, the cells are classified into squamous cells, cuboidal cells, columnar cells and transitional cells. Squamous cells are flat in shape and the nucleus is located near the upper surface. Cuboidal cells are cube-like cells or hexagon-shaped with a central, round nucleus. Columnar cells are tall with an oval nucleus near the basement membrane. These cells may present with microvilli or minute the surface extensions to increase the surface area for absorbing substances. Transitional cells range from flat to tall cells that can extend or compress in response to body movement.

Based on the number of cell layers, three types—simple, stratified and pseudostratified—have been described. Simple cuboidal epithelium describes a single layer of cells and is found in glands and kidney tubules. Simple columnar epithelium lines the gastrointestinal system, Stratified epithelium describes epithelium consisting of multiple layers and is found in the oral cavity. Pseudostratified epithelium describes a single layer of cells of different sizes, giving the appearance of being multilayered and is found lining the respiratory system.

Basement Membrane

The basement membrane (**Fig. 31.9**), also called the basal lamina, is a specialized form of extracellular matrix. It is usually 30–60 nm thick and is composed of collagenous and non-collagenous glycoproteins and proteoglycans. It is difficult to be observed with conventional light microscopy but is clearly visualized under an electron microscope. It lies under sheets of epithelial cell and can surround cells in muscle fibres. It is also present between two sheets of cells, such as the endothelial cells of blood vessels and the epithelial cells of another tissue in the kidney glomerulus.

The basement membrane consists of a mixture of collagens, laminin (glycoprotein), perlecan (heparan sulphate glycoprotein) and entactin (glycoprotein). These proteins can bind to each other to make a highly cross-linked extracellular matrix. It helps to attach and anchor the cells to the underlying connective tissue. Proteins (integrins and proteoglycans) in the cell membranes attach to proteins in the basal lamina, which in turn is linked to the extracellular matrix of connective tissue.

The basement membrane consists of three distinct layers: (i) lamina lucida—electron lucent (very little staining under electron microscopy), (ii) lamina densa—electron dense and (iii) lamina reticularis—can be associated with reticular fibres of the underlying connective tissue.

CONNECTIVE TISSUE

Connective tissue (**Fig. 31.10**) fills the spaces between tissues and bind structures together. It provides structural and metabolic support for other tissues and organs. Connective tissue is made up of cells and extracellular matrix. The extracellular

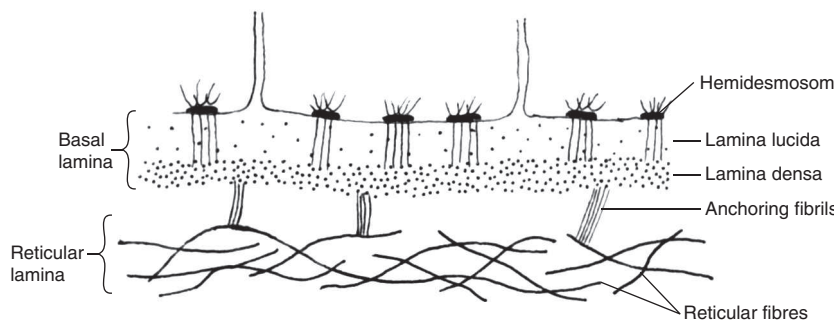


Figure 31.9 Basement membrane. (*Source*: Brijesh Kumar, Histology: Text & Atlas. Wolters Kluwer India, New Delhi; 2013.)

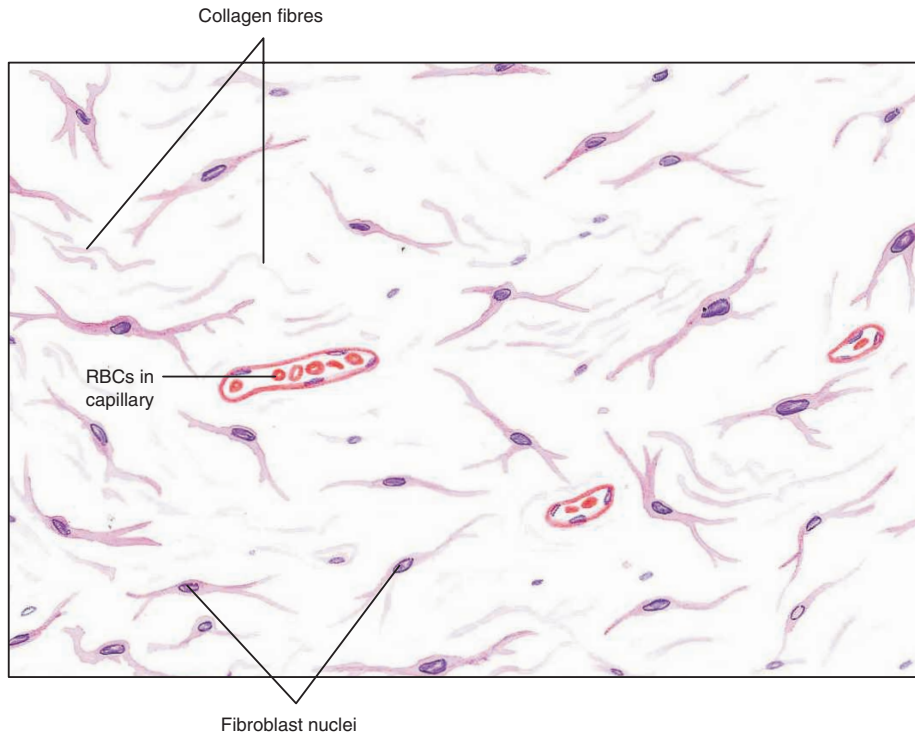


Figure 31.10 Connective tissue. (*Source*: DR Singh, Essentials of Anatomy for Dentistry Students, 2nd edn. Wolters Kluwer India, New Delhi; 2017.)

matrix is made up of fibres in a protein and polysaccharide matrix, secreted and organized by cells in the extracellular matrix. Variations in the composition of the extracellular matrix determine the properties of the connective tissue. The matrix is made up of glycoproteins, fibrous proteins, glycosaminoglycans and water.

Connective tissue is either loose or dense (**Fig. 31.11**), depending on the arrangement of the fibres. Loose connective tissue contains many cells in a matrix which consist of few fibres. Dense connective tissue contains a densely arranged network of collagen fibres. Dense connective tissue is called regular if the fibres are oriented in one direction and irregular in case of random orientation.

Connective tissue has numerous cell types, fibroblasts, fat cells or adipocytes, macrophages, monocytes, lymphocytes, plasma cells, eosinophils and mast cells.

Fibroblasts are the commonest cell type of connective tissue. They synthesize collagen and ground substance of the extracellular matrix. They are oval with an elongated nucleus and contain large amounts of the organelles such as mitochondria and rough ER which are necessary for the synthesis and excretion of proteins. The resting fibroblast is called a fibrocyte which contains less number of organelles. Fibroblasts with a contractile function are called myofibroblasts.

Macrophages are large, round cells that contain a central round nucleus and have abundant clear, often vacuolated, cytoplasm. They arise from monocytes and are representative of the reticuloendothelial, or mononuclear phagocyte, system. Monocytes originate in the bone marrow from where they are released into the bloodstream to enter connective tissues, where they differentiate into macrophages. Macrophages change their appearance depending on the demand for phagocytic activity. They are indistinguishable from fibroblasts but can be recognized when they internalize large amounts of visible tracer substances such as dyes or carbon particles.

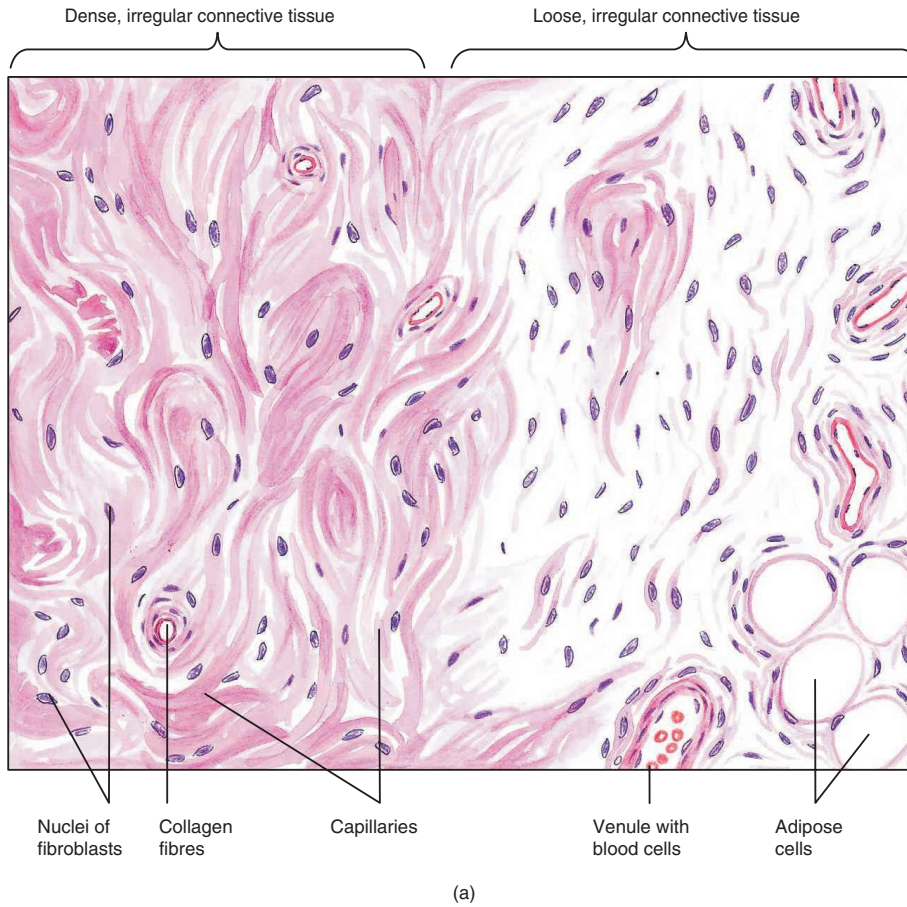


Figure 31.11 Connective tissue: (a) Dense, regular. (*Continued*)

Macrophages phagocytose foreign material in the connective tissue layer and also play an important role as antigen-presenting cells.

Mast cells are also called mastocyte or labrocyte and are round or oval shaped with an oval or bean-shaped nucleus. The cytoplasm of the mast cells is however filled with dark, blue/violet grains which represent their secretory vesicles. These cells mediate immune responses to foreign particles by releasing large amounts of histamine and enzymes in response to antigen recognition.

Lymphocytes are small cells with round nuclei and minimal cytoplasm. They are common in the lamina propria zone. T and B lymphocytes are indistinguishable by light and electron microscopy and require special immunological stains. Natural killer cells tend to be larger cells with relatively large granules scattered in their cytoplasm. B cells mature into plasma cells upon activation by engagement with antigen or with certain B-cell mitogens.

Plasma cells are terminally differentiated B lymphocytes that have developed a characteristic morphology. The size of the cell is large with abundant cytoplasm. The nucleus is eccentrically placed and the overall shape of the cell generally resembles a wedge or comet with the nucleus leading the cytoplasm. The chromatin is just as thick and aligned in a cartwheel pattern. The cytoplasm is usually more basophilic than the cytoplasm of a normal lymphocyte and will have a well-defined perinuclear halo or noticeable clearing in the Golgi area.

Eosinophilic cells are large round or oval cells, which contain large amounts of bright red granules

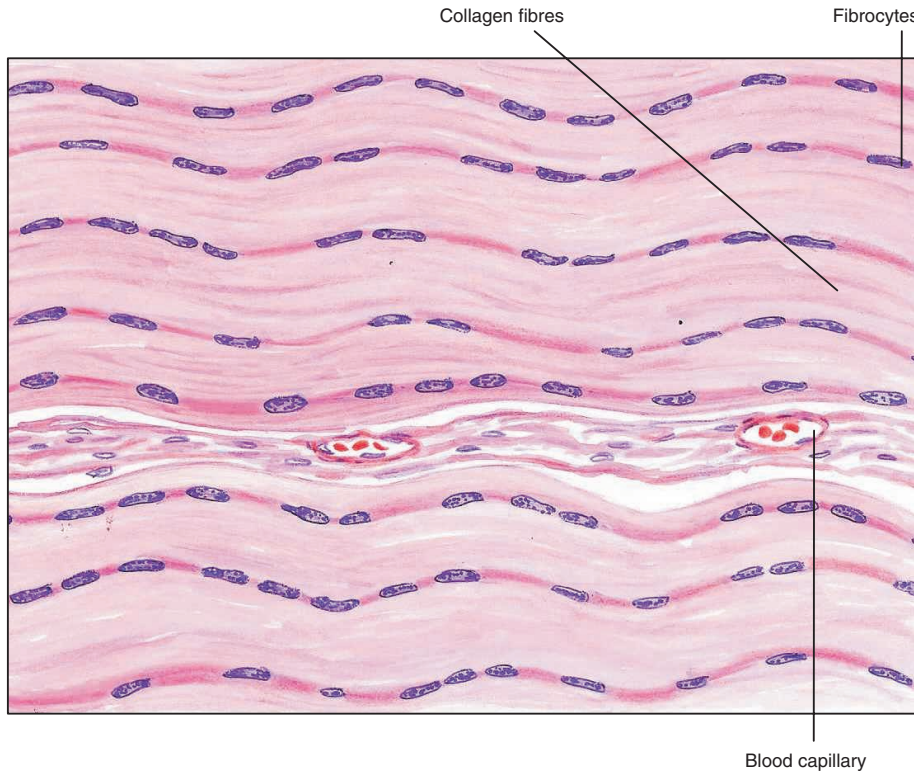


Figure 31.11 (*Continued*) Connective tissue: (b) dense, irregular. (*Source*: DR Singh, Essentials of Anatomy for Dentistry Students, 2nd edn. Wolters Kluwer India, New Delhi; 2017.)

in their cytoplasm. They originate in the bone marrow and enter connective tissues during the initial phases of the inflammatory reactions, where they phagocytose antigen–antibody complexes.

SPECIALIZED CONNECTIVE TISSUE

Adipose Tissue

Adipose tissue (**Fig. 31.12**) is a specialized type of connective tissue in which adipocytes or fat cells are found. These cells can be found isolated or in groups within loose or irregular connective tissue, often in large aggregates. Adipocytes are unilocular and measure about 100 μm or more. Each cell contains a droplet of lipid that fills almost the entire cell. The lipid a droplet displaces and flattens the nucleus against the cell membrane. Lipid storage and mobilization is under nervous and hormonal control. Adipocytes also have an endocrine function—they secrete the protein leptin which provides brain centres which regulate appetite with feedback about the body's fat reserves. White fat cells are specialized for the storage of triglyceride and occur singly or in small groups scattered throughout the loose connective tissue. Brown fat cells are highly specialized for temperature regulation. These cells are abundant in newborns and hibernating mammals but are rare in adults.

Cartilage

Cartilage (**Fig. 31.13**) is a strong, flexible and semi-rigid tissue. It is made of chondroblasts and chondrocytes and extracellular matrix containing

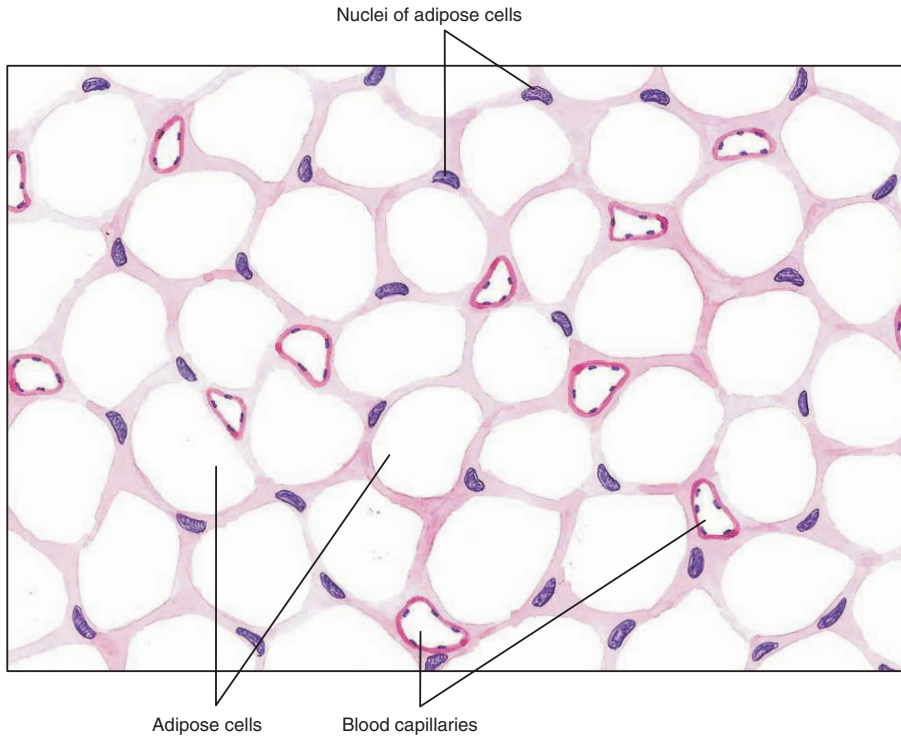


Figure 31.12 Adipose tissue. (*Source*: DR Singh, Essentials of Anatomy for Dentistry Students, 2nd edn. Wolters Kluwer India, New Delhi; 2017.)

10% aggrecan, 75% water and a mix of collagen fibres.

The extracellular matrix of cartilage is secreted by chondroblasts and due to continuous secretion, they become trapped inside it and mature into cells called chondrocytes. The chondrocytes divide and form daughter cells which tend to remain close together. They are enclosed in spaces called lacunae. The active chondrocytes are large secretory cells with basophilic cytoplasm due to increased presence of rough ER. A dense fibrous connective tissue capsule known as the perichondrium surrounds cartilage.

Based on the abundance of fibres and the characteristics of the matrix, cartilage is classified into the following three types:

1. Hyaline cartilage is composed of type II collagen and chondromucoprotein. Increased presence of negatively charged sulphate groups makes it appear intensely basophilic under H&E.
2. Fibrocartilage is composed of type I collagen fibres. It is located in regions where tendons attach to bones.
3. Elastic cartilage is characterized by abundant elastic fibres and cells. It is made up of type II collagen.

Bone

Bone (**Fig. 31.14**) is a rigid connective tissue and functions as a mechanical support and ion reserve for metabolic functions. It consists of cells and matrix. Bone matrix is made up of 40% organic component and 60% of inorganic component. Organic constituents include type I collagen, proteoglycans, non-collagenous proteins osteocalcin, osteonectin and osteopontin. Inorganic contents include predominantly calcium and phosphorous

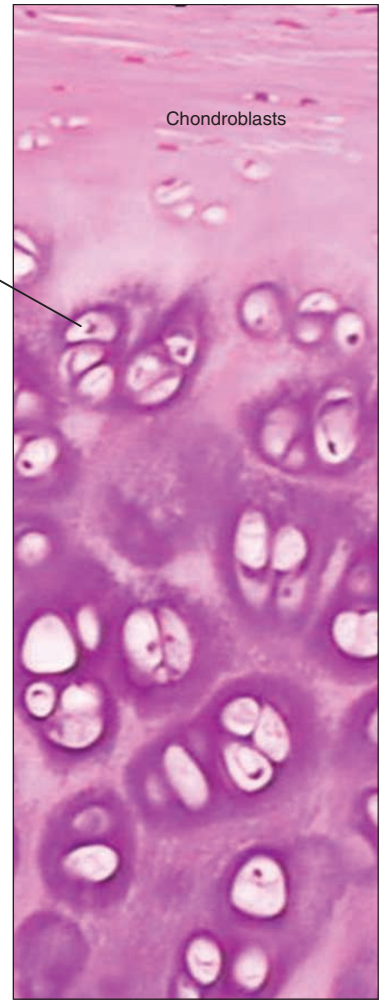


Figure 31.13 Cartilage. (*Source*: DR Singh, Essentials of Anatomy for Dentistry Students, 2nd edn. Wolters Kluwer India, New Delhi; 2017.)

in the form of calcium hydroxyapatite and osteocalcium phosphate.

The cellular components include osteoblasts, osteoclasts and osteocytes. Osteoblasts synthesize the bone matrix and are derived from osteoprogenitor cells. Osteoclasts are bone resorbing cells which are derived from the monocytes. Osteocytes are inactive osteoblasts that have become trapped within the bone matrix.

Bone is divided macroscopically into compact and trabecular types.

Compact bone or cortical bone is thick and dense and forms the outer part of the bone proper. It provides mechanical support to the bone. Mature compact bone consists of lamellae that form concentric rings around larger longitudinal canals called Haversian canals. Haversian canals run parallel to the surface and along the long axis of the bone. The canals and the surrounding lamellae are called a Haversian system or an osteon. A Haversian canal generally contains one or two capillaries and nerve fibres. Haversian canals are interconnected by horizontally placed canals called Volkmann's canals

Trabecular bone, also known as cancellous bone or spongy bone, forms the inner part of the bone and helps in metabolism. They are highly vascular and contains red or yellow marrow depending on the age of the individual. The functional unit of cancellous bone is the trabecula. Trabecula are arranged as a network and are few cell layers thick. There are no blood vessels within the matrix of spongy bone but are well nourished from the adjacent blood vessels in the marrow spaces.

Blood

Blood is a fluid connective tissue and consist of plasma and cells. Blood cells, constitute 35–50% of the volume of blood and are of three basic types: erythrocytes or red blood cells, leucocytes or white blood cells and platelets or thrombocytes. Plasma constitutes 55% of the blood volume. It consists of water (92%), proteins, lipids, inorganic ions and glucose.

Erythrocytes, or red blood cells (**Fig. 31.15**), are the main group of cells in blood. They are biconcave disc shaped and lack nuclei. Red blood cells have a characteristic pink appearance due to their high content of haemoglobin. The central pale area of each red blood cell is due to the concavity of the disc. Red blood cells help to carry oxygen from lungs to the tissues.

White blood cells are less common than red blood cells. They are divided into two main classes: granulocytes (includes neutrophils, eosinophils and basophils) and agranulocytes (includes lymphocytes and monocytes) based on the presence or absence of granules in their cytoplasm.

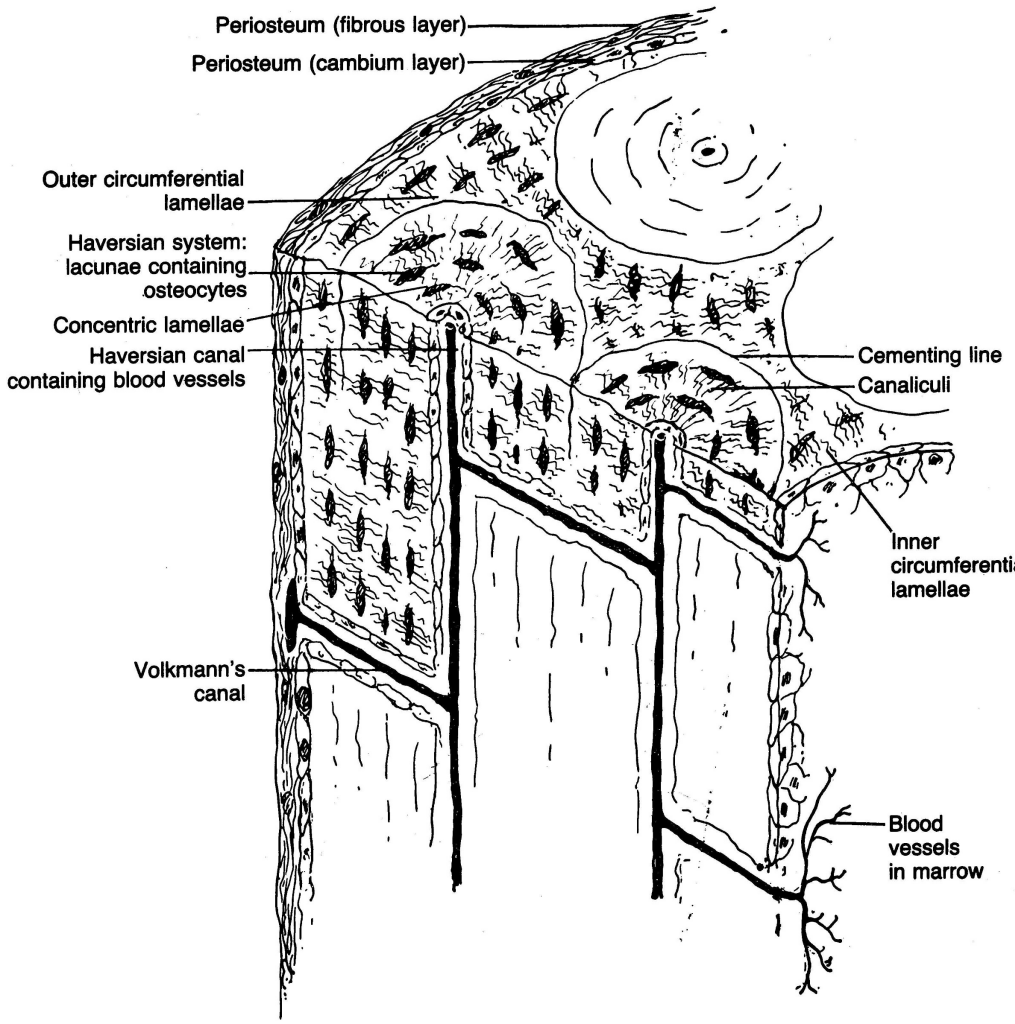


Figure 31.14 Bone. (*Source*: Turek's Orthopaedics Principles and Their Application, 7th edn. Anil K Jain [ed]. Wolters Kluwer India, New Delhi; 2016.)

Neutrophils are the commonest type of white blood cell and have three types of granules: lysosomes, secretory granules and anti-microbial enzymes that have glycoproteins and gelatinase. They are motile and phagocytic and will destroy damaged tissue and bacteria. Neutrophils play an important role in inflammatory reactions.

Eosinophils (**Fig. 31.16**) account for 1–6% of white blood cells. They contain a bilobed nucleus and cytoplasm filled with large granules. Granules contain granule proteins, cytokines, growth factors

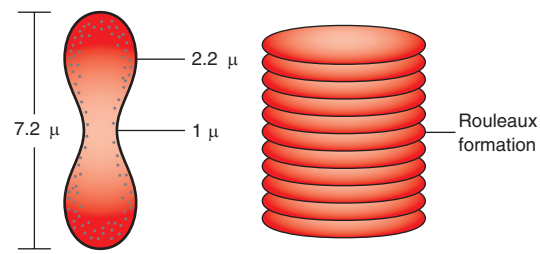


Figure 31.15 Erythrocytes. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

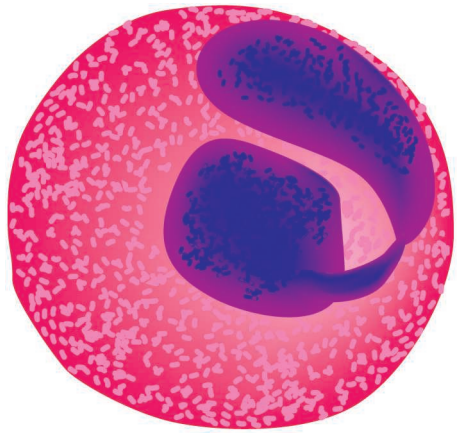


Figure 31.16 Eosinophils. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

and chemokines that are secreted in response to receptor stimulation. Eosinophil degranulation is thought to be an essential component of the late-phase mucosal tissue response to allergen challenge. Eosinophil degranulation has been detected in allergic rhinitis, cutaneous allergic reactions and atopic asthma.

Basophils (**Fig. 31.17**) account for 0.5–1% of circulating white blood cells. They have a centrally placed nucleus with numerous granules in the cytoplasm. The granules tend to mask the nucleus and contain histamine, leukotrienes and heparin. Histamine is released during allergic and inflammatory reactions. Leukotrienes are substances in the body that produce allergic and inflammatory reactions, similar to histamine. Heparin is a naturally occurring substance in the body that prevents clotting.

Lymphocytes (**Fig. 31.18**) are white blood cells and are initiated by the immune system. They play an important role in defence against cancerous cells, pathogens and foreign matter. Lymphocytes are of three types: B cells, T cells and natural killer cells. B lymphocytes (B cells) and T lymphocytes (T cells) play a crucial role in specific immune responses. B cells are generated from bone marrow in adults. They are provoked when there is an antigen entry. They respond to produce antibodies that are specific to that antigen. Production of antibodies contributes to the humoral form of immunity where the antibodies circulate in body fluids.

T cells are responsible for cell-mediated immunity. Receptors on T cell help in recognition of various types of antigens. There are three major classes of T cells: cytotoxic T cells, helper T cells and regulatory T cells. Cytotoxic T cells directly terminate cells containing antigens by binding to them and lysing or causing them to burst open. Helper T cells precipitate the production of antibodies by B cells and also produce substances that activate other T cells. Regulatory T cells or

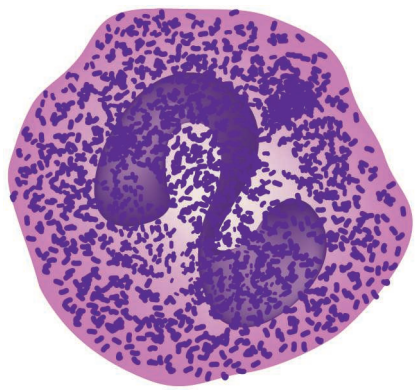


Figure 31.17 Basophils. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

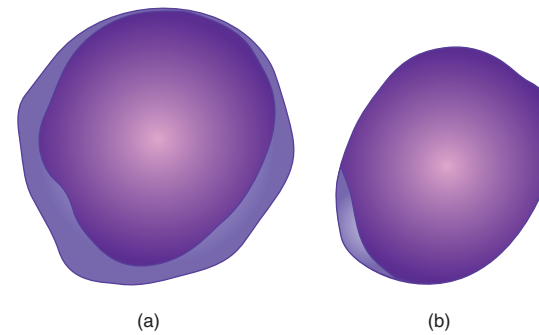


Figure 31.18 Lymphocytes: (a) Large and (b) small. (Source: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

suppressor T cells suppress the response of B cells and other T cells to antigens.

Natural killer cells are similar to cytotoxic T cells, but the cell's response to an antigen is non-specific. They contain granules that break down the cell membrane of diseased or tumour cells causing the target cell to burst. NK cells can also induce infected cells to undergo apoptosis.

Muscle Tissue

Muscles are primarily responsible for maintaining and changing posture, locomotion as well as movement of internal organs by attaching themselves to bones and blood vessels. They account for about 40% of total body weight. Three types of muscle fibres have been observed: skeletal, smooth and cardiac.

Skeletal muscle (**Fig. 31.19**) is attached to bones and is responsible for skeletal movements. The basic unit is the muscle fibre with many nuclei. These muscle fibres are striated and each acts independent of the neighbouring muscle fibres. Each muscle is surrounded by a connective tissue sheath called the epimysium. Epimysium extends inside the fibres and divides them into compartments and forms bundles or fascicles of muscle fibres. Each bundle is further covered by perimysium, and the tissue surrounding each muscle fibre is called endomysium. The muscle fibre has a membranous covering called sarcolemma and cytoplasm called sarcoplasm, which is the cell cytoplasm. Each muscle fibre contains cylindrical organelles known as myofibrils which are made of bundles of actin and myosin proteins. Myofibrils are further surrounded by a network of tubules and channels called the sarcoplasmic reticulum in which calcium is stored which is important in muscle contraction.

Smooth muscles are found in the walls of the hollow internal organs such as blood vessels, gastrointestinal tract, bladder and uterus. They are under the control of the autonomic nervous system. The smooth muscle cell is non-striated and is spindle shaped with a centrally placed nucleus. The have actin and myosin contractile proteins, and thick and thin filaments. These thin filaments are anchored by dense bodies. A dense body is analogous to the Z-discs of

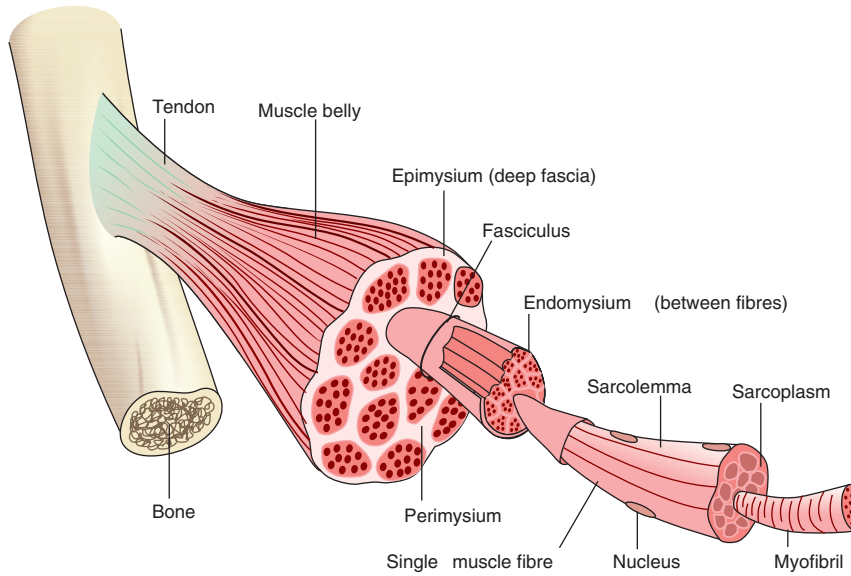


Figure 31.19 Muscle tissue. (*Source*: DR Singh, Essentials of Anatomy for Dentistry Students, 2nd edn. Wolters Kluwer India, New Delhi; 2017.)

skeletal and cardiac muscle fibres and is fastened to the sarcolemma. Calcium ions are supplied by the SR in the fibres and by sequestration from the extracellular fluid through membrane indentations called calveoli.

Cardiac muscle tissue is found in the heart and is a highly coordinated contractile system. The cardiac muscle is striated and organized into sarcomeres. The muscle fibre cells are extensively branched and are connected to one another at their ends by intercalated discs which help in wave-like contraction. This network of electrically connected cardiac muscle cells creates a functional unit of contraction called a syncytium.

Nerve Tissue

Nerves are involved in control of the body movements and perception of the organ systems. They are broadly classified into two sections: the central nervous system and the peripheral nervous system. The central nervous system consists of the brain and the spinal cord. The peripheral nervous system consists of the neurons and parts of neurons found outside of the CNS, includes sensory neurons and motor neurons. The neurons found in the nervous system are of three types: sensory neurons, motor neurons, and interneurons. Sensory neurons bring signals into the CNS, and motor neurons carry signals out of the CNS. Interneurons are found only in the CNS and connect one neuron to another.

A neuron (**Fig. 31.20**) is the structural and functional unit of the nervous system. A neuron has cell body called soma and two types of processes called axons and dendrites.

Soma consists of a nucleus and a large number of Nissl's granules in the cytoplasm. Nissl's granules are responsible for protein synthesis. They execute this function by the presence of ribonucleoprotein. The cytoplasm of the neuron is called neuroplasm. It contains cytoplasmic threads and extend throughout the entire length of the axon and dendrites. The neuron membrane covers the cell body. The cell body is located in they grey matter of the central nervous system—brain and spinal cord.

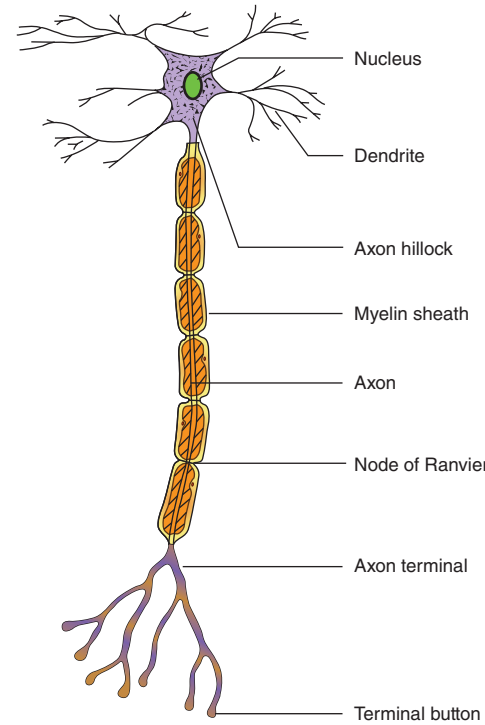


Figure 31.20 Neuron. (*Source*: D Venkatesh and HH Sudhakar, Textbook of Medical Physiology. Wolters Kluwer India, New Delhi; 2015.)

The short cytoplasmic processes of cell body which receives stimulus from other neuron are called dendrites. The dendrites conduct nerve impulses induced by stimuli towards the cell body.

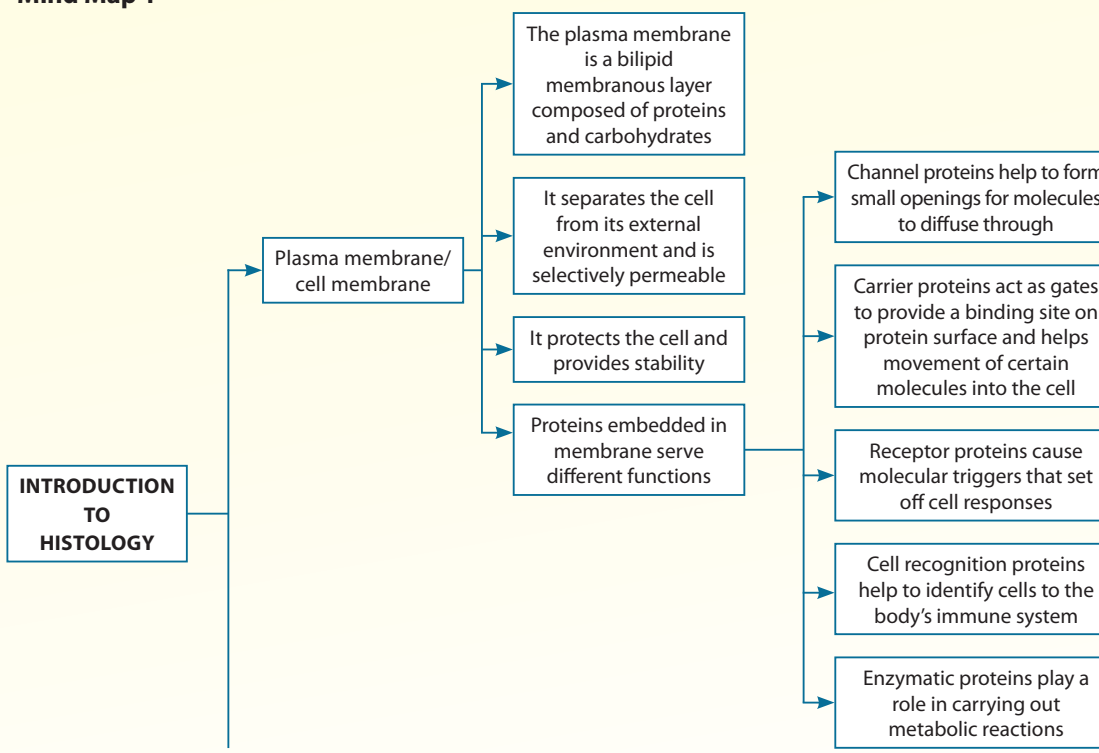
The long cytoplasmic process of cell body which transmits impulse from cell body to other neuron is termed axon. The axon arises from the cell body. The point at which it arises is seen as a conical elevation and referred to as the axon hillock. The axon hillock region does not contain Nissl's granules. The length of axon is variable and depends on the functional relationship of the neuron.

Key Points

1. Plasma membrane is a bilipid membranous layer composed of proteins and carbohydrates. It separates the cell from its external environment.
2. DNA forms a complex with numerous proteins to form a precise fibre called chromatin. Chromatin has subunits euchromatin and heterochromatin.
3. Three types of RNA (messenger RNA, ribosomal RNA and transfer RNA) are found in the cell and are involved in the process of transcription.
4. Mitochondria generate ATP molecules by aerobic respiration.
5. Lysosomes contain 40 different types of hydrolytic enzymes for breakdown of cellular waste products, fats, carbohydrates, proteins and other macromolecules into simple compounds.
6. DNA synthesis occurs at the G_2 phase of cell cycle.
7. The occluding junction consist of transmembrane proteins claudin and occludin.
8. The basement membrane consists of a mixture of collagens, laminin, perlecan and entactin.
9. Mast cells or labrocyte mediate immune responses to foreign particles by releasing large amounts of histamine and enzymes in response to antigen recognition.
10. Hyaline cartilage is composed of type II collagen and chondromucoprotein.
11. Organic components of bone include type I collagen, proteoglycans and non-collagenous proteins osteocalcin, osteonectin and osteopontin.
12. Three major classes of T cells—cytotoxic T cells, helper T cells and regulatory T cells—play a major role in cell-mediated immunity.

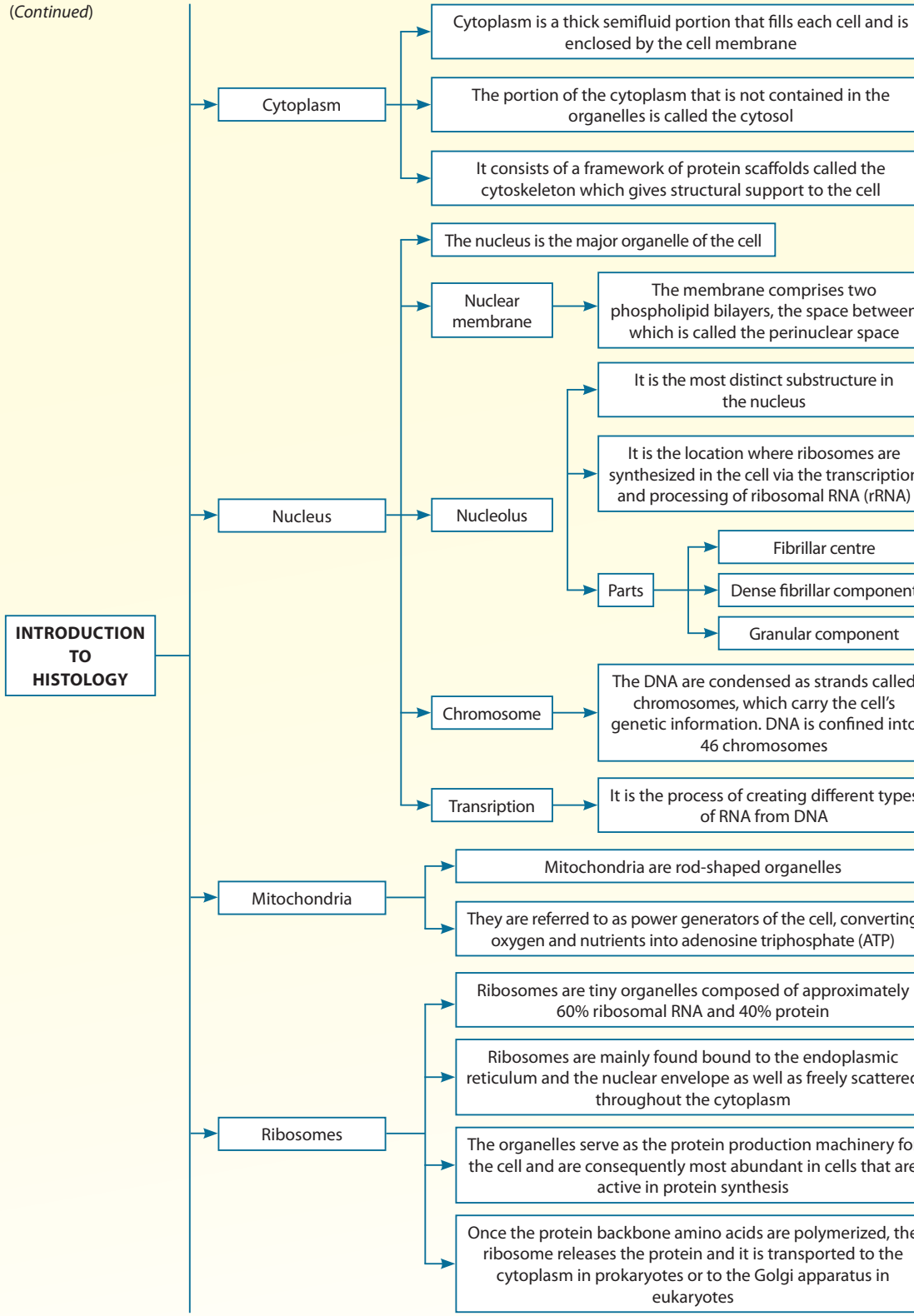
Mind Map

Mind Map 1



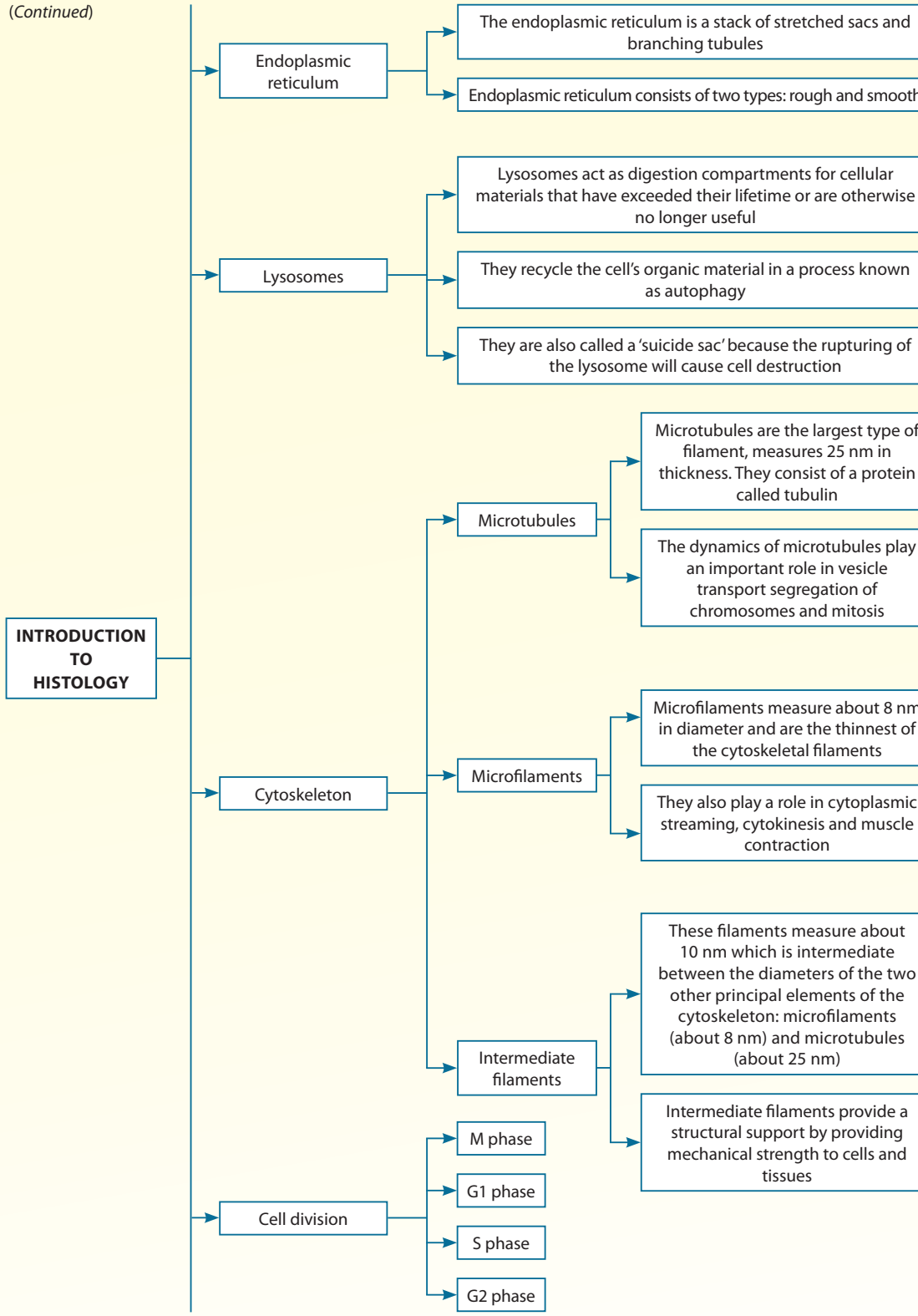
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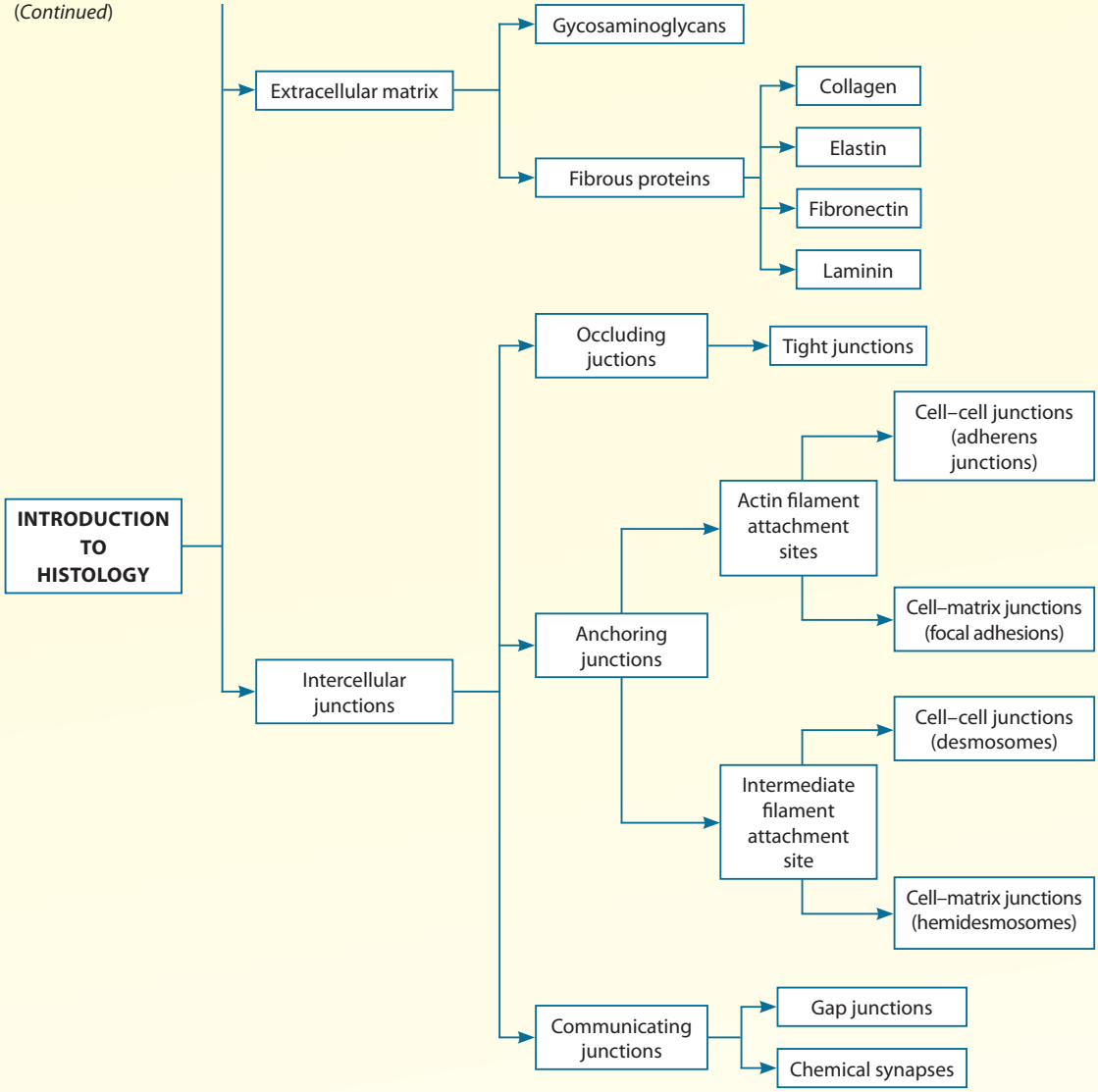
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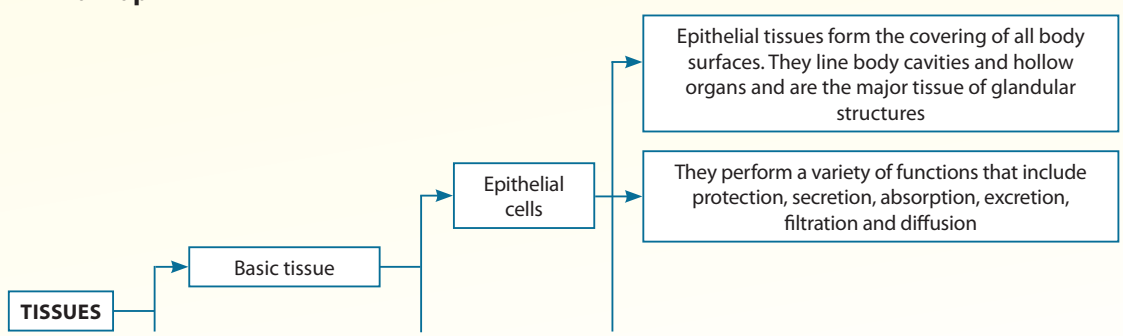


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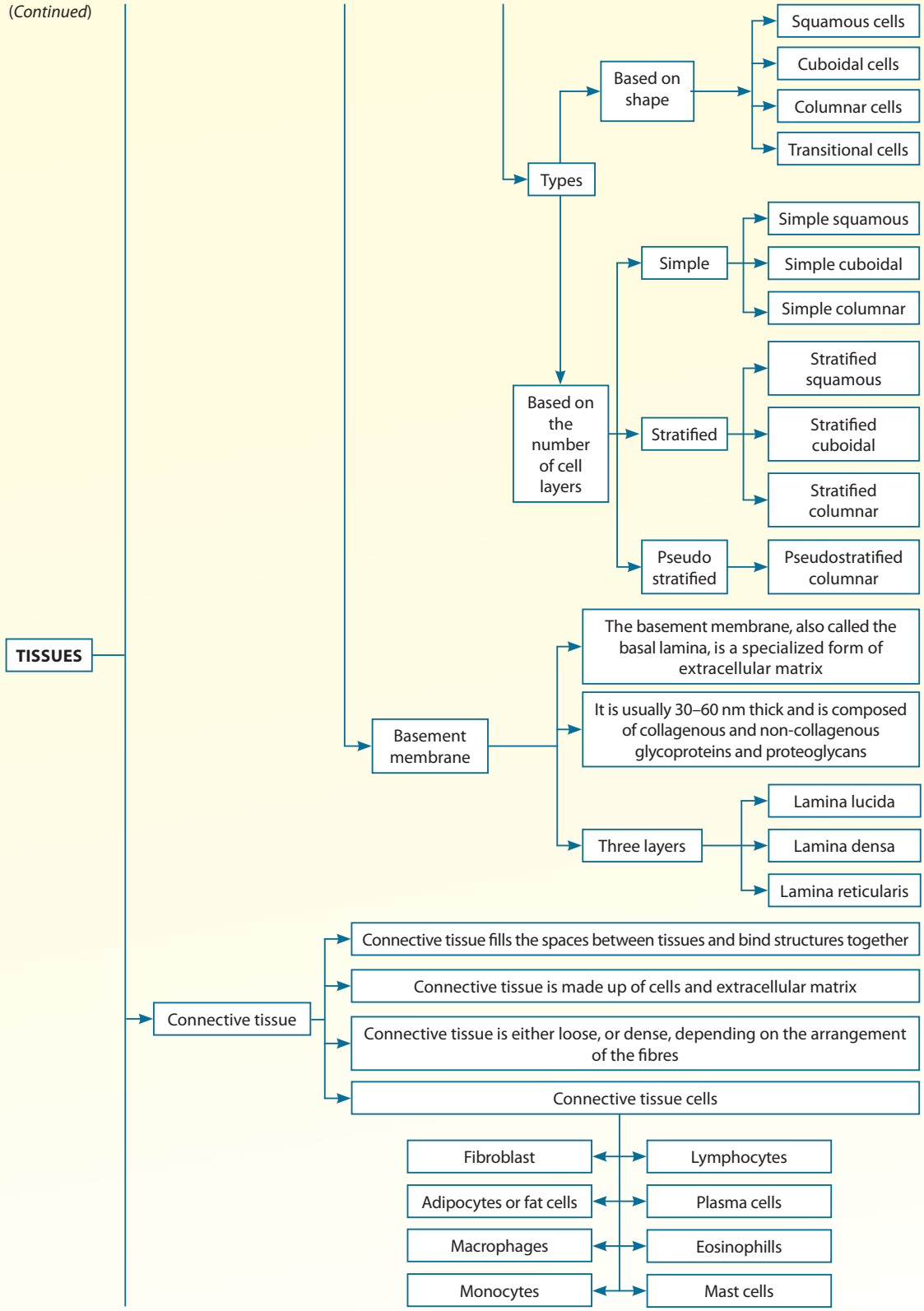


Mind Map 2



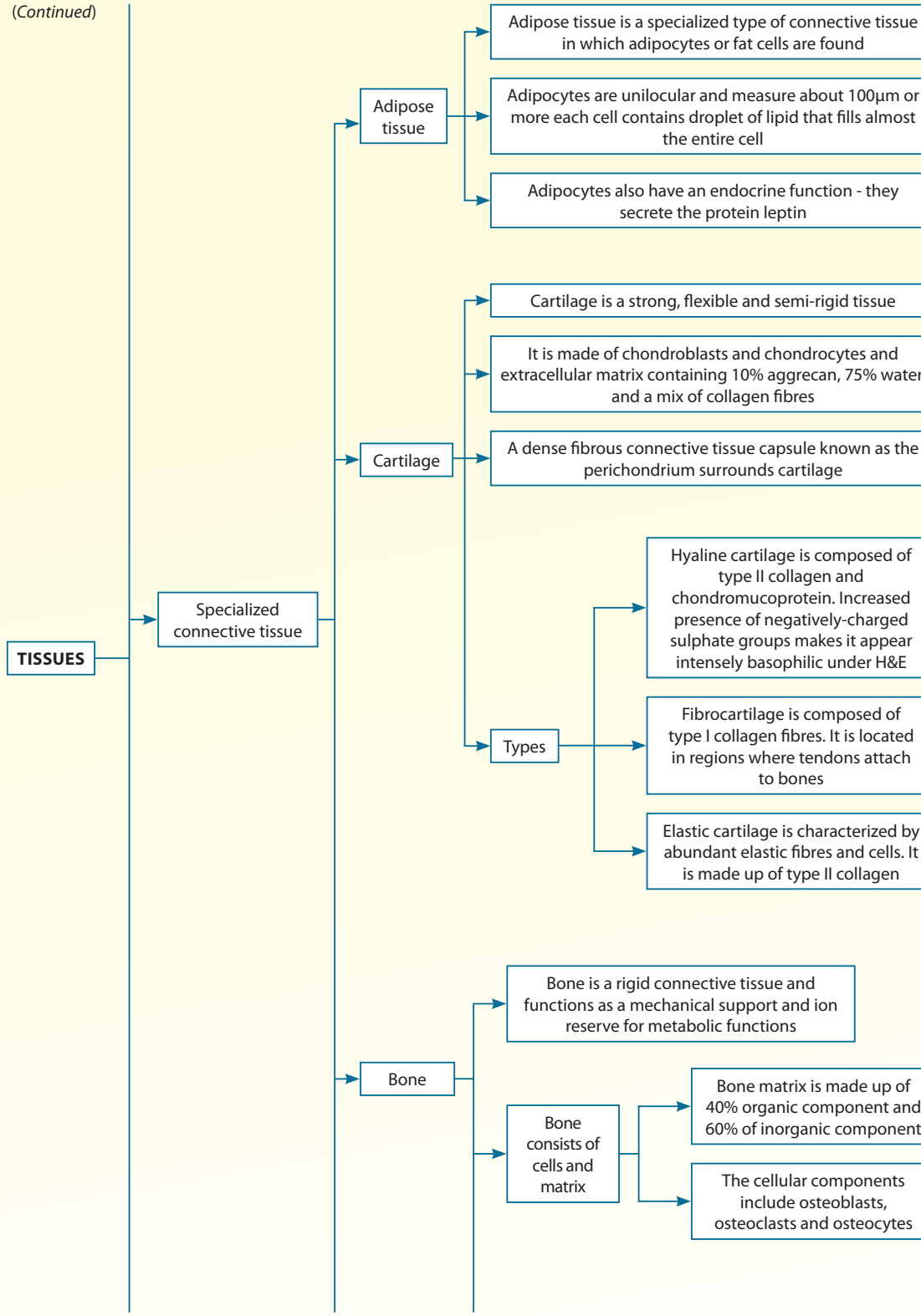
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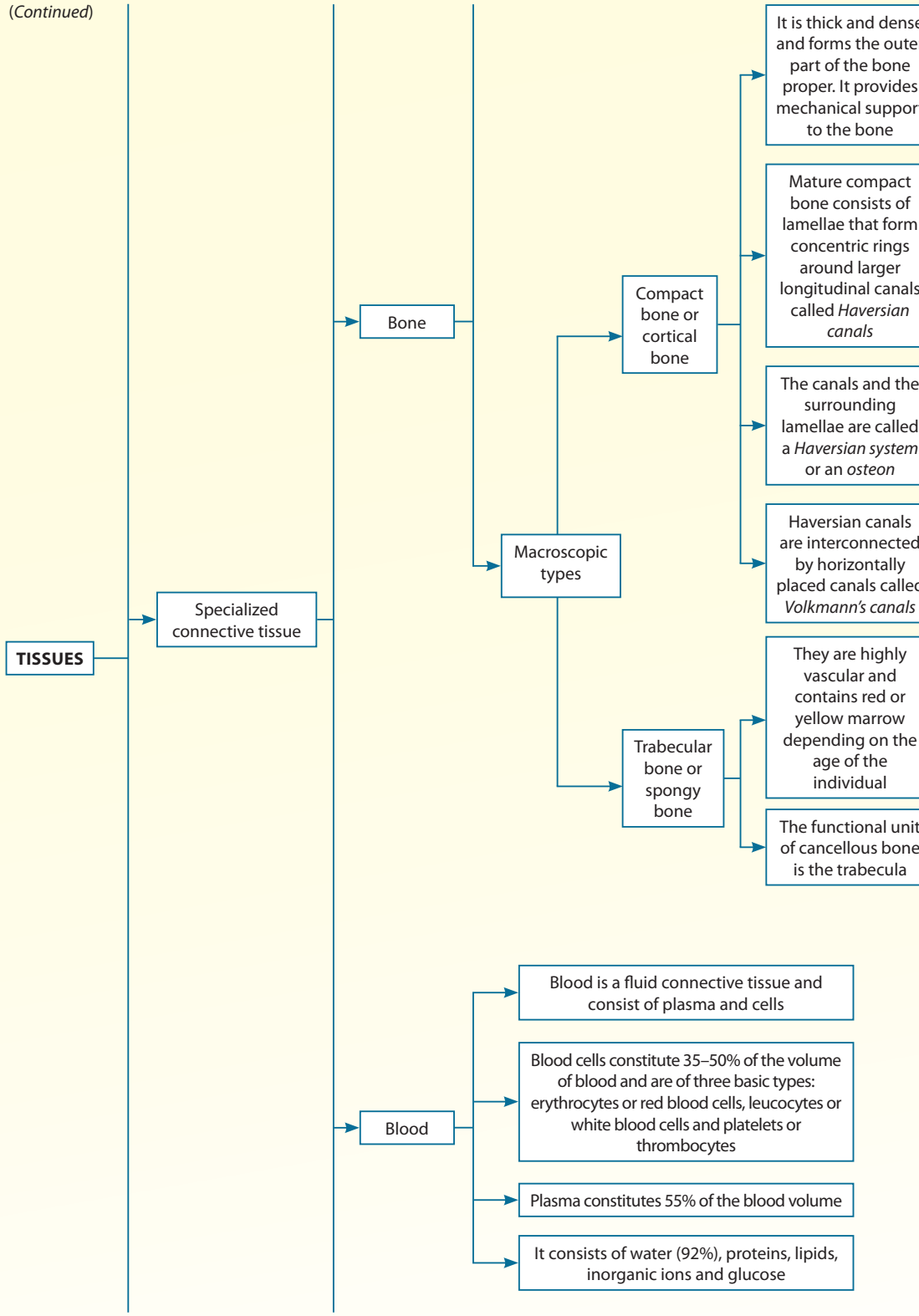
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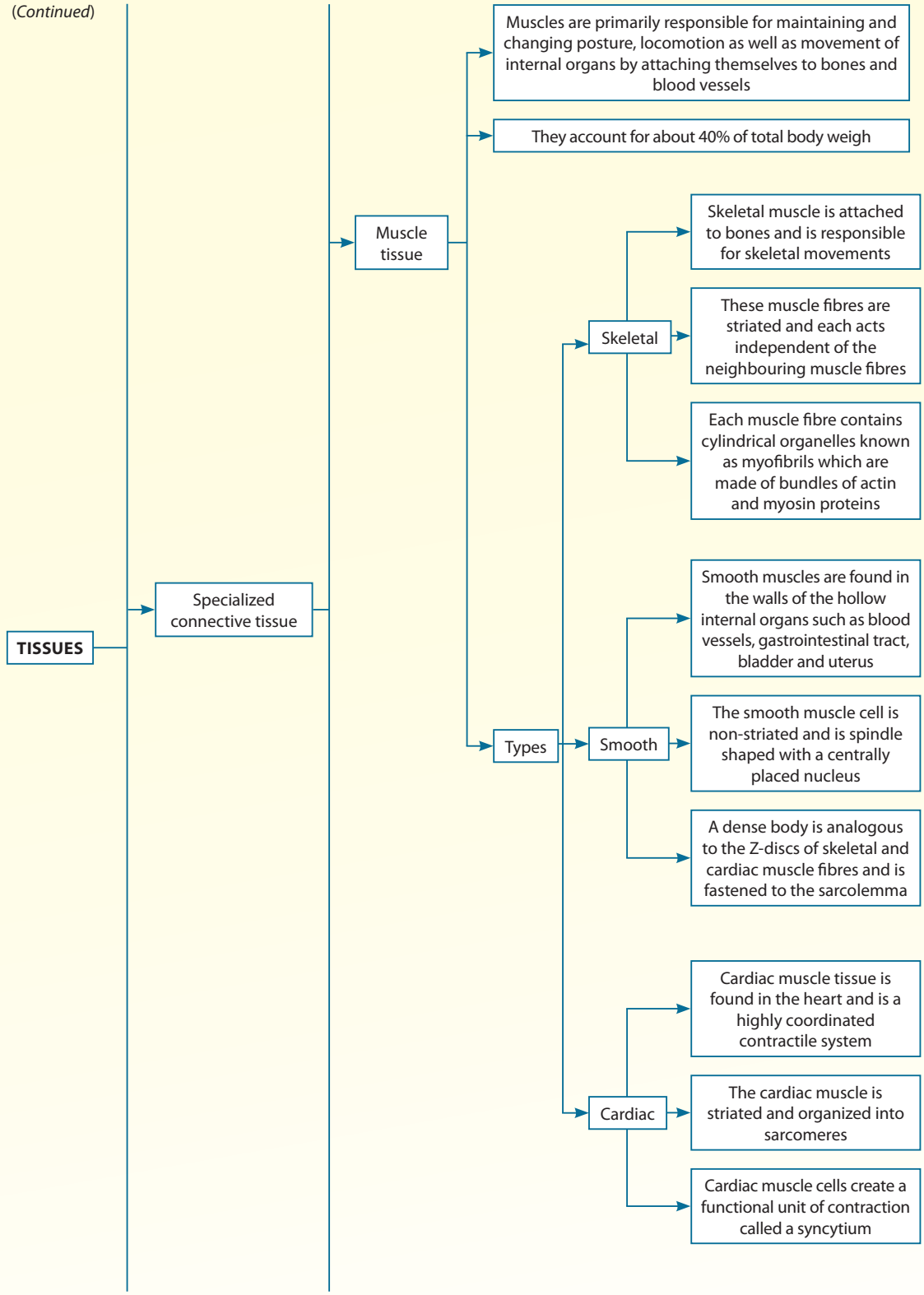
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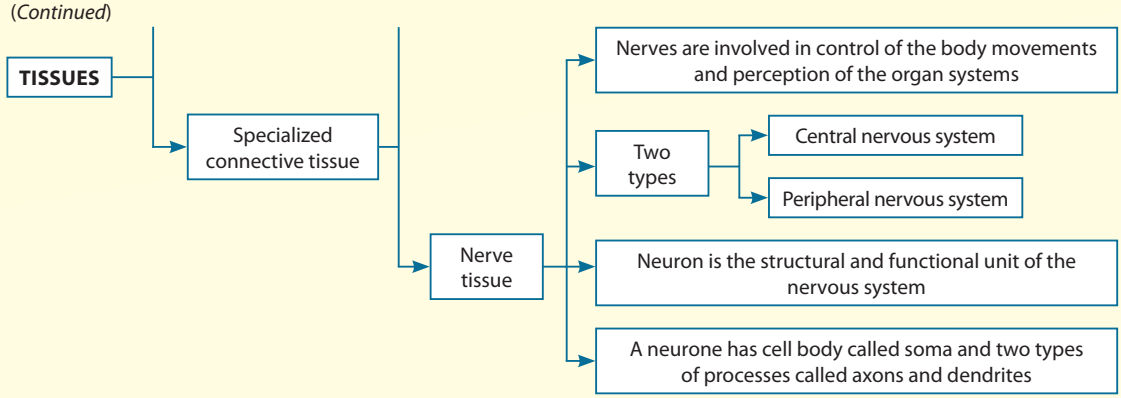
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Multiple Choice Questions

1. Nissl's granules are seen in
   (a) Muscle fibril
   (b) Neuron
   (c) Adipocyte
   (d) All of the above
2. Highly coordinated contractile tissue—syncytium is seen in
   (a) Skeletal muscle
   (b) Smooth muscle
   (c) Cardiac muscle
   (d) None of the above
3. Sarcoplasmic reticulum is seen in
   (a) Neuron
   (b) Cartilage
   (c) Adipose tissue
   (d) Muscle
4. Basophils consist of
   (a) Histamine
   (b) Leukotrienes
   (c) Heparin
   (d) All of the above
5. The dense fibrous connective tissue capsule surrounding cartilage is known as
   (a) Perichondrium
   (b) Periosteum
   (c) Endosteum
   (d) None of the above
6. Examples of granulocytes include
   (a) Eosinophils
   (b) Neutrophils
   (c) Lymphocyte
   (d) Both a and b
   (e) a–c

7. The basement membrane consists of
   (a) Lamina lucida
   (b) Lamina densa
   (c) Lamina reticularis
   (d) Both a and b
   (e) a–c
8. Gap junctions are composed of transmembrane proteins
   (a) Connexins
   (b) Claudins
   (c) Occludins
   (d) All of the above
9. Examples of fibrous proteins include
   (a) Collage
   (b) Elastin
   (c) Fibronectin
   (d) All of the above
10. Microfilaments, microtubules and intermediate filaments are components of
   (a) Muscle fibril
   (b) Adipose tissue
   (c) Nerve tissue
   (d) Cytoskeleton

CHAPTER 32



General Embryology

Overview

The sperm fertilizes the ovum to form zygote. In the first week of prenatal development, the zygote undergoes a series of mitotic division to form morula. Secretion of fluid by the cells within the morula results in a fluid-filled structure called the blastula or blastocyst which implants in the uterus. In the second week of prenatal development, a bilaminar embryonic disc is formed and placenta develops. In the third week of prenatal development, the three germ layers (endoderm, ectoderm and mesoderm) are established and this process is called gastrulation. Further, notochord and neural tube development occurs. The notochord serves as the basis for the axial skeleton while brain and spinal cord develop from the neural tube. During the third week, another specialized group of cells differentiate from the neuroectoderm called the neural crest cells. These cells migrate and disperse into the embryonic mesenchyme, involving in the formation of various head and neck structures. Hence, the neural crest cells are considered the fourth embryonic layer. The mesoderm differentiates into paraxial, lateral and intermediate mesoderm. The thickenings (38 pairs) in the paraxial mesoderm are called somites which give rise to bone, cartilage, muscle and neck, thus forming the structures of head, neck and trunk. In the fourth week of prenatal development, the six paired branchial arches are formed as a result of lateral mesodermal thickenings at the wall of the foregut. Each arch is composed of a skeletal component, neural component, vascular component and brachiomeric constituting many of the head and neck structures.

FIRST WEEK OF PRENATAL DEVELOPMENT

The sperm fertilizes the ovum to form the *zygote* (**Fig. 32.1a** and **b**). The zygote undergoes a series of mitotic divisions called *cleavage*, which result in the formation of a ball-like cell mass called morula (**Fig. 32.1c**). The *morula* consists of a group of centrally placed cells termed *inner cell mass* that are surrounded by a peripheral layer of cells called *outer cell mass*. Secretion of fluid by the cells within the morula results in a fluid-filled structure called the *blastula* or *blastocyst*. The blastocyst is lined by a *trophoblast layer* derived from the outer cell mass of the morula, which helps in implantation and formation of the placenta. Within the blastocyst is the inner cell mass or the *embryoblast layer* that gives rise to the embryo proper (**Fig. 32.2**). The blastocyst undergoes *implantation* in the endometrium of the uterus by the end of the first week (**Fig. 32.3**).

Prenatal developmental stages are briefly outlined in **Table 32.1**.

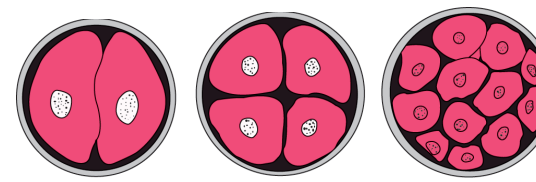


Figure 32.1 (a) Two-cell stage of the zygote. (b) Four-cell stage of the zygote. (c) Morula.

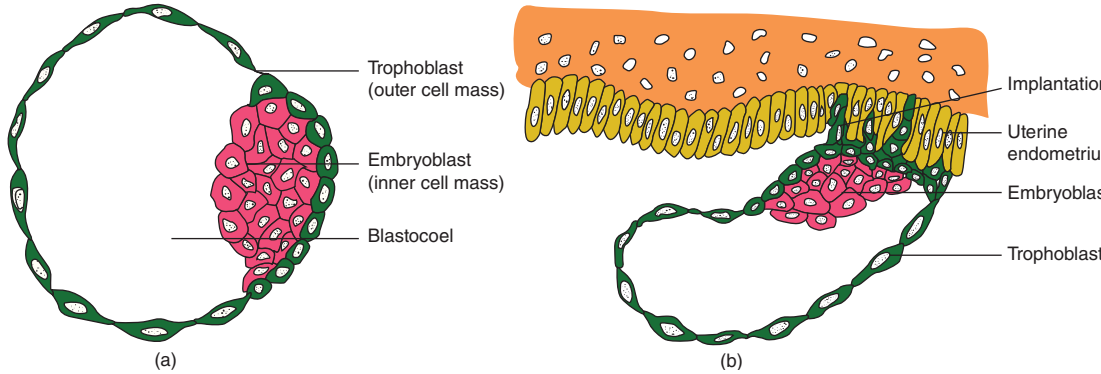


Figure 32.2 (a) Section of blastocyst at fifth day of development showing the embryoblast and the trophoblast. (b) Section of blastocyst at seventh day of development showing implantation of blastocyst in uterine mucosa.

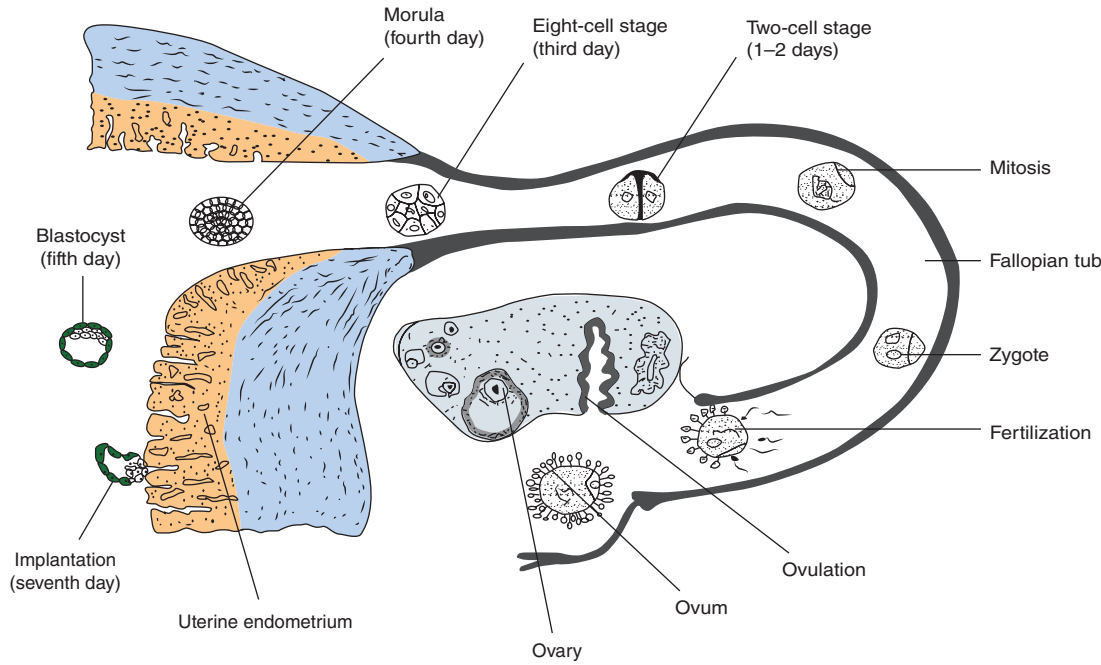


Figure 32.3 Events during the first week of development.

Applied Histology

Embryonic Stem Cells

The inner cell mass of the morula can contribute embryonic stem cells which are pluripotent, capable of differentiating into any tissue. The storage and utilization of these cells can aid in the effective management of many diseases.

Applied Histology

Ectopic Pregnancy

The implantation can also occur outside the uterus. Many a times, such an event occurs in the fallopian tube. This can turn out to be a life-threatening condition to the pregnant female at times.

Table 32.1 Periods of Prenatal Development[a]

Period		Time Period	Stages	Major Events
Preimplantation period or period of ovum		1st–7th day	Zygote to blastocyst	• Fertilization and implantation
Embryonic period (2nd–8th week)	Pre-somite	8th–20th day	Blastocyst to embryo	• Formation of germ layers and nutritional membranes
	Somite	21st–31st day		• Formation of a basic pattern of organ systems
	Post-somite	4th–8th week		• Rapid growth of the organ system • Formation of the external body form
Foetal period		3rd–10th month	Embryo to foetus	• Maturation

[a]The period of sensitivity to teratogens that affects development is between 3 and 8 weeks, the period of organogenesis.

SECOND WEEK OF PRENATAL DEVELOPMENT

In the second week of prenatal development, the *bilaminar embryonic disc* is developed from the cells of the embryoblast. The bilaminar disc consists of a superior *epiblast layer* composed of tall columnar cells and an inferior *hypoblast layer* composed of cuboidal cells. The bilaminar disc is suspended between two fluid-filled cavities: amniotic cavity and yolk sac. Later, the placenta develops from the interactions of the trophoblast layers (syncytiotrophoblast and cytotrophoblast) and the endometrium of the uterus (**Fig. 32.4**).

THIRD WEEK OF PRENATAL DEVELOPMENT

Gastrulation

The characteristic event in the third week of development is *gastrulation,* the process that establishes

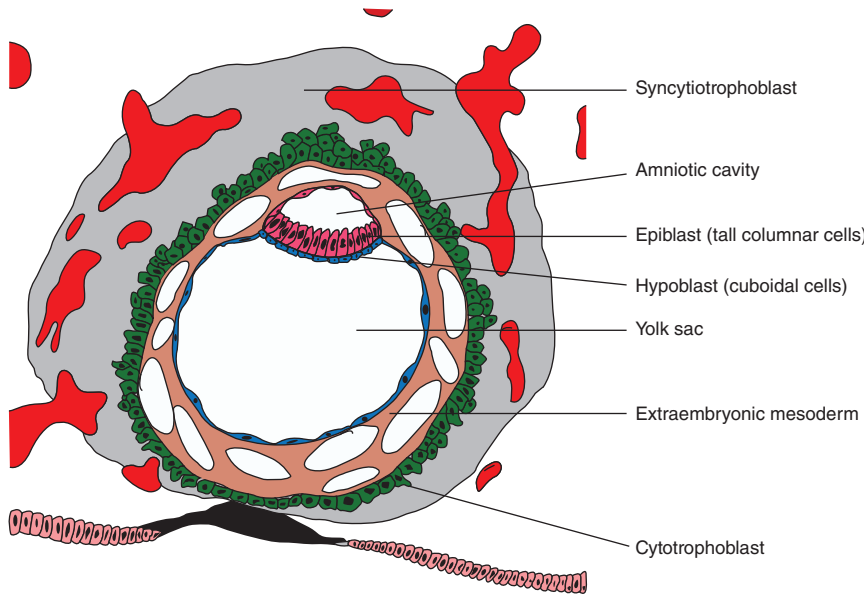


Figure 32.4 Human blastocyst of 12 days showing a bilaminar embryonic disc (epiblast layer and hypoblast layer), amniotic cavity and yolk sac.

Table 32.2 Derivatives of the Three Germ Layers[a]

Ectodermal Derivatives	Mesodermal Derivatives	Endodermal Derivatives
• Epidermis of the skin along with glands (subcutaneous and mammary glands), hair and nails • Epithelium of mouth and nasal cavity • Sensory epithelium of ear, nose and eye • Neuroectoderm cells • Lens, cornea and retina of the eye • Nervous system • Posterior pituitary • Neural crest cells	• Musculoskeletal system • Connective tissue of the gastrointestinal tract • Dermis of the skin • Cardiovascular system • Peritoneum • Reproductive system • Excretory system	• Epithelial lining of respiratory passages and digestive tract • Endocrine glands and organs (liver and pancreas)

[a]Epithelium is derived from all three germ layers—the epithelial lining inside viscera is derived from the endoderm, the mesothelial lining outside of viscera from the mesoderm and skin epithelium from the ectoderm.

the three germ layers from which the entire human body develops (**Table 32.2**).

Gastrulation begins with the formation of the primitive streak on the surface of epiblast. Increased proliferation of cells in the midline area of the bilaminar germ disc results in the formation of a rod-shaped thickening called *primitive streak*. In the cephalic end of the streak is a slightly elevated area called *primitive node* (**Figs 32.5** and **32.6**).

In the area of the primitive streak, cells from the epiblast layer migrate and locate themselves in between the epiblast and the hypoblast layers, forming the *embryonic mesoderm* (**Figs 32.5** and **32.6**). Some of the cells displace the hypoblast layer to form the *endoderm*. The remaining cells of the epiblast form the *ectoderm*. The mesodermal cells are pluripotent cells and have the potential to differentiate into different types of connective tissue, forming cells such as fibroblasts, chondroblasts and osteoblasts. Each embryonic layer is distinct; thus, it gives rise to specific tissues.

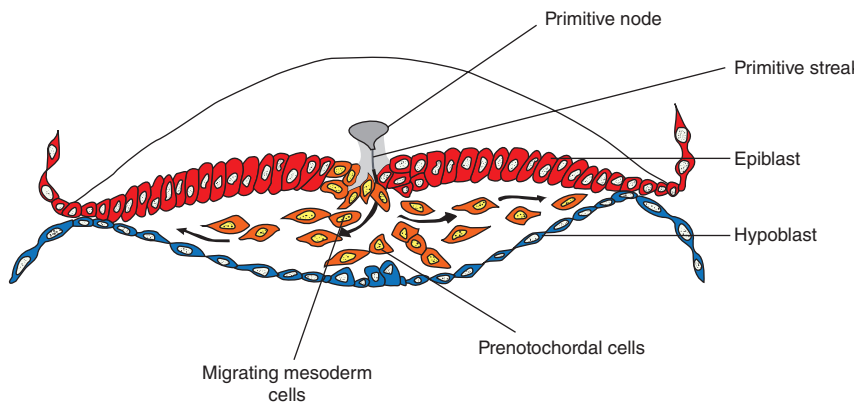


Figure 32.5 Cross-section of a germ disc at the cranial end of the primitive streak showing the migration of the epiblast cells to form mesoderm.

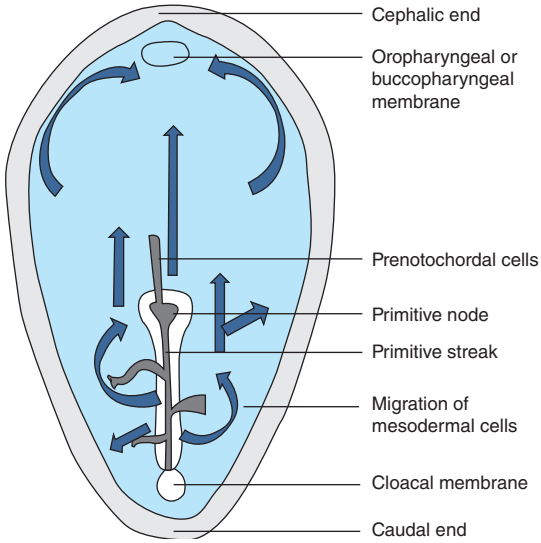


Figure 32.6 Dorsal view of the trilaminar embryonic germ disc at the third week of development showing the primitive streak, buccopharyngeal membrane, cloacal membrane and migration of prechordal cells.

Applied Histology

Gastrulation-Related Tumour

Sometimes, persistent primitive streak cells can proliferate leading to tumours in the sacrococcygeal region. This is one of the most common tumours in the newborn. The tumour mass is composed of tissue derived from all three germ layers and is called *teratoma*.

The body axis (anteroposterior, dorsoventral, right–left) is established during gastrulation. At the completion of the third week, a distinct cephalic and caudal end can be identified in the germ disc. Two embryonic membranes—*buccopharyngeal* or *oropharyngeal membrane*—at the cephalic end and a *cloacal membrane* at the caudal end appear in the germ disc (**Fig. 32.6**). These membranes consist of only ectoderm externally and endoderm internally without the intermediate mesodermal layer. The location of these membranes denotes the location of future primitive mouth and anus.

Applied Histology

Ectodermal Dysplasia

This is a congenital disorder. The structures developing from the ectoderm such as skin, hair, teeth, nails and salivary glands are defective in this syndrome. The child would present with a partial edentulous state or complete absence of teeth.

Development of Notochord

Synchronizing with the formation of the mesoderm is the formation of the *notochord*. Some of the invading prenotochordal cells interpose with the hypoblast layer to form the *notochordal plate* (**Fig. 32.7a**). As the hypoblast layer is replaced by the endoderm, the notochordal plate proliferates to form an axial thickening. This thickening appears as a furrow and the margins of the furrow fuse later to form a solid rod of cells which gets separated from the endoderm to form the notochord (**Fig. 32.7b**). The cells of the notochord are formed from the mesoderm. The notochord serves as a basis for the axial skeleton.

The notochord secretes a protein called the *sonic hedgehog homolog* (SHH), a key morphogen that regulates organogenesis and plays a critical role in *signalling the development of motoneurons*.

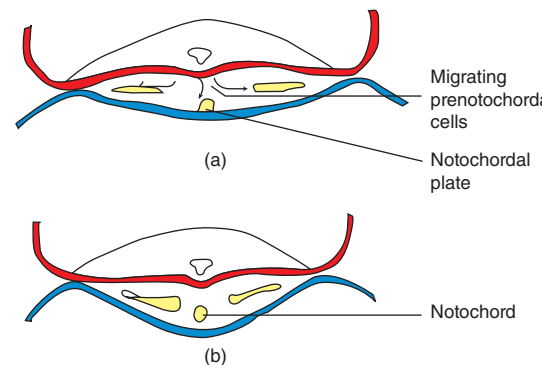


Figure 32.7 Cross-section of the trilaminar embryonic germ disc showing (a) prenotochordal cells migrating from the epiblast getting intercalated with the hypoblast layer to form the notochordal plate and (b) notochord getting separated from the endoderm.

The secretion of SHH establishes the *ventral pole* of the dorsal–ventral axis in the developing embryo; thus, the notochord defines the axis of the embryo.

Neurulation

The process of formation of the neural tube is called *neurulation*. During the later part of the third week of intrauterine life (IUL), a specialized group of cells called *neuroectoderm cells* differentiates from the ectoderm. These cells proliferate and localize themselves as a thick band called the neural plate, which extends from the cephalic end to the caudal end of the embryonic disc (**Fig. 32.8a**). The *neural plate* undergoes further thickening and invaginates centrally to form a *neural groove* (**Fig. 32.8b**). At the end of the third week, the groove further deepens, being surrounded by the neural folds. During the fourth week, the *neural folds* fuse at the superior end of the neural groove to form the *neural tube* (**Fig. 32.8c**). The neural tube soon sinks below the surface epithelium.

The anterior portion of the neural tube bulges to form the forebrain, midbrain and hind brain. The hind brain develops into a series of eight bulges known as rhombomeres, caudal to which the spinal cord develops.

The skull, vertebral column, and membranes of the brain develop from the mesoderm surrounding the neural tube and the notochord. The mesoderm is absent in the region of future olfactory, otic and optic placodes. Lateral to the neural tube is the paraxial mesoderm which forms somatomeres in the cranial end and well-segmented somites in the caudal end. The somatomeres are seven in number.

Neural Crest Cells

During the third week of IUL, another specialized group of cells differentiate from the neuroectoderm cells. These cells, called the *neural crest cells,* migrate from the crest of the neural folds prior to neural tube closure and disperse into the embryonic mesenchyme (**Fig. 32.8d**). These cells differentiate into different types of cells based on

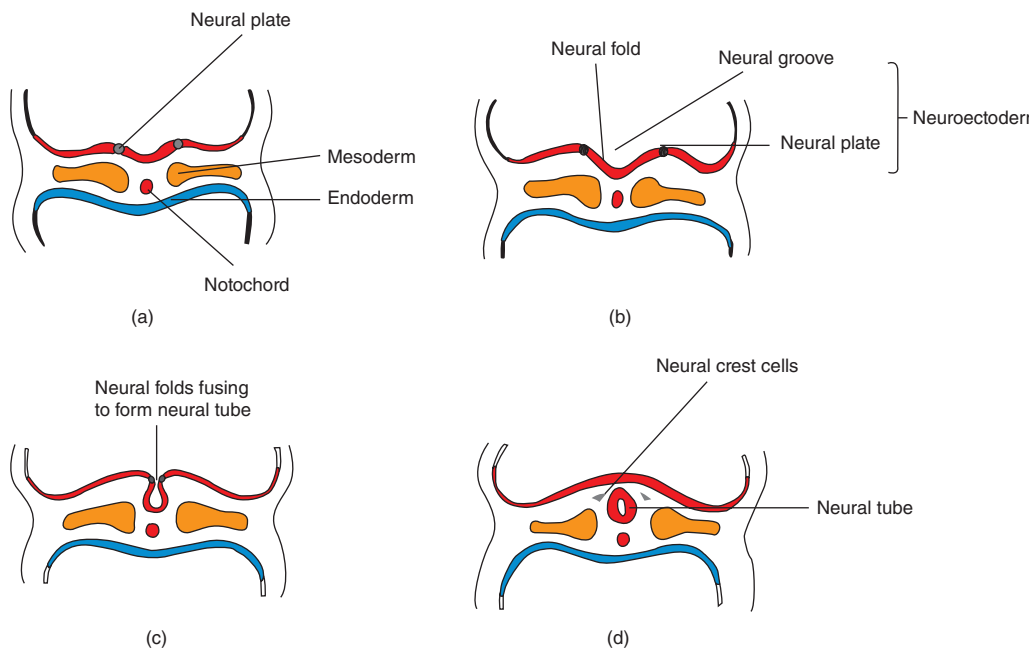


Figure 32.8 Transverse sections showing (a) the appearance of the neural plate, (b) the formation of the neural fold and neural groove, (c) the fusion of the neural folds to form the neural tube and (d) the migration of neural crest cells from the crest of the neural folds to the surrounding embryonic mesenchyme.

Table 32.3 Derivatives of Neural Crest Cells

Derivative	Cell Type or Structure Derived
Peripheral nervous system	• Neurons, including sensory ganglia, sympathetic and parasympathetic ganglia and plexuses • Neuroglial cells • Schwann cells
Endocrine and paraendocrine derivatives	• Adrenal medulla • Calcitonin-secreting cells • Carotid body type I cells
Pigment cells	• Melanocytes
Facial cartilage and bone	• Facial and anterior ventral skull cartilage and bones
Connective tissue	• Corneal endothelium and stroma • Dental papillae • Dermis, smooth muscle and adipose tissue of skin of head and neck • Connective tissue of salivary, lachrymal, thymus, thyroid and pituitary glands • Connective tissue and smooth muscle in arteries of aortic arch origin • Odontoblasts

the local environmental influences and involve in the formation of various head and neck structures, including the branchial arches. Hence, the neural crest cells are considered the fourth embryonic layer (**Table 32.3**).

Streams of the neural crest cells arise from the midbrain and the first two rhombomeres, and they migrate to the mesenchyme, below the developing forebrain and the first branchial arch. The cells from the rest of the rhombomeres reinforce the remaining branchial arches (**Fig. 32.9**). These migrating neural crest cells express homeobox genes in the rhombomeres from which they originate. The homeobox genes

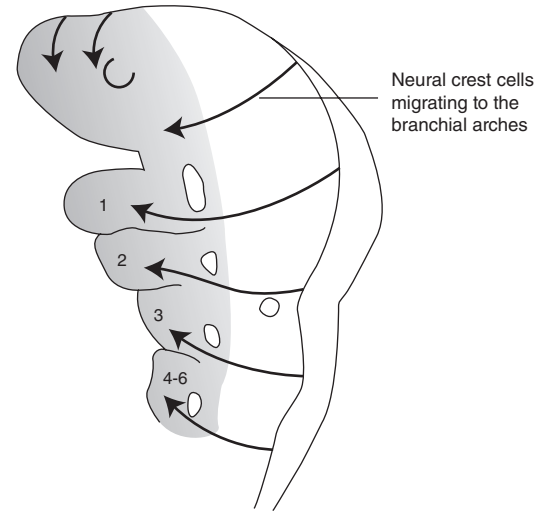


Figure 32.9 Migration of the neural crest cells to the branchial arches.

play an important role in the development of the craniofacial region.

Applied Histology

Treacher Collins Syndrome

In this syndrome, there is a failure of migration of the neural crest cells. Consequently, there are underdeveloped facial bones, micrognathia, downwardly slanted eyes, drooping lateral part of lower eyelids, hearing loss and malformed ears.

Derivatives of Mesodermal Germ Layers

By the end of the third week, the mesoderm differentiates into the paraxial mesoderm, intermediate mesoderm and lateral plate mesoderm (**Fig. 32.10a**). The paraxial mesoderm differentiates into 38 paired cuboidal aggregates of cells called *somites* located on either side of the developing midline central nervous system (**Fig. 32.10b**). Somites appear as distinct elevations on the surface of the embryo and give rise to sclerotome (bone and cartilage), myotome (muscles) and dermatome (dermis of the skin), forming the structures of head, neck and trunk (**Fig. 32.11**; **Table 32.4**).

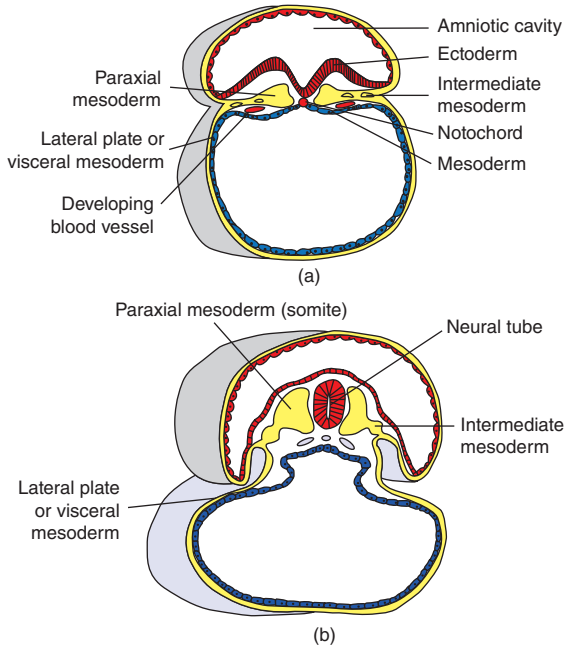


Figure 32.10 Transverse sections showing (a) formation of paraxial mesoderm (future somites), intermediate mesoderm and lateral plate mesoderm and (b) formation of somites.

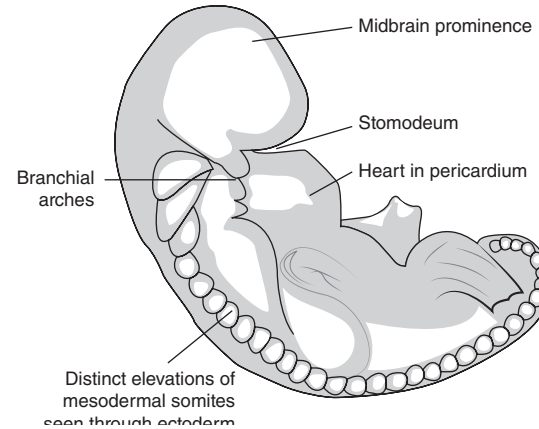


Figure 32.11 A 27-day-old embryo showing the developing branchial arches, brain and the distinct elevations of somites.

FOURTH WEEK OF PRENATAL DEVELOPMENT

The important events in the fourth week of IUL are the cephalocaudal folding of the embryo, rupture of the buccopharyngeal membrane and development of branchial arches. At the fourth week, the embryonic disc undergoes cephalocaudal folding resulting from excessive proliferation of the ectoderm. The developing forebrain grows beyond the buccopharyngeal membrane and overhangs above the developing heart. The primitive oral cavity, the *stomodeum,* is located between the developing brain and the pericardium and is separated from the primitive foregut by the buccopharyngeal membrane. Lateral mesodermal thickenings develop in the wall of the cranial part of the foregut which results in the formation of the *pharyngeal arches* or *branchial arches* (**Figs 32.11** and **32.12**). The branchial arches contribute extensively to the formation of the face, neck, palate, nasal cavity, larynx, pharynx and oral cavity.

Branchial Arches

After the cephalocaudal folding in the fourth week of IUL, the buccopharyngeal membrane ruptures and a communication is established between the primitive oral cavity and the

Table 32.4 Derivatives of Cranial Somites

Somites	Muscles (Myotome)	Bone (Sclerotome)	Nerve
Occipital somites (four in number)	Intrinsic muscles of tongue and styloglossus, genioglossus and hyoglossus	Basiocciput	Hypoglossal nerve
Prechordal somites	Extrinsic ocular muscles	Nasal capsule and septum	Oculomotor, trochlear and abducens
Cervical somites	Geniohyoid and infrahyoid	Cervical vertebrae	C1 and C2 (spinal nerves)

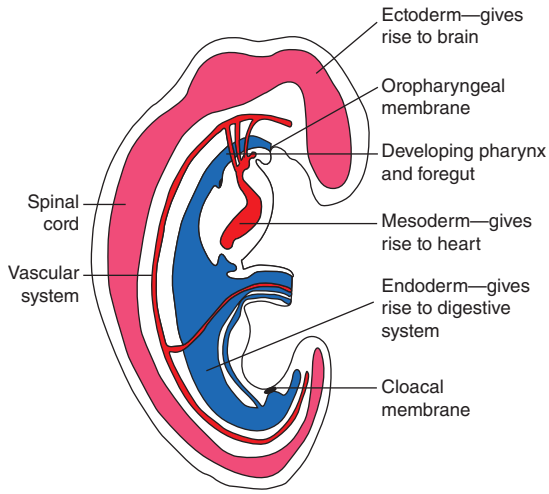


Figure 32.12 Section of an embryo showing ectoderm and endoderm with mesoderm in between except at the two embryonic membranes (oropharyngeal and cloacal membrane) and stomodeum between the developing forebrain and heart.

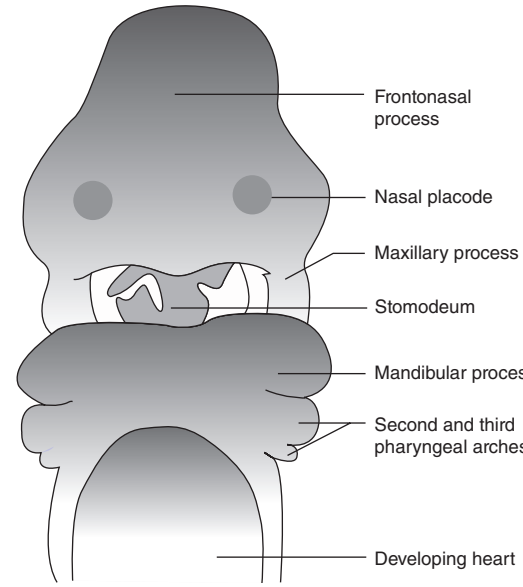


Figure 32.13 Frontal view of a 4½-week-old embryo with the developing branchial arches meeting in the midline.

primitive foregut. During this late somite period, six paired branchial arches develop from the lateral aspect of the developing pharynx as a series of mesodermal outpouchings and grow ventromedially to meet their counterparts in the midline (**Fig. 32.13**).

The mesenchyme of the pharyngeal arch is derived from the lateral plate mesoderm and reinforced by the neural crest cells. The myoblasts and endothelial cells are derived from the mesoderm and the skeletal tissue, and the connective tissue cells are derived from the neural crest cells. The arches progressively separate the stomodeum from the developing heart (**Fig. 32.13**).

The ectomesenchyme of the branchial arches initially exists as a thin sheet between the ectoderm and endoderm, and as growth proceeds, it forms cylindrical masses that produce round ridge-like prominences on the ectodermal and endodermal surfaces (**Fig. 32.14**). The arches are clearly seen as bulges on the lateral aspect of the embryo separated by the *branchial grooves* or *clefts*. On the inner aspect of the pharynx, the corresponding depressions are called the *pharyngeal pouches* (**Fig. 32.14**). In between the consecutive arches, the ectodermal lining of the pharyngeal cleft and the endodermal lining of the pharyngeal pouch meet without the intervening mesoderm to form the *branchial membrane*. Thus, the branchial apparatus is composed of four elements:

1. Branchial arches
2. Branchial groove (pharyngeal cleft or ectodermal cleft)
3. Branchial pouch
4. Branchial membrane

Components of Branchial Arches (Fig. 32.15)

1. **Cartilage rods:** These are derived from the neural crest cells and give rise to skeleton, cartilages and ligaments of the arch. Some cartilage rods disappear leaving remnants.
2. **Branchiomere:** These are muscular components.
3. **Vascular component**
4. **Neural component:** Sensory, special visceral and motor nerve.

Each arch is invaded by two nerves: pretrematic nerve and post-trematic nerve.

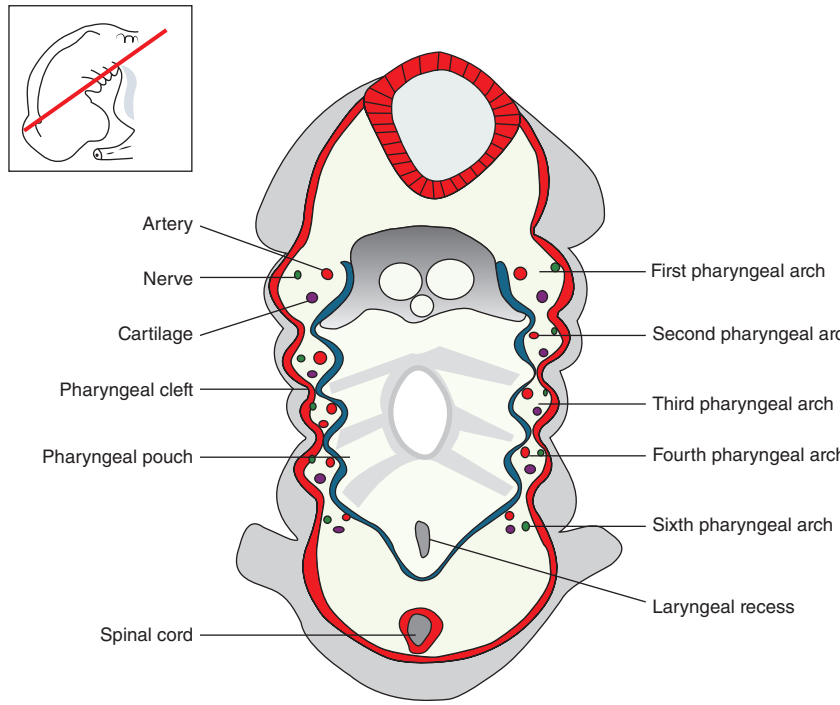


Figure 32.14 Branchial arches, pouches and clefts in the coronal plane.

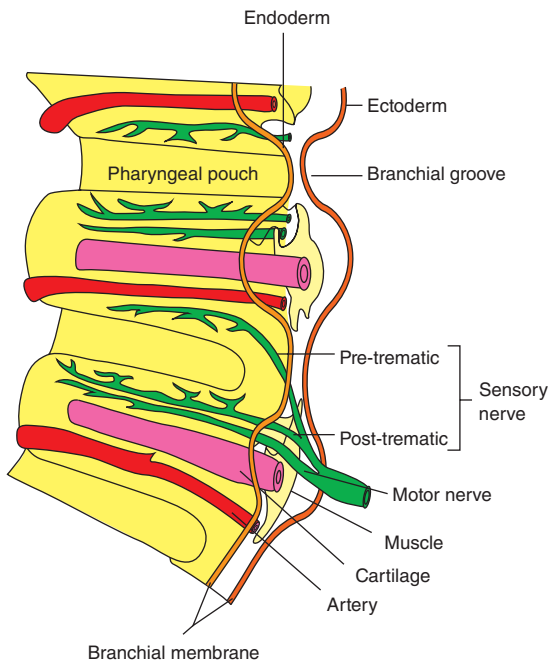


Figure 32.15 Components of branchial arches.

Of the six pharyngeal arches, the fifth arch exists transiently during embryologic growth and development. The first three arches contribute to the structures above the larynx while the fourth and sixth arches contribute to the larynx and trachea.

First Pharyngeal Arch

The first branchial arch or the mandibular arch consists of a paired *maxillary process* that extends from the dorsal portion and a paired *mandibular process* that extends from the ventral portion. The *maxillary bone,* including *premaxilla* and *zygomatic bone*, develops from the mesenchyme of the maxillary process through membranous ossification. The *mandible* is developed from the mandibular process through membranous ossification of mesenchymal tissues around Meckel's cartilage. *Meckel's cartilage* serves as a template for the formation of the mandible and later disappears after forming the *spine of sphenoid* and a major portion of the

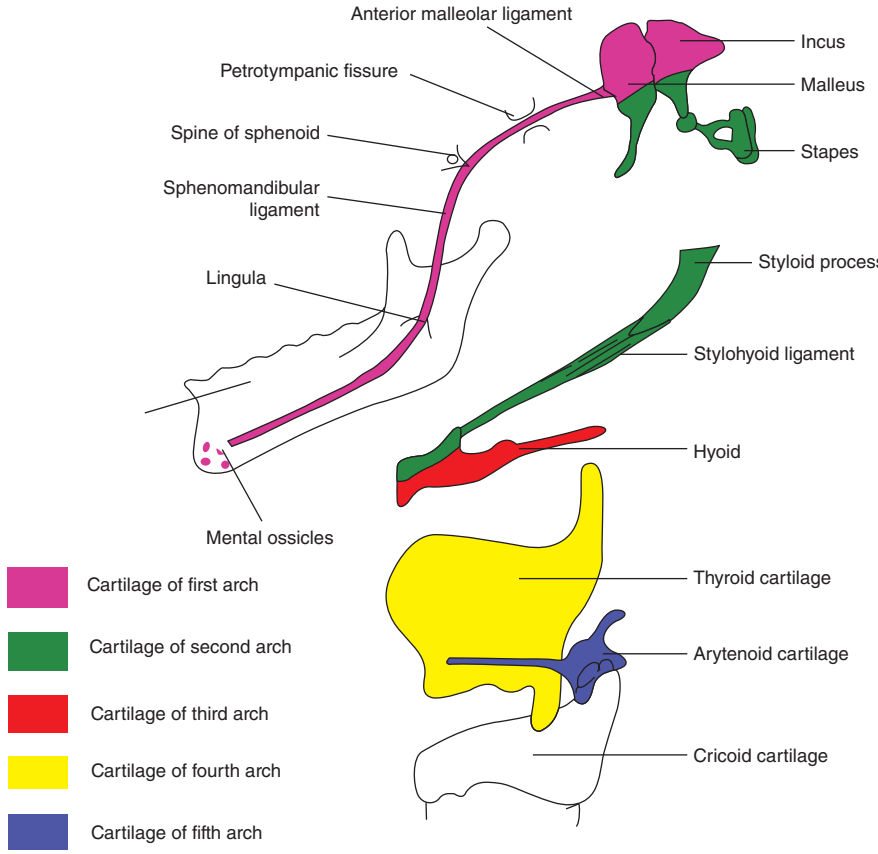


Figure 32.16 Skeletal derivatives of branchial arches.

incus and *malleus* of the ear ossicles (**Fig. 32.16**). The remnants of Meckel's cartilage are present in adult life as the *sphenomandibular ligament* and the *anterior malleolar ligament*. The neural crest cells that migrate into the mesenchyme of the first arch give rise to the *muscles of mastication, anterior belly of digastric, mylohyoid, tensor tympani* and *tensor veli palati*. The motor nerve supply to the muscles of the first arch is by the *mandibular branch of the trigeminal nerve* (**Fig. 32.17**).

During the fifth week of IUL, primitive muscle cells begin to differentiate from the mesenchyme of the mandibular arch. These cells then begin to migrate and orient themselves at the future site of origin and insertion. By the 7th week, the primitive cells begin to further differentiate, and by the 10th week, they become well organized and nerve branches from the trigeminal nerve are incorporated in the muscle masses.

The muscles of arches do not always attach themselves to bones and cartilages of the same arch. Some muscle cells migrate to the surrounding regions to attach themselves to the bones of other arches. The nerve supply of the muscle, however, is derived from the same arch.

The mesenchyme from the first arch also contributes to the *dermis of the skin of the face*. The sensory supply to the skin of the face is provided by the ophthalmic, maxillary and mandibular branches of the trigeminal nerve. The first arch contributes to the development of the *maxillary artery* and proximal portion of the *external carotid artery*.

Second Pharyngeal Arch

The mesoderm of the second pharyngeal arch or the hyoid arch gives rise to the *muscles of facial expression, buccinator, platysma, stapedius,*

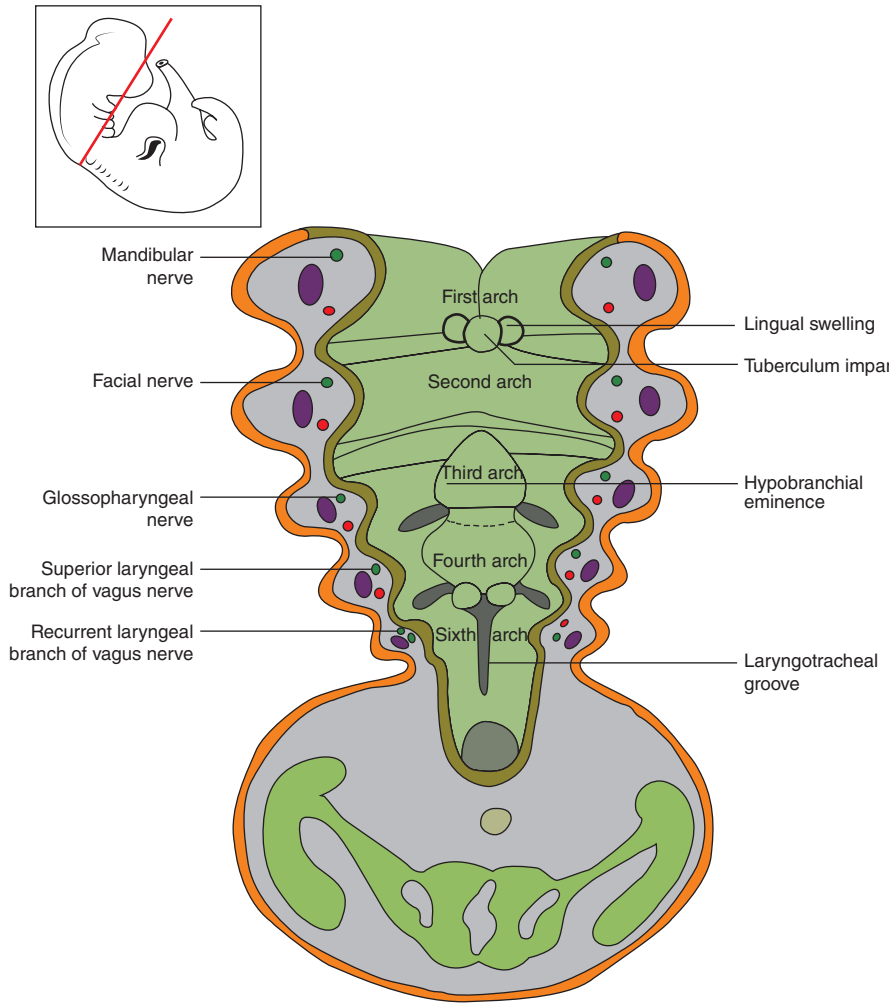


Figure 32.17 Nerves of branchial arches.

stylohyoid, posterior belly of the digastric and *auricular muscles*. The nerve of the second arch, the *facial nerve,* supplies the muscles of the second arch. The special sensory component of the facial nerve, *chorda tympani,* supplies the anterior two-third of the tongue as a *pre-trematic nerve* to the first arch. The cartilage of the second pharyngeal arch, or *Reichert's cartilage,* gives rise to the *styloid process, stylohyoid ligament, lesser horn* and *upper part of the body of the hyoid bone and stapes* and makes contributions to the *incus* and *malleus* (**Fig. 32.16**; **Table 32.5**). The manubrium of malleus and the long crus of incus are derived from the second arch, whereas the footplate of stapes is developed from the otic capsule. The artery of the second arch, *stapedial artery,* disappears during the foetal period.

Third Pharyngeal Arch

The muscle of the third arch is the *stylopharyngeus,* and it is supplied by the nerve of the third arch, the *glossopharyngeal nerve.* The mucosa of the posterior one-third of the tongue is derived from the third arch and is supplied by the glossopharyngeal nerve. This arch contributes to the

Table 32.5 Derivatives of Branchial Arches

Derivatives / Branchial Arch	Skeletal Muscle	Bone	Cartilage	Ligaments	Nerve	Artery
		Viscerocranium				
First arch (mandibular arch)	Muscles of mastication, anterior belly of the digastric, mylohyoid, tensor tympani and tensor veli palati	Maxilla, zygomatic bone, part of temporal bone, mandible, spine of sphenoid, incus and malleus	Meckel's cartilage	Anterior malleolar ligament, sphenomandibular ligament	Maxillary and mandibular divisions of trigeminal nerve	Maxillary artery and contributions to external carotid artery
Second arch (hyoid arch)	Muscles of facial expression, buccinator, platysma, stapedius, stylohyoid, posterior digastric muscle and auricular muscle	Stapes, styloid process, lesser horn and upper part of body of hyoid	Reichert's cartilage	Stylohyoid ligament	Facial nerve	Stapedial artery and small contribution to facial artery
Third arch	Stylopharyngeus	Greater horn and lower part of body of hyoid and thymus	–	–	Glossopharyngeal nerve forming pharyngeal nerve plexus	Proximal one-third of internal carotid artery and contributions to common carotid artery
Fourth arch	Pharyngeal constrictors, cricothyroid, palatoglossus and intrinsic muscles of soft palate	Thyroid cartilage and epiglottis	–	–	Vagus nerve and superior laryngeal nerve (pharyngeal nerve plexus)	Proximal part of subclavian artery (right side) and aortic arch (left side)
Fifth arch	–	Lower part of thyroid cartilage and laryngeal cartilages	–	–	–	–
Sixth arch	Intrinsic muscles of larynx except cricothyroid	Cricoid, arytenoid and corniculate cartilage	–	–	Vagus nerve and recurrent laryngeal nerve	Proximal part of pulmonary artery (right side), pulmonary artery and ductus arteriosus (left side)
Post-branchial region	Trapezius and sternocleidomastoid	–	–	–	Spinal accessory	Tracheal cartilages

development of *common* and *internal carotid arteries*. The cartilages of the arch give rise to the *lower part of the body* and *greater horn of the hyoid bone* (**Fig. 32.16**; **Table 32.5**).

Fourth Pharyngeal Arch

The muscles of this arch—*pharyngeal constrictor, cricothyroid, palatoglossus* and *intrinsic muscles of the soft palate*—are supplied by the *superior laryngeal branch of the vagus nerve* through the *pharyngeal plexus*. The cartilage of the fourth arch develops into the *thyroid cartilage* and *epiglottis*. This arch contributes to the development of the proximal part of the subclavian artery on the right side and the aortic arch on the left side (**Fig. 32.16**; **Table 32.5**).

Fifth Pharyngeal Arch

The fifth pharyngeal arch soon disappears after formation, contributing very little to the development of the thyroid and laryngeal cartilages. The cartilage of the fourth and the fifth pharyngeal arches fuses to form the *thyroid, arytenoid, corniculate* and *cuneiform cartilages* (**Table 32.5**).

Sixth Pharyngeal Arch

The intrinsic *muscles of larynx* except *cricothyroid* are derived from the sixth arch and are supplied by the *recurrent laryngeal branch of vagus*. The cartilages of the sixth arch are the *cricoid, arytenoid* and *corniculate cartilages*. The sixth arch of the endothelial tissue develops into the proximal part of the pulmonary arteries and the transient ductus arteriosus that is present only in the foetal circulation.

The post-branchial muscles, sternocleidomastoid and trapezius, are derived from the branchial mesoderm and the somites and are supplied by the spinal accessory nerve. The other striated muscles of head and neck are derived from the cranial somites and are supplied by the cranial and spinal nerves (**Table 32.5**).

Pharyngeal Pouch and Grooves

The *pharyngeal pouch* is an endodermal outpocketing of the foregut between the projections of the adjacent branchial arches. Similar to the pouches are the ectodermal grooves that are present externally between the adjacent branchial arches. The *branchial membrane* is a site of contact of the ectoderm of the branchial groove with the endoderm of the pharyngeal pouch in between the arches (**Fig. 32.18**).

First Pharyngeal Pouch

The first pharyngeal pouch elongates to form a dorsal diverticulum called the *tubotympanic*

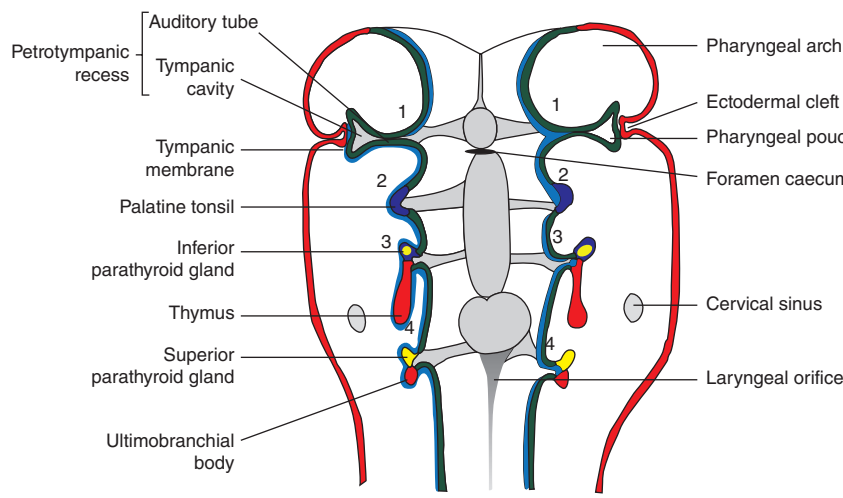


Figure 32.18 Derivatives of branchial pouches. 1, First pharyngeal pouch; 2, second pharyngeal pouch; 3, third pharyngeal pouch; and 4, fourth pharyngeal pouch.

recess while the ventral portion is obliterated by the developing tongue. The distal portion of the tubotympanic recess dilates to form the *primitive middle ear* or *tympanic antrum*. The distal ends of Meckel's and Reichert's cartilages occupy the tympanum to form the ear ossicles. The proximal portion of the tubotympanic recess remains narrow, forming the *auditory tube* or the *Eustachian tube* or the *pharyngotympanic tube* that maintains the communication between the pharynx and the middle ear cavity (**Fig. 32.18**; **Table 32.6**). The endodermal lining of the tympanic cavity along with the ectoderm of the first branchial groove (branchial membrane) aids in the formation of the *tympanic membrane* or *eardrum*. The endodermal lining of the pharynx slowly develops into respiratory epithelium (ciliated columnar). The proximal portion of the auditory tube is lined with the respiratory epithelium.

Second Pharyngeal Pouch

The endoderm of the second pharyngeal pouch proliferates and invades into the adjacent mesenchyme. Then the epithelial bud is secondarily invaded by the surrounding mesenchyme, which forms the primordium of the palatine tonsil. The tonsil is then infiltrated with lymphatic tissue between the third and the fifth month of IUL. The dorsal part of the second pharyngeal pouch remains as the *tonsillar fossae* in the adults, and the epithelial lining of the crypts of the palatine tonsils is derived from the endoderm of the second pharyngeal pouch. The ventral portion of the pouch is obliterated by the developing tongue (**Fig. 32.18**; **Table 32.6**).

Third Pharyngeal Pouch

The third pharyngeal pouch expands into a dorsal and a ventral compartment, and its connection with the pharynx is obliterated. During the fifth week of IUL, the epithelium of the upper compartment differentiates into the *parathyroid gland tissue* while the lower compartment forms the *thymus*. After development, the thymus migrates caudally and medially to its final position in the anterior portion of the thorax, where it fuses with the counterpart from the opposite side. The parathyroid tissue of the third pouch migrates and gets embedded in the dorsal surface of the thyroid gland to form the *inferior parathyroid glands* (**Fig. 32.18**; **Table 32.6**).

Fourth Pharyngeal Pouch

The dorsal diverticulum of the fourth pouch forms the superior parathyroid gland. The final position of the parathyroid gland occurs because the parathyroid tissues from the third pharyngeal pouch migrate caudal to the parathyroid tissues from the fourth pharyngeal pouch (**Fig. 32.18**; **Table 32.6**).

Table 32.6 Derivatives of Pharyngeal Pouches

Pouch	Derivatives	
	Dorsal	**Ventral**
First pharyngeal pouch	Gives rise to the tubotympanic recess, auditory tube and tympanic cavity	Obliterated by tongue
Second pharyngeal pouch	The endodermal lining proliferates to form tonsillar fossae and palatine tonsil	Obliterated by tongue
Third pharyngeal pouch	Inferior parathyroid (III) gland	Thymus
Fourth pharyngeal pouch	Superior parathyroid (IV) gland	–
Fifth pharyngeal pouch	Ultimobranchial body and C cells of thyroid	–

Applied Histology

Di George Syndrome

Failure of neural crest cells' migration to the pharyngeal arches leads to Di George syndrome. Defective parathyroid gland, hypocalcaemia, low set ears, microsomia and cleft palate are some of the manifestations of this syndrome.

Fifth Pharyngeal Pouch

The fifth pouch appears as the diverticulum of the fourth pouch. The endoderm of the fifth pouch develops into the ultimobranchial body. Calcitonin-secreting C cells of the thyroid gland are formed in the ultimobranchial body (**Fig. 32.16**; **Table 32.6**).

Branchial Grooves

Four branchial grooves separate the branchial arches externally on each side; only one pair of branchial grooves forms a structure in the adult. The first branchial groove forms the external auditory meatus. The ectoderm of the first branchial groove forms the lining of the external auditory meatus and the external surface of the tympanic membrane. The first branchial membrane forms the tympanic membrane. The second, third and fourth grooves are obliterated by the overgrowth of the second pharyngeal arch externally (**Fig. 32.19**). The remnants of the second, third and fourth pharyngeal grooves form the cervical sinus.

Applied Histology

Branchial Cyst

Cervical sinus involutes at around the seventh week of IUL. Failure in complete involution of the sinus leads to an ectoderm-lined cavity called the branchial cyst.

Branchial Fistula

The cervical sinus may sometimes open into the neck to form the branchial fistula or may open into both the neck and the pharynx to form the pharyngocutaneous fistula.

The developmental stages of an embryo are summarized in **Table 32.7**.

Table 32.7 Summary of the Key Events in the Development of an Embryo

Period of Gestation	Events
Day 1	• Fertilization
Day 2	• 2-cell stage—after 30 hours • 4-cell stage—after 40 hours
Day 3	• 16-cell stage—early morula
Day 4	• Early blastocyst stage
Day 5	• Late blastocyst stage
Day 6	• Implantation begins
Day 7	• Implantation completes
Week 2	• Primitive streak appears • Notochord appears
Week 3	• Gastrulation, neurulation and migration of neural crest cells occur • Cephalocaudal folding of the embryo begins
Week 4	• Cephalocaudal folding of the embryo continues • Rupture of the buccopharyngeal membrane occurs • First, second and third visceral arches develop • Optic vesicles are formed • Otic placodes appear
Week 5	• Fourth visceral arch develops • Nasal pits are formed
Week 6	• External auricle develops from the auricular hillocks
Week 7	• Formation of the upper lip occurs • Fusion of the facial process begins
Week 8	• Formation of the tongue and palate occurs • Fusion of the facial process completes

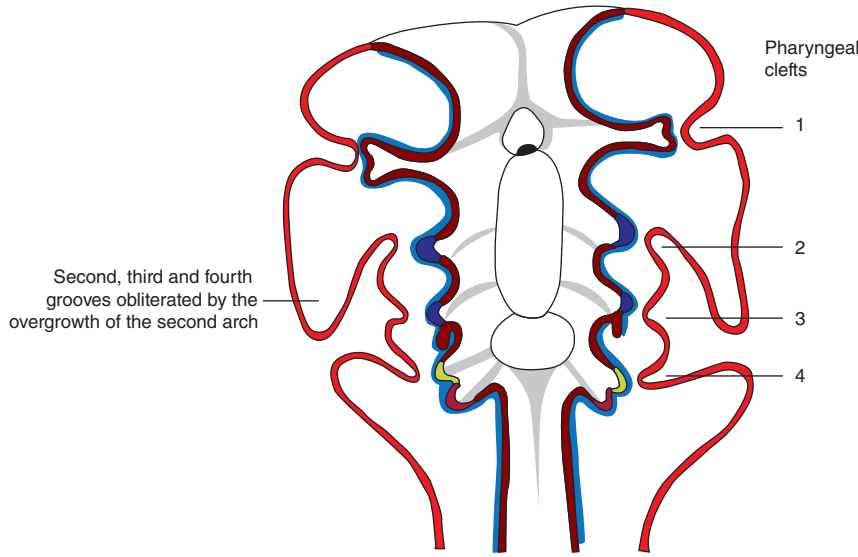
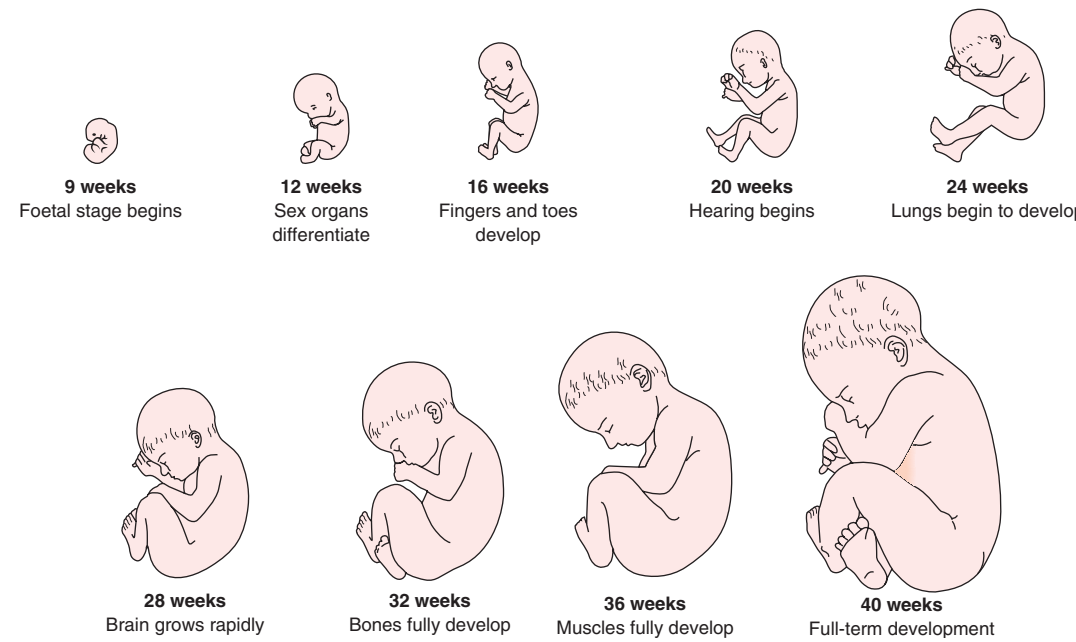


Figure 32.19 Derivatives of branchial grooves. 1, 2, 3 and 4 refer to branchial grooves.

ADDITIONAL READING

Carnegie Stages of Development

The Carnegie system describes the different stages of maturation of embryos. The stages are numbered from 1 to 23 based on the morphology of the embryo. The parameters that are used in staging are the body length, external body shape and degree of development of internal organs. Staging is not dependent on the chronological age or the size of the embryo. The differentiation is arbitrarily based on the maturity of the physical features. This system is widely used as reference during ultrasonographic assessment during pregnancy.



Developmental Timing

Developmental biology in a living being involves a series of well-orchestrated timeline of events. The developmental stages are pronounced by switching on and off of complement genes. MicroRNAs control the duration of activity of these genes. However, regulation of miRNAs are not known. Developmental defects arise when there is a defect in the timing of activation of these genes. The degree of mutation of these genes determines the outcome of maturation—precocious or delayed. The *LIN-42* gene has been found to regulate developmental timing through miRNAs. It has also been found to be similar to genes that control the circadian rhythm in mice and humans. *LIN-42* acts as a part of the developmental clock and the levels of protein expression oscillate over the course of development. It provides a rhythmical pattern or temporal memory to the organism so that every developmental step is executed in order (excerpts from Roberto Perales et al. 2014).

Molecular Basis of Craniofacial Placode Development

Placode development is a highly controlled series of events coordinated by unique signalling pathways and transcription factors. Signalling molecules form a niche of creating various transcription factors and establishes a non-neural and

Stage	Days	Size (mm)	Events
1	1	0.1–0.15	Fertilized oocyte, pronuclei
2	2–3	0.1–0.2	Cell division with reduction in cytoplasmic volume, formation of inner and outer cell mass
3	4–5	0.1–0.2	Loss of zona pellucida, free blastocyst
4	5–6	0.1–0.2	Attaching blastocyst
5	7–12	0.1–0.2	Implantation
6	13–15	0.2	Extraembryonic mesoderm, primitive streak
7	15–17	0.4	Gastrulation, notochordal process
8	17–19	1.0–1.5	Primitive pit, notochordal canal
9	19–21	1.5–2.5	Somite number 1–3 neural folds, cardiac primordium, head fold
10	22–23	2–3.5	Somite number 4–12 neural fold fuses
11	23–26	2.5–4.5	Somite number 13–20 rostral neuropore closes
12	26–30	3–5	Somite number 21–29 caudal neuropore closes
13	28–32	4–6	Somite number 30 leg buds, lens placode, pharyngeal arches
14	31–35	5–7	Lens pit, optic cup
15	35–38	7–9	Lens vesicle, nasal pit, hand plate
16	37–42	8–11	Nasal pits moved ventrally, auricular hillocks, foot plate
17	42–44	11–14	Finger rays
18	44–48	13–17	Ossification commences
19	48–51	16–18	Straightening of trunk
20	51–53	18–22	Upper limbs longer and bent at elbow
21	53–54	22–24	Hands and feet turned inwards
22	54–56	23–28	Eyelids, external ears
23	56–60	27–31	Rounded head, body and limbs

neural boundary, which leads to the formation of the neural border that forms the neural crest and placodes. Various developmental defects arise due to mutation of genes regulating placode development. Targeting these signalling pathways and transcription factors during placode induction is vital to prevent disease and defects associated with neural crest and placode-derived sensory organs.

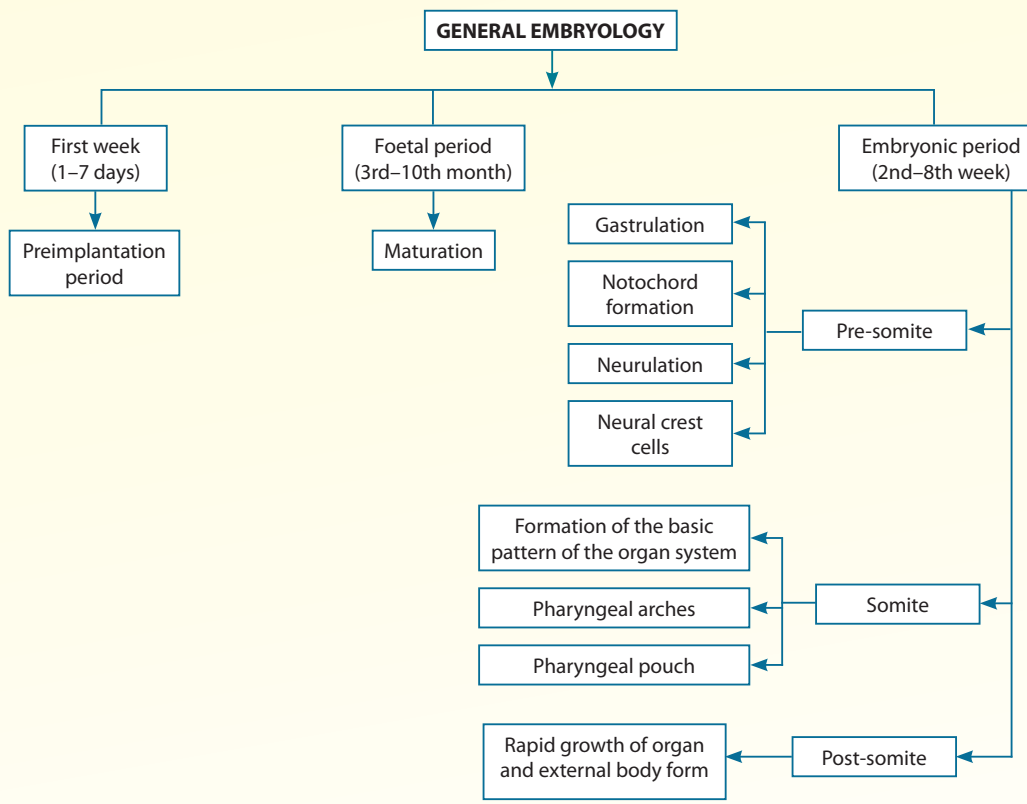
Inititiation and specificity of the pre-placodal region is controlled by the fibroblast growth factor, bone morphogenetic protein, WNT and retinoic acid signalling pathways and is characterized by expression of the EYA and SIX family of transcriptional regulators. Differentiation of the lineage towards a particular placodal function is regulated by pioneer factors. Pioneer factors are expressed early during initiation of the pre-placodal region, where they bind to the enhancers of lineage-specific genes thus keeping them poised for transcription by recruiting other co-factors. Lineage-specific signals promote the differentiation of the cells towards their respective placodal fates. FOXI3 is one of the pioneering factors in regulating the otic placode. Pioneer factors also regulate lineage-specific gene expression during cellular reprogramming in stem cells (excerpts from Sunita et al. 2016).

Key Points

1. The formation of blastocyst from the zygote and implantation of the blastocyst in the endometrium of the uterus take place by the end of the first week.
2. The bilaminar germ disc comprises a superior epiblast layer composed of tall columnar cells and an inferior hypoblast layer composed of cuboidal cells.
3. The characteristic event in the third week of development is gastrulation—the formation of the three germ layers.
4. Gastrulation begins with the formation of the primitive streak and the primitive node.
5. At the end of the third week, two embryonic membranes—the buccopharyngeal membrane or oropharyngeal membrane at the cephalic end and a cloacal membrane at the caudal end—appear in the germ disc.
6. The buccopharyngeal membrane and the cloacal membrane consist only of ectoderm and endoderm without an intermediate mesoderm and denote the locations of the future oral cavity and the anus.
7. Invading prenotochordal cells from the epiblast, through the primitive streak, interpose with the hypoblast to form the notochordal plate, which gives rise to notochord.
8. The cells of the notochord are formed from the mesoderm. The notochord serves as the basis for the axial skeleton.
9. Neuroectoderm cells differentiate from the ectoderm during the later part of the third week of intrauterine life (IUL).
10. Neuroectoderm cells proliferate to form the neural plate. The neural groove appears in the neural plate and is surrounded by the neural folds. During the fourth week, the neural folds fuse to form the neural tube.
11. The anterior portion of the neural tube bulges to form the forebrain, midbrain and hind brain, and the spinal cord develops caudal to the hind brain.
12. Neural crest cells are often referred to as the fourth germ layer.
13. The paraxial mesoderm differentiates into 38 paired cuboidal aggregates called somites which give rise to the sclerotome (bone and cartilage), myotome (muscles) and dermatome (dermis of the skin), forming the structures of the head, neck and trunk.
14. At the fourth week of IUL, the buccopharyngeal membrane ruptures and a communication is established between the primitive oral cavity and the primitive foregut.

15. The branchial arches are separated by the branchial grooves or clefts on the lateral aspect and by the pharyngeal pouches on the inner aspect. In between the consecutive arches, the ectodermal lining of the pharyngeal cleft and the endodermal lining of the pharyngeal pouch meet without the intervening mesoderm, forming the branchial membrane.
16. Each branchial arch consists of a cartilage, a branchiomere, a vascular component and a neural component.
17. The derivatives of each branchial arch are supplied by a pre-trematic nerve and a post-trematic nerve.
18. The cartilage of the first arch is Meckel's cartilage and that of the second arch is Reichert's cartilage.
19. The special sensory component of the facial nerve (nerve of the second arch), the chorda tympani, supplies the anterior two-third of the tongue as a pre-trematic nerve to the first arch.
20. The endodermal lining of the tympanic cavity, along with the ectoderm of the first branchial groove (branchial membrane), aids in the formation of the tympanic membrane or eardrum.
21. The period of sensitivity to teratogens that affect development is between 3 and 8 weeks, the period of organogenesis.

Mind Map



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Multiple Choice Questions

1. The inner cell mass of the morula gives rise to the
   (a) Cytotrophoblast
   (b) Embryo
   (c) Syncytiotrophoblast
   (d) Placenta
2. The blastocyst undergoes implantation in the endometrium of the uterus in the
   (a) Seventh week of gestation
   (b) Eighth week of gestation
   (c) Seventh day of gestation
   (d) Eighth day of gestation
3. Gastrulation is the establishment of the
   (a) Neural tube
   (b) Three germ layers
   (c) Branchial arches
   (d) Notochord
4. The placenta is formed by the reaction of the
   (a) Trophoblast layer with the endometrium of the uterus
   (b) Epiblast with the endometrium of the uterus
   (c) Hypoblast with the endometrium of the uterus
   (d) Trophoblast layer with the myometrium of the uterus
5. The primitive node appears in the
   (a) Cephalic end of the primitive streak
   (b) Caudal end of the primitive streak
   (c) Lateral end of the primitive streak
   (d) Mesial end of the primitive streak
6. The buccopharyngeal membrane is composed of the
   (a) Endoderm and mesoderm
   (b) Ectoderm and endoderm

(c) Ectoderm and mesoderm
(d) Ectoderm only

7. The secretion of sonic hedgehog protein by the _____ defines the dorsoventral axis of the embryo.
   (a) Neural crest cells
   (b) Notochord
   (c) Neural tube
   (d) Neural plate
8. Neurulation is the formation of the
   (a) Neural crest cells
   (b) Notochord
   (c) Neural tube
   (d) Notochordal plate
9. Somites are derived from the
   (a) Lateral plate mesoderm
   (b) Intermediate mesoderm
   (c) Paraxial mesoderm
   (d) Extraembryonic mesenchyme
10. The epithelial lining of the inside of the visceral organs are derived from the
    (a) Endoderm
    (b) Ectoderm
    (c) Mesoderm
    (d) None of the above
11. The stomodeum is located between the
    (a) Developing midbrain and pericardium
    (b) Developing hind brain and pericardium
    (c) Developing forebrain and branchial arches
    (d) Developing forebrain and pericardium
12. Cephalocaudal folding of the embryo begins at the
    (a) Third week of IUL
    (b) Fourth week of IUL
    (c) Fifth week of IUL
    (d) Sixth week of IUL
13. The buccopharyngeal membrane ruptures at the
    (a) Third week of IUL
    (b) Fourth week of IUL
    (c) Fifth week of IUL
    (d) Sixth week of IUL
14. On the lateral aspect of the embryo, the branchial arches are separated by the
    (a) Branchial pouches
    (b) Branchial clefts
    (c) Branchial membrane
    (d) Branchial fistula
15. The remnants of Meckel's cartilage are the
    (a) Stylomandibular ligament
    (b) Sphenomandibular ligament
    (c) Anterior malleolar ligament
    (d) Both b and c
16. The cartilage of the second arch is
    (a) Meckel's cartilage
    (b) Reichert's cartilage
    (c) Thyroid cartilage
    (d) Epiglottic cartilage
17. The second arch is known as
    (a) Reichert's arch
    (b) Styloid arch
    (c) Hyoid arch
    (d) Mandibular arch
18. The dorsal diverticulum of the first pharyngeal pouch forms the
    (a) Tonsillar fossae
    (b) Tubotympanic recess
    (c) Tympanic membrane
    (d) External auditory meatus
19. The remnants of the dorsal part of the second pharyngeal pouch in adult life are present as the
    (a) Tonsillar fossae
    (b) Tubotympanic recess
    (c) Tympanic membrane
    (d) External auditory meatus
20. The remnants of the second, third and fourth pharyngeal or branchial grooves form the
    (a) Tonsillar fossae
    (b) Tympanic membrane
    (c) Cervical sinus
    (d) External auditory meatus

CHAPTER 33



Embryology of the Head, Face and Oral Cavity

Overview

The two categories of skull bones are neurocranium and viscerocranium. Neurocranium is divided into membranous desmocranium and cartilaginous chondrocranium. Membranous ossification occurs in desmocranium and forms most of the cranial vault as well as a portion of the base of the skull. The rest of the skull passes through a phase of chondrification formed from cartilagenous chondrocranium. There are 110 ossificaiton centres seen in the developing skull. The body and ramus of the mandible develop from Meckle's cartilage, which is the primary cartilage. The condylar process, coronoid process and symphysis develop from the secondary cartilage called condylar, coronoid and symphyseal cartilages. At early intrauterine life (IUL), the primitive joint between the malleus and incus briefly functions as jaw joint. At the 12th week of IUL, mesenchymal differentiation between condylar and temporal blastema and eventually the temporomandibular joint is formed. The face develops from the frontonasal process, paired maxillary and mandibular processes. Optic and olfactory placodes are formed as thickenings in the frontonasal process. Olfactory placodes proliferate and deepen leading to the development of the median nasal process medially and the lateral nasal process laterally with a central pit called nasal/olfactory pit. The nasal pit further enlarges towards the developing brain, producing the nasal sac which later develops into the nasal cavities. The fusion of the maxillary process and the median nasal process forms the palate and the upper lip. The mandibular processes fuse to form the lower lip. The tongue develops from the endodermal lining of the first four branchial arches, with the invading muscle tissue from the occipital myotome. The primary palate is derived from the globular process or the premaxillary segment of the median nasal process. The secondary palate is formed from the extensions of the maxillary process. Later, the primary and secondary palates are fused to each other.

DEVELOPMENT OF CRANIUM

The bones of the skull are grouped under two categories: *neurocranium* (protective covering of the brain) and *viscerocranium* (bones of the face) (**Fig. 33.1**). Developmentally, the neurocranium is divided into membranous desmocranium and cartilaginous *chondrocranium*. Most of the cranial vault and a portion of the base of the skull are developed through membranous ossification while the rest of the skull passes through a phase of chondrification (i.e. formation of cartilage) during development, forming the chondrocranium. The viscerocranium is developed from the branchial or visceral arches.

Membranous Neurocranium (Desmocranium)

The desmocranium appears in the fourth week of IUL as a condensation of mesenchyme around the developing brain. The mesenchyme is composed of an inner endomenix and outer ectomenix. The endomenix is of the neural crest origin and it differentiates into the arachnoid and pia mater. The ectomenix is of the mesodermal origin and it differentiates into the skull bone and dura mater (**Fig. 33.2**). Several primary and secondary ossification centres develop during the eighth week of IUL in the outer layer of the ectomenix to form the individual bones (**Table 33.1**; **Fig. 33.3**).

Chondrocranium

The major portion of the base of the skull is developed by endochondral ossification from a

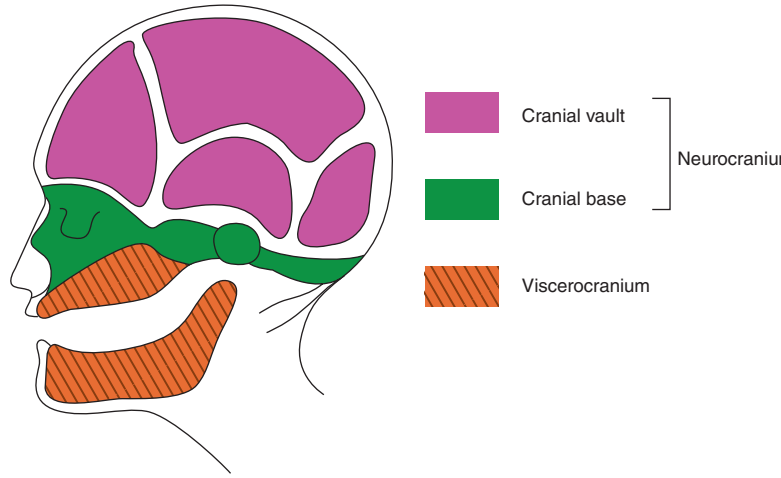


Figure 33.1 Divisions of the skull.

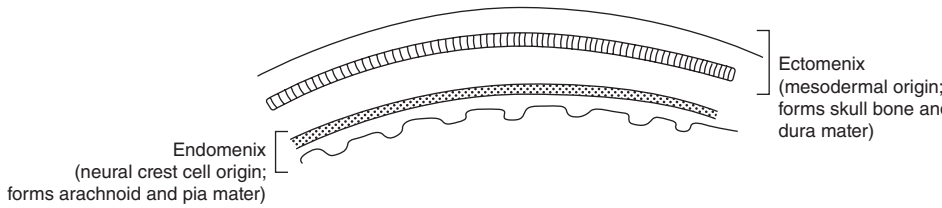


Figure 33.2 Embryonic precursors of the components of desmocranium.

number of separate cartilages. The chondrocranium undergoes a phase of chondrification during development and may or may not remain as cartilage in adult life.

The chondrification primarily occurs in two regions:

1. In the region of notochord *(parachordal chondrocranium)*
2. In front of notochord *(prechordal chondrocranium)*

The parachordal chondrocranium is derived from the neural crest cells while the prechordal chondrocranium is derived from occipital myotomes (Fig. 33.4).

The sphenoid bone develops from the cartilages of the prechordal chondrocranium. Two

SECTION IV

Table 33.1 Development of Desmocranium

Bone	Type of Ossification	Number of Ossification Centres
Frontal bone	Intramembranous	One primary and three secondary
Parietal bone	Intramembranous	Two primary
Squamous occipital	Intramembranous	Two primary
Rest of the occipital bone	Endochondral ossification	–
Squamous temporal	Intramembranous	One primary
Tympanic part of the temporal bone	Intramembranous	One primary
Rest of the temporal bone	Endochondral ossification	–

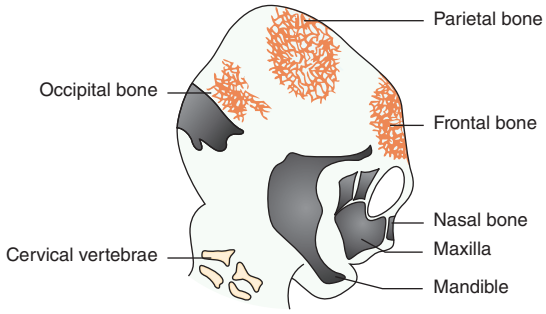


Figure 33.3 A 3-month skull showing ossification progressing from the primary ossification centres.

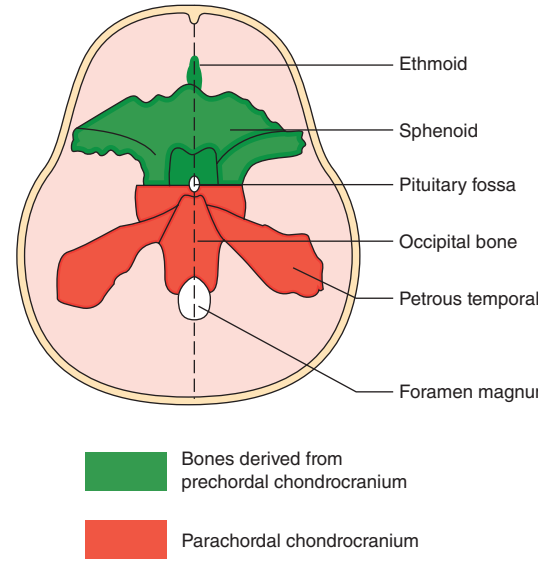


Figure 33.4 Dorsal view of the base of the skull showing the prechordal and parachordal chondrocranium.

hypophyseal cartilages develop on either side of the developing pituitary gland and fuse to form the *polar cartilage*, which later gives rise to the *sella turcica* and the *posterior part of the body of sphenoid*. Cranial to the developing pituitary gland, two *sphenoid (trabecular) cartilages* form that fuse to form the *anterior part of the body of sphenoid*. The chondrification centres in mesenchymal condensation surrounding the developing stalk of hypophysis *(ali sphenoid* and *orbitosphenoid cartilages)* spread out laterally to form the greater and lesser wings of the sphenoid. During the fifth week, the developing auditory vesicles are surrounded by the *otic capsules*. This part later fuses with the *parachordal cartilages* to form the *mastoid* and the *petrous parts of the temporal bone*. The *nasal capsule* chondrifies in the second month of IUL. The parachordal cartilages formed around the cranial end of the notochord form the primordium of the *basilar portion* of the occipital bone. At the caudal end are the *four occipital* somites forming the *condylar portion* of the occipital bone (**Fig. 33.5**).

The separate centres of chondrification later fuse to form the chondrocranium. The ossifying chondrocranium meets the ossifying descranium to form the neurocranium. Approximately 110 ossification centres appear in the embryonic skull and fuse to produce 45 bones in a newborn skull that are reduced to 32 bones in a young adult.

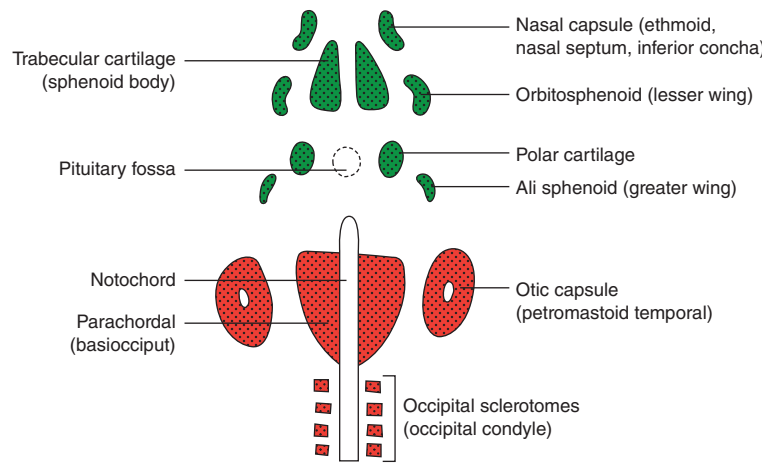


Figure 33.5 Primordial cartilages of the base of the skull.

DEVELOPMENT OF THE MANDIBLE

In the sixth week of IUL, Meckel's cartilage extends as a solid rod of hyaline cartilage from the otic capsule to the midline. The right- and left-side cartilages are separated in the midline by a thin band of mesenchyme and the cartilage is surrounded by a fibrous capsule. The inferior alveolar and lingual branch of the mandibular nerve runs along the medial and lateral aspect of the cartilage. The inferior alveolar nerve bifurcates to form the incisive and mental branches at the site of the future mental foramen.

Later, a mesenchymal condensation appears on either side near the bifurcation of the inferior alveolar nerve at the site of future mental foramen. In the seventh week of IUL, a single ossification centre for each half of the mandible begins in the mesenchymal condensation (**Fig. 33.6**). The mandible is the second bone after the clavicle to ossify in the entire skeletal system. The ossification spreads around the inferior alveolar nerve towards the point of the future mandibular foramen posteriorly and towards the midline anteriorly. The ossification forms a trough around the inferior alveolar nerve and is later converted into the mandibular canal in which the nerve lies. From this bony canal, the alveolar plates develop in relation to the developing tooth germs. After the formation of the body of the mandible, the ramus is formed by the spread of ossification posteriorly into the mesenchyme of the first arch. The mandible formation is almost complete by the end of the 10th week, formed almost entirely by intramembranous ossification, and is entirely independent of Meckel's cartilage. The union of the two separate centres of ossification occurs in the midline between the 4th and the 12th month postnatally.

The dorsal end of Meckel's cartilage ends in the tympanic cavity of the middle ear and is surrounded by the developing petrous part of the temporal bone. The auditory ossicles, *incus* and *malleus,* of the inner ear are derived from Meckel's cartilage. A part of the cartilage transforms to form the *anterior malleolar ligament.* During the 24th week of IUL, the major portion of Meckel's cartilage between the mental foramen and mandibular foramen degenerates while the fibrocellular capsule of the cartilage persists between the lingula of the mandible and the spine of the sphenoid as the *sphenomandibular ligament.* Some remnants forming accessory endochondral ossicles are evident in the symphyseal region ventral to the mental foramen (**Fig. 33.7**).

The growth of the mandible further takes place by the appearance of three *secondary cartilages*: condylar coronoid and symphyseal cartilages. These cartilages are developmentally and functionally different from Meckel's cartilage, which is a *primary cartilage* (**Table 33.2**).

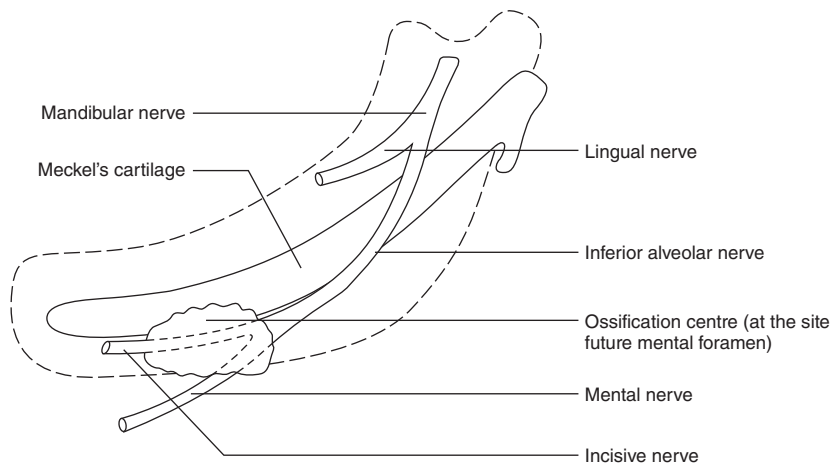


Figure 33.6 Lateral view of the developing mandible showing the ossification centre lateral to Meckel's cartilage at the bifurcation of the inferior alveolar nerve.

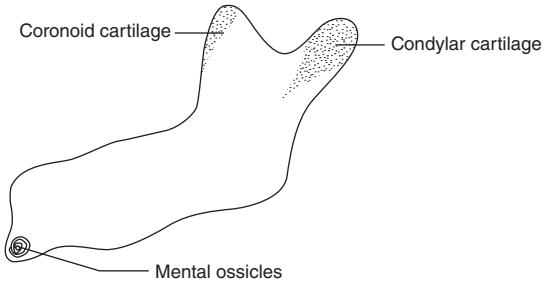


Figure 33.7 Accessory cartilages of the mandible.

The condyle appears as a cone-shaped cartilage during the 10th week of IUL, occupying most of the developing ramus (**Fig. 33.7**). The condylar head increases in size by both *interstitial* and *appositional* growth. The first evidence of endochondral ossification is seen in the 14th week of IUL. By the 20th week, most of the cartilage is replaced by bone and only a thin layer of cartilage remains in the head of the condyle. The remnant of the cartilage is present in adult life as a growth cartilage and articular cartilage of the temporomandibular joint.

The coronoid cartilage appears in the 14th week of IUL, contributing to the development of the coronoid process. It soon becomes incorporated into the developing ramus and disappears before birth (**Fig. 33.7**). Two islands of symphyseal cartilage appear on either side of the midline in the symphyseal region independent of Meckel's cartilage (**Fig. 33.6**). It ossifies in the seventh month of IUL but as a variant some remnants may be present as *mental ossicles* in the fibrous union of the mandibular mid-line at birth. These ossicles ossify and are incorporated into the bone postnatally, during which the fibrous union *(syndesmosis)* between the two halves of the mandible is converted into a bony union *(synostosis)*.

Table 33.2 Characteristics of Primary and Secondary Cartilages

Primary Cartilage	Secondary Cartilage
Exists in the axial skeleton, skull base and epiphyseal cartilage of limbs	Exists in condyle, coronoid process and sutures
Dividing cells are differentiated chondroblasts and synthesize intracellular matrix	Dividing cells are prechondroblasts
Dividing cells are surrounded by a cartilaginous matrix that isolates the cells from local factors that can restrain or stimulate the cartilaginous growth	Dividing cells are not surrounded by a cartilaginous matrix and are not isolated from local factors

Development of the Temporomandibular Joint

The temporomandibular joint (TMJ) is considered a *secondary joint*, both developmentally and phylogenetically. The primitive joint between the malleus and incus briefly functions as a jaw joint from as early as eighth week of IUL till before the formation of a definite TMJ. The development of TMJ is different from the other synovial joints (**Table 33.3**; **Figs 33.8** and **33.9**).

Table 33.3 Differences Between the Development of the Temporomandibular Joint and Other Synovial Joints

Temporomandibular Joint	Other Synovial Joints
Develops from two widely separated condylar and temporal blastema[a]	Develop by a cavity formation in a single blastema from which the endochondral bones develop
Presence of hyaline cartilage	Fibrocartilage

[a]Blastema is a definite mass of undifferentiated pluripotent cells.

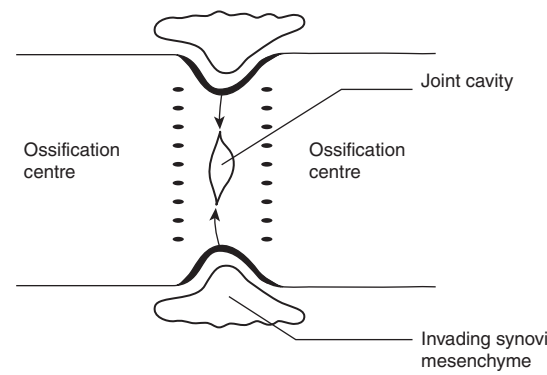


Figure 33.8 Development of other synovial joints.

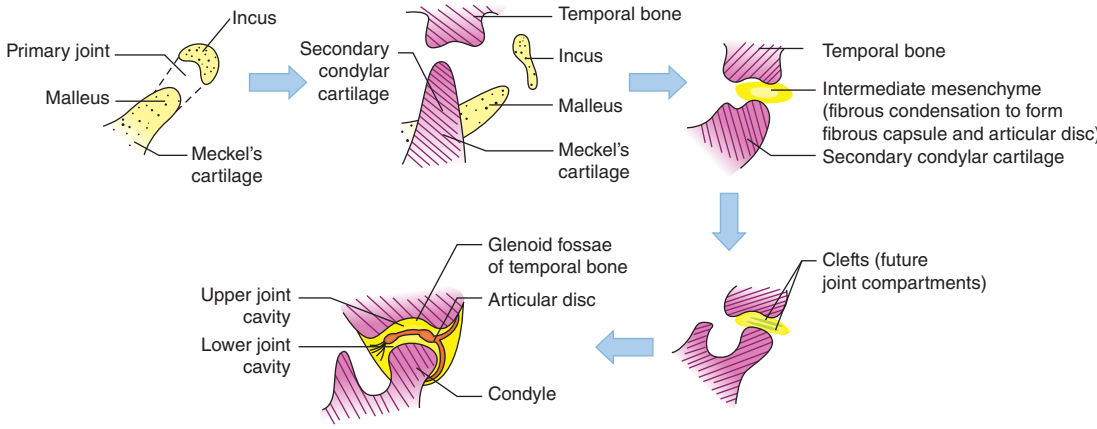


Figure 33.9 Development of the temporomandibular joint.

Between the 10th and 12th weeks of IUL, the condylar cartilage grows towards the temporal bone. The mesenchyme between the condylar and the temporal blastema differentiates into a fibrous tissue which later forms the articular disc and the fibrous joint capsule. During the 12th week of IUL, the primitive superior and inferior joint cavity appears as a cleft in the vascular fibrous tissue, defining the shape of the articular disc. The cavity is later invaded by the synovial membrane. The developing articular disc assumes its characteristic biconvex shape and is continuous with the tendon of the lateral pterygoid muscle anteriorly. Posteriorly, the disc is attached to the malleus by the discomalleolar ligament.

DEVELOPMENT OF THE HYOID BONE

The hyoid bone develops through endochondral ossification of the cartilage of second and third arches from six centres of ossification. Two ossification centres, one each for the right and left greater horns, appear just before birth; and two centres, one each for the right and left halves of the body, appear at birth. The two centres for the lesser horn appear after 2 years postnatally, and the fusion of these ossification centres occurs later in postnatal life.

DEVELOPMENT OF THE FACE

The face develops from the five processes surrounding the stomodeum, namely the frontonasal process, and the paired maxillary and mandibular processes. At the end of the fourth week of IUL, the mesenchyme between the ventral aspect of the forebrain and the ectodermal covering of the stomodeum bulges to form the *frontonasal process*. The maxillary and mandibular processes can be distinguished on the lateral and caudal aspect of the stomodeum (**Fig. 33.10**).

At the fifth week of IUL, the ectodermal lining of the frontonasal process forms a thickening on both the anterior and inferolateral borders to form the optic and *olfactory placodes.* These placodes form the lens of the eye and the olfactory epithelium, respectively. As the olfactory placodes proliferate and enlarge, a depression *(olfactory pit* or *nasal pit)* appears in the centre. The medial arm end of the placodes is called the *median nasal process* (MNP) and the lateral arm is called the *lateral nasal process* (LNP; **Fig. 33.11**). During the sixth week, the nasal pits deepen due to the proliferation of mesenchyme of the surrounding nasal process and partly due to the invagination of ectoderm into the underlying tissue. The nasal pit further enlarges towards the developing brain, producing

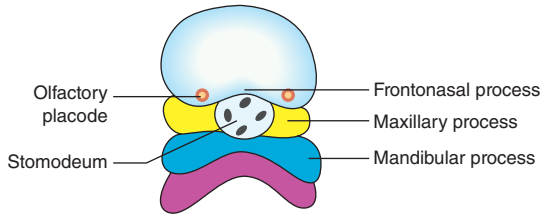


Figure 33.10 A 4-week-old embryo showing the facial processes.

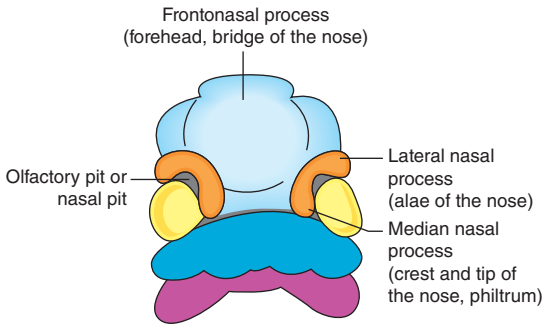


Figure 33.11 Embryo showing the median nasal process, lateral nasal process and olfactory pit.

the *nasal sac*. The nasal sacs later develop into the nasal cavities. At this point, the *oronasal membrane* separates the developing nasal cavity and oral cavity (*see* **Fig. 33.13a**).

The maxillary processes enlarge to form the cheek, maxillary bone and zygomatic bone. The maxillary process grows in the ventral direction and fuses with the LNP to establish continuity between the future cheek and the nose. Between the merging LNP and the maxillary process is the *naso-optic furrow* (**Fig. 33.12**).

The fusion of the various facial processes results in extensions of the mesenchyme from the MNP that bulge into the stomodeum in the anterior region to form the *premaxillary process* or the *globular process*, which later gives rise to the primary palate.

Before the rupture of the oronasal membrane, a sheet of epithelium is seen in front of the nasal pit, known as the *nasal fin*. The fin is eventually incorporated into the oronasal membrane or the walls of the developing nasal cavity. Persistence and proliferation of nasal fin prevent fusion of MNP and maxillary process, leading to a cleft lip.

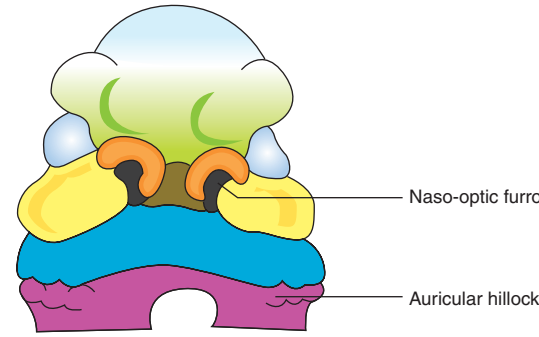


Figure 33.12 Embryo showing the naso-optic furrow and auricular hillocks.

At the end of the sixth week, the oronasal membrane (**Fig. 33.13a**) begins to rupture, and during the seventh week of IUL, a connection is established between the primitive nasal cavity and the stomodeum (**Fig. 33.13b**). Thus, the primitive posterior apertures of the nose are established in the midline on either side immediately posterior to the primary palate (**Fig. 33.13c**). Later, with the formation of the secondary palate and further development of the nasal cavity, the posterior nasal aperture migrates posteriorly, and in adult life, the posterior aperture of the nasal cavity opens in the nasopharynx (**Fig. 33.13d**).

The right and the left MNPs fuse to form the middle portion of the nose, including the root, crest and tip of the nose. The MNP also gives rise to the philtrum and the premaxillary segment (globular process), which is associated with the development of maxillary incisors and their associated structures, the primary palate and the nasal septum. The LNP forms the ala of the nose. The fusion of the lateral nasal, median nasal and maxillary processes forms the external nares (**Fig. 33.14**; **Table 33.4**).

The maxillary process grows medially, meeting the MNP in the midline. The right and left median nasal processes fuse with each other and fuse with the maxillary processes on the corresponding side to form the upper lip (**Box 33.1**). Thus, the philtrum of the upper lip is derived from the MNP and the upper lip is derived from the maxillary process. The mandibular processes grow medially towards each other and fuse to establish the continuity of the lower lip.

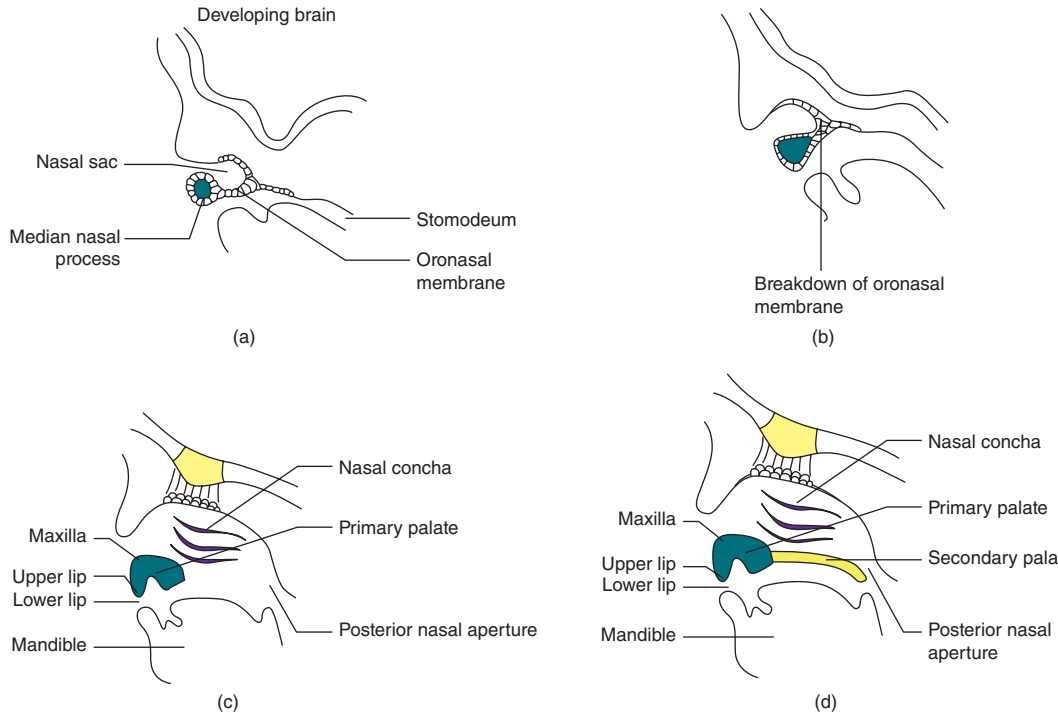


Figure 33.13 Sagittal section of the embryo showing (a) oronasal membrane, (b) rupturing of the oronasal membrane, (c) formation of the primary palate and the posterior nasal aperture and (d) formation of the secondary palate and the migration of the posterior nasal aperture.

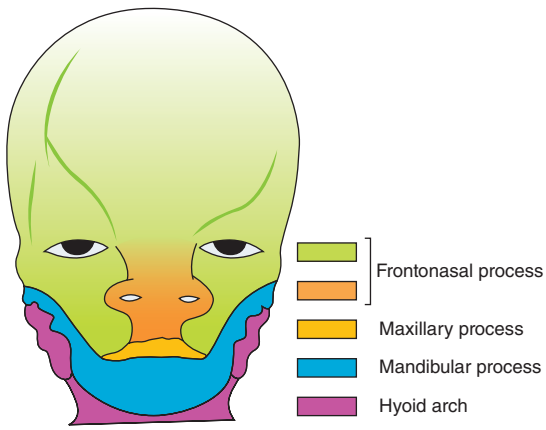


Figure 33.14 An 8-week-old embryo showing the contribution of various facial processes involved in the development of face.

Table 33.4 List of the Various Embryonic Processes and Their Contributions to the Development of Face

Embryologic Process	Structures of the Face
Frontonasal process	Forehead
Frontonasal process	Nose—bridge
Median nasal processes	Nose—crest and tip
Lateral nasal processes	Nose—alae
Median nasal processes	Philtrum of the lip
Maxillary process	Upper lip
Maxillary process	Cheeks
Palatine process of the maxillary process	Secondary palate
Globular process	Primary palate
Mandibular process	Lower lip

The surface ectoderm proliferates into the underlying mesenchyme to form a band of epithelial cells called *vestibular lamina*. The cells of the vestibular lamina undergo autolysis to establish the *labial* and *buccal sulcus*. Thus, the upper lip and lower lip are separated from the corresponding jaws.

Development of Facial Skeleton

Facial skeleton develops intramembranously from ossification centres in the embryonic facial process. The first ossification centre appears in the eighth week of IUL for the vomer. Later, two ossification centres for the vomer and a single ossification centre for the palatine bone appear on either side. The primary ossification centre for the maxilla appears in the region of the future infraorbital foramen. At the end of the eighth week, the ossification centres for the zygomatic and alveolar processes of the maxilla appear. The ossification centre for the nasal and lacrimal bones appears in the frontonasal process in the third month of IUL. Bony fusion of the various units occurs at the fifth month of IUL.

Box 33.1 Theories About the Development of the Upper Lip

Two different theories have been proposed for the development of the upper lip. One theory suggests that the maxillary process overgrows the median nasal process at the midline, so that the entire upper lip is developed from the maxillary process and only the philtrum is developed from the median nasal process. The other theory suggests that the middle third of the upper lip is developed from the median nasal process. Although histologic evidences support the latter theory, a possible migration of the maxillary mesenchymal tissue towards the midline after the fusion of facial processes cannot be excluded. The sensory distribution to the upper lip by the infraorbital branch of the maxillary nerve supports the view that the upper lip is derived entirely from the maxillary process.

Applied Anatomy

Facial Clefts

One of the extremely rare congenital anomalies is the occurrence of facial cleft. An opening or a gap in the face is called facial cleft. The most commonly proposed reason for clefting is failure of the fusion of the embryologic processes and inward growth of the mesoderm. Other causes such as defective migration of neural crest cells and genetics are also considered. *Oblique facial cleft* occurs due to failure of fusion of maxillary prominence with the lateral nasal process. *Lateral facial cleft* occurs due to failure of the fusion of maxillary and mandibular processes. Persistence of the furrow between the two mandibular processes results in a rare *median mandibular cleft*. Retardation of the development of the mandibular process may result in *micrognathia*. The lateral borders of the maxillary and mandibular processes fuse to form the cheek, thus establishing the width of the mouth. Errors in the extension of the fusion of these two processes may produce a small mouth (*microstomia*) or a relatively wide mouth (*macrostomia*). Rarely, the two processes merge completely to form *astomia*.

Cleft Lip

Developmental defects of the face are due to the failure of fusion of facial processes. Failure of fusion of the globular process and the maxillary process on one side results in *unilateral cleft of the upper lip* while failure on both sides results in *bilateral cleft lip*. The *median cleft lip* or *harelip* is due to the incomplete fusion of right and left MNPs to form the globular process. This may also lead to midline grooving of the nose, leading to the formation of *bifid nose*.

Fissural Cysts

Occasionally, cystic spaces lined by remnant epithelium are encountered along the zones of fusion of embryonic processes. Nasopalatine cyst and median mandibular cyst are fissural cysts.

DEVELOPMENT OF PARANASAL AIR SINUSES

The paranasal air sinuses develop as a pneumatic diverticulum in the lateral wall of the nose and extend into the corresponding bones. The maxillary, sphenoidal, frontal and ethmoidal air sinuses develop at the end of the third month of IUL as a diverticulum of the middle and superior nasal meatus and the sphenoethmoidal recess. The maxillary sinus is the first paranasal air sinus to develop. It enlarges in size but maintains its communication with the oral cavity. Though the development begins prenatally, it continues through the entire lifetime.

DEVELOPMENT OF THE TONGUE

The tongue develops from the endodermal lining of the first four branchial arches, with the invading muscle tissue from the occipital myotome (**Fig. 33.15**). In the fourth week of IUL, two *lateral lingual swellings* develop and one *medial swelling*, the *tuberculum impar*, originates from the ventral aspect of the first branchial arch. The caudal border of the median tuberculum impar is the *foramen caecum*, the opening of thyroid diverticulum. The two lateral swellings enlarge and overgrow the tuberculum impar and fuse to form the anterior two-third of the tongue (**Fig. 33.16a**). A median swelling called *copula* is formed from the ventral aspect of the second, third and fourth arches. This forms the mucosa covering the posterior one-third of the tongue.

The epiglottis develops from the posterior division of the copula, the *hypobranchial eminence* (**Fig. 33.16b**). A V-shaped *sulcus terminalis* with foramen caecum at the apex separates the anterior two-third and posterior one-third of the tongue. The circumvallate papilla lining the sulcus terminalis develops between 2 and 5 months of IUL. The gustatory cells of the taste buds begin to develop by an inductive mechanism between the epithelial cells and the invading gustatory nerve cells (chorda tympani, glossopharyngeal and vagus nerves) in the 11th week of IUL and extend after birth. The tongue is developed from the contribution of different arches which is reflected in the nerve supply (**Table 33.5**).

The intrinsic muscles of the tongue, except the palatoglossus, arise on the floor of the pharynx from the occipital myotome and are supplied by the hypoglossal nerve. The palatoglossus is supplied by the pharyngeal plexus.

Applied Histology

Cleft Tongue

Partial or complete failure of fusion of the lateral lingual swellings during embryogenesis leads to cleft tongue. Cleft tongue is one of the features of the oro-facial-digital syndrome.

DEVELOPMENT OF THE PALATE

The palate is formed by the fusion of the primary palate, developed from the globular process of the frontonasal process, and the right and the left palatine processes of the maxillary process.

Primary Palate

The primary palate is derived from the globular process or the premaxillary segment of the MNP, which grows internally into the stomodeum. The premaxillary segments give rise to the philtrum of the upper lip, the median part of the maxillary bone with its four incisors and the primary palate.

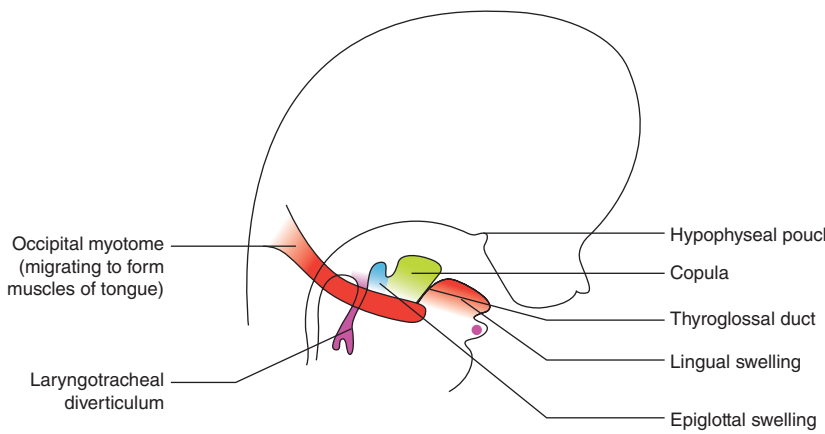


Figure 33.15 Midsagittal section showing the developing lingual swelling and invading occipital myotome.

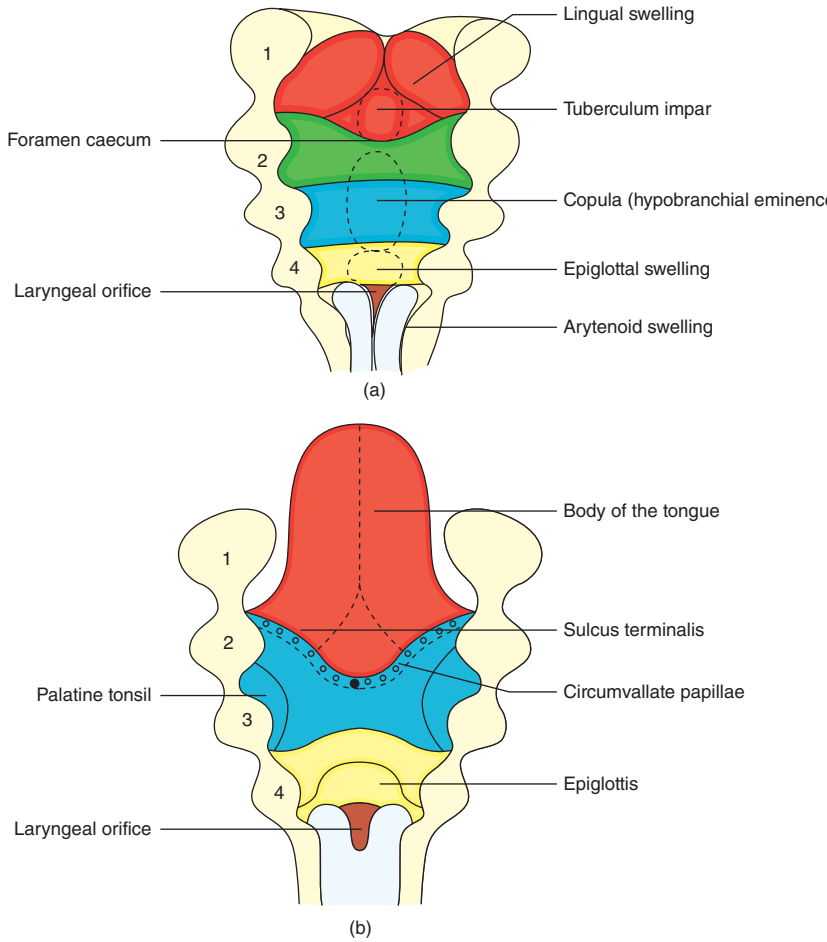


Figure 33.16 Ventral view of the pharynx showing the developing tongue. 1, 2 and 3 refer to pharyngeal arches.

Table 33.5 Embryologic Origin and Sensory Innervation of the Tongue

Parts	Origin	General Sensory Innervations	Special Sensory (taste) Innervation
Anterior two-third of body of the tongue	Two lateral lingual swellings (first pharyngeal arch)	Lingual branch of mandibular branch of trigeminal nerve	Chorda tympani branch of facial nerve
Posterior one-third of root of the tongue	Copula of the second, third and anterior parts of the fourth pharyngeal arch	Glossopharyngeal nerve	Glossopharyngeal nerve
Epiglottis	Hypobranchial eminence (fourth pharyngeal arch)	Superior laryngeal branch of vagus nerve	Vagus nerve

Secondary Palate

In the sixth week of IUL, two outgrowths develop from the maxillary process towards the midline, called *palatal shelves*. The *palatal shelves* are vertically oriented on either side of the developing tongue. The growth of the palatal shelf is directed downwards. In the eighth week of IUL, the developing tongue withdraws from between the palatal shelves, descends and occupies a more inferior position. The right and the left palatine shelves ascend to a horizontal position above the tongue and fuse with each other to form the secondary palate in the ninth week of IUL. The line of fusion is present as the *midpalatine suture* in adult life. The ossification of midpalatine suture starts during early adolescence (**Fig. 33.17**).

Anteriorly, the palatine shelves fuse with the primary palate. The closure of the secondary palate proceeds gradually from the anterior to the posterior direction. The *incisive papilla* overlying the incisive foramen marks the junction of the primary palate and the secondary palate. The developing nasal septum grows downwards and fuses with the cranial aspect of the developing palate (**Fig. 33.17a** and **b**).

Transition of Palatal Shelves from Vertical To Horizontal Position

Several reasons have been proposed for the rapid elevation of the palatal shelves, including biochemical transformations, variations in the blood flow, rapid differential growth, intrinsic shelf force and muscular movements.

One of the important factors contributing to the elevation and fusion of palatal shelves is the descent of the tongue from between the palatine shelves. Before the eighth week of IUL, the head is folded on the developing thorax; the mandible and the lower lip are rudimentary and still developing. The

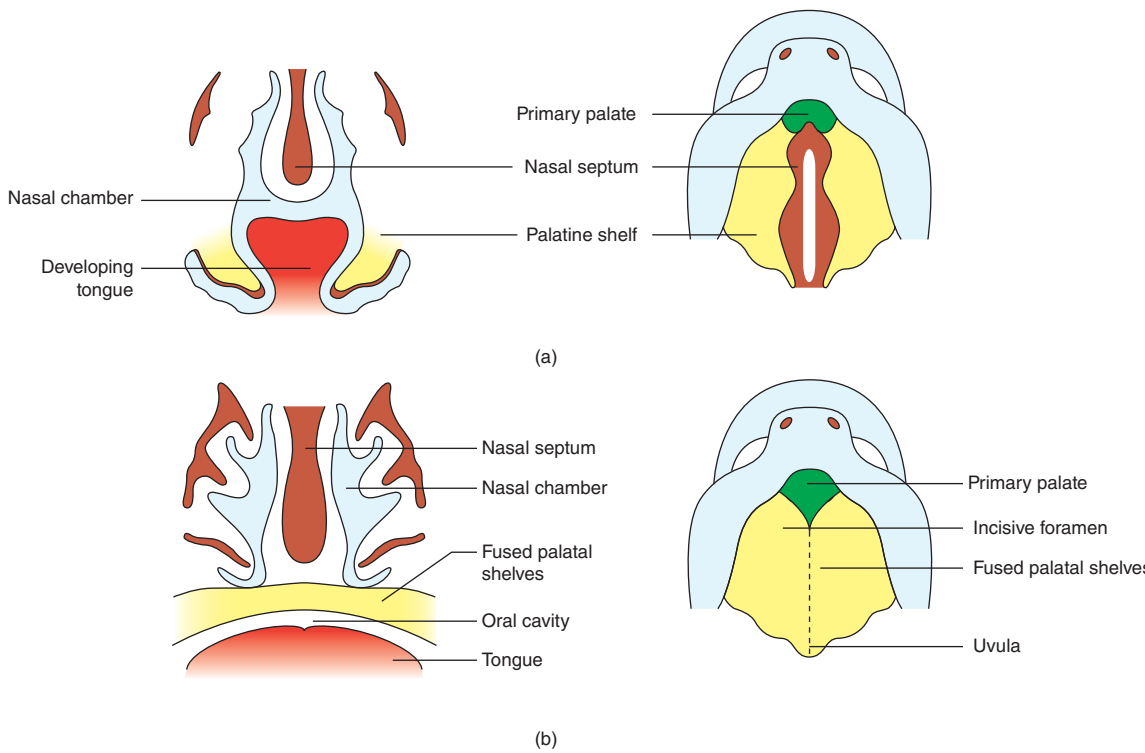


Figure 33.17 Formation of the secondary palate and its fusion with the primary palate and nasal septum.

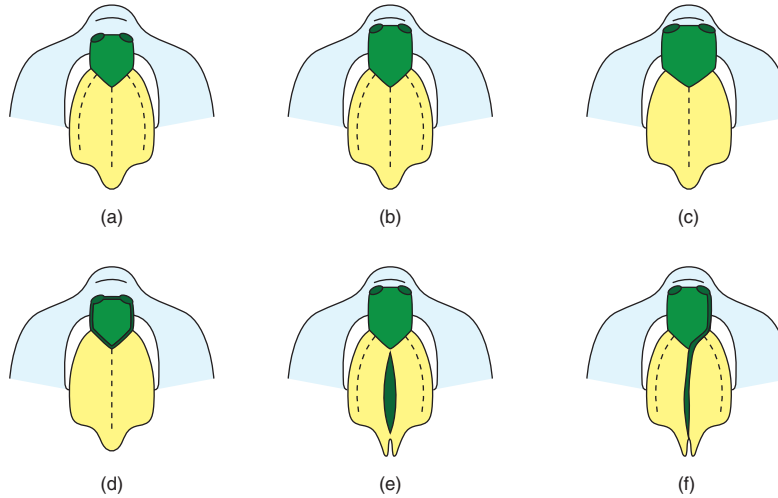


Figure 33.18 (a) Normal palate, (b) unilateral cleft lip involving lip and alveolus, (c) unilateral cleft lip involving lip, alveolus and primary palate, (d) bilateral cleft lip involving lip, alveolus and primary palate, (e) isolated cleft palate and (f) cleft palate with the unilateral cleft lip.

lower lip is positioned behind the upper lip, leaving the tongue to assume a more superior position in the oral cavity. By the ninth week of IUL, the face lifts from the thorax. The mandible grows so that the lower lip moves forward, thus permitting the tongue to descend. Any factor that prevents the normal descent of tongue may prevent the elevation of palatine shelves and thus result in a cleft palate.

Mechanism of Fusion of Palatine Shelves

The two palatine shelves meet and the adhesion of the epithelium of the two shelves takes place, forming a midline epithelial seam. The epithelial adhesion is facilitated by the *degenerating surface epithelial cells* and surface accumulation of *glycoprotein*. This epithelial layer soon thins down to a single layer of cells due to *programmed cell death* and then breaks up into discrete islands of cells, leading to the *mesenchymal coalescence* of the palatal shelves. The basal lamina around the cells is lost and the epithelial cells undergo an *epithelio-mesenchymal* transformation into mesenchymal cells. Sometimes, the islands of cells remain even after shelf approximation to form *epithelial pearls*. Failure of fusion of palatal shelves results in cleft palate (**Fig. 33.18a–f.**)

Applied Histology

Cleft Palate

Any factor that prevents the normal descent of tongue may prevent the elevation of palatine shelves and thus result in a *cleft palate*. Cleft palate can be complete or incomplete, unilateral or bilateral. Submucous cleft can also occur.

Pierre Robin Syndrome

Micrognathia, cleft palate and glossoptosis (protruded tongue) are the features of Pierre Robin syndrome. The failure in the development of mandible leads to failure in the downward movement of tongue with growth. This subsequently impedes the horizontal ascent of the palatine shelves leading to cleft palate.

DEVELOPMENT OF SALIVARY GLANDS

The major salivary glands develop as an epithelial bud originating from the oral epithelium (**Fig. 33.19**). The development of salivary glands is discussed in detail in Chapter 7.

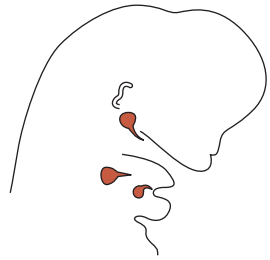


Figure 33.19 Epithelial buds for three major salivary glands originating from the oral epithelium.

Applied Histology

Neonatal Palatal Cysts

In neonates, small multiple cysts can be evidenced usually at the junction of hard palate and soft palate. These cysts are formed from the epithelial remnants of the developing salivary glands. They are termed *Epstein pearls* and *Bohn's nodules*.

ADDITIONAL READING

Molecular Control of Palatogenesis

Activation of palatal cell proliferation occurs due to expression of sonic hedgehog (Shh) in the oral epithelium and binding to its receptor patched 1 (Ptc) in the underlying mesenchyme. Fibroblast growth factor 10 and its receptor Fgfr2b are expressed in the palatal mesenchyme and the epithelium, respectively, and regulate cell proliferation and survival. Both Shh and Fgf10 constantly maintain their expression during palatal outgrowth. Signalling events are moderated by bone morphogenetic protein (BMP) through Bmpr1a receptor in the mesenchyme. They regulate palate growth and expression of *Msx1* and *Shox2*. BMP signalling also helps in maintenance of Shh expression in the palatal epithelium. Zonal control in the anterior part of the palate is exerted by ephrin B1 (EfnB1) signalling through its receptors EphB2 and EphB3. The posterior part is controlled by expression of *Mn1*, *Tbx22*, *Meox2* and *Barx1* genes along with *Tbx22* acting downstream of *Mn1*. Mediolateral patterning of the palatal shelves during vertical outgrowth involves *Osr1* expression in the lateral mesenchyme and *Osr2* within the lateral part of the mesenchyme and in the medial mesenchyme. The expression of both *Osr1* and *Osr2* is dependent on Shh signalling. Repression of Shh signalling along the mediolateral axis is executed by Dlx5-Fgf7. Palatal fusion is regulated by Tgfβ signalling via Alk5 and Tgfβr2 receptors to activate Smad2/Smad4 and p38 MAPK pathways, which together regulate p21 expression in the MES. This pathway, along with the transcription factors Snai1 and Snai2, promotes MES apoptosis and disintegration. Runx1, which is expressed in MEE, is required for anterior palatal fusion (excerpts from Bush and Jiang 2012).

Facial Morphogenesis

Facial complex is one of the most intricate and heterogeneous parts of our body. Irrespective of the research work done in the biology of facial development, the functional and adaptive placement and spatial integration of sensory organs, skeletal structures, nervous system and feeding apparatus are yet to be well understood. Congenital craniofacial abnormalities affect the form and function of the face in terms of deformities, distractions, elongations, shortenings, asymmetries and generally aberrant structures. The origin of the cells of the craniofacial complex happens from four main sources: neural crest stem cells, paraxial mesoderm, epidermis and endoderm. Migratory neural crest stem cells and the paraxial mesoderm give rise to the non-epithelial tissues of the facial region. The primitive epidermis and endoderm give rise to the epithelialized structures which consist of lining of tissues, exocrine glands, hair follicles and teeth. Para-axial mesoderm initiates the striated muscle cells and endothelial cells and forms the vascular system of the craniofacial region.

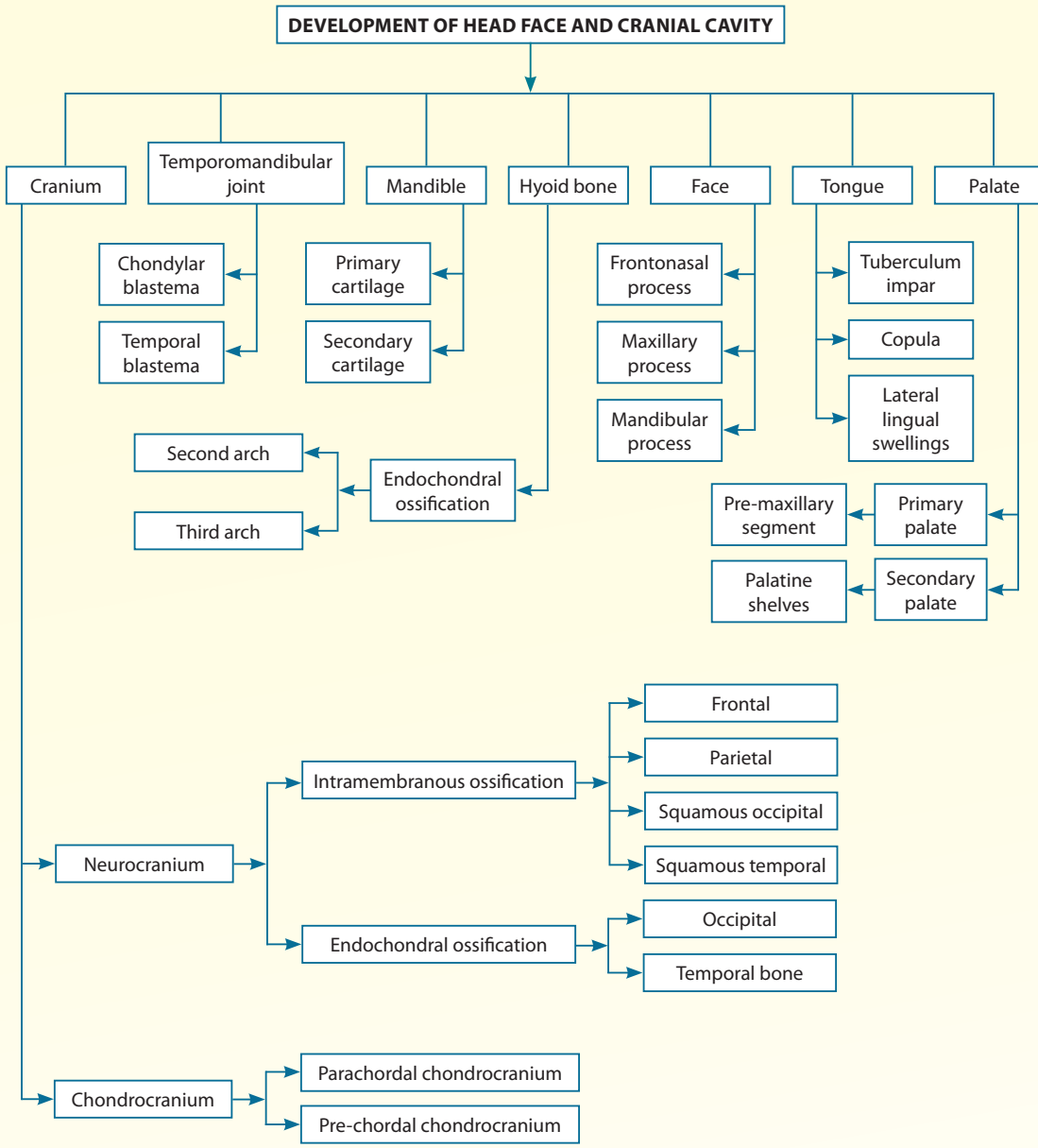
The neural crest cells are a major contributor in the craniofacial region. The primitive stages of development involve overlapping of multiple spatially defined oligopotent ectomesenchymal

clones. Cellular activities during morphogenetic events were analysed by combining clonal analysis, computer simulations, mouse mutants and live imaging. Facial morphogenesis has been found to result from an array of local cellular activities in the ectomesenchyme involving oriented divisions and crowd movements of cells during morphogenetic events (excerpts from Kauka et al. 2016).

Key Points

1. The bones of the skull are grouped under two categories: neurocranium and viscerocranium.
2. Developmentally, the neurocranium is divided into membranous desmocranium and cartilaginous chondrocranium.
3. Viscerocranium (bones of the face) is developed from visceral arches or branchial arches.
4. The chondrification of the base of the skull primarily occurs in two regions: in the region of notochord (parachordal chondrocranium) and in front of the notochord (prechordal chondrocranium).
5. In the sixth week of intrauterine life, a mesenchymal condensation appears lateral to Meckel's cartilage on both the right and the left sides, at the site of the future mental foramen that forms the future mandible.
6. The union of the two separate centres of ossification of the mandible occurs in the midline between the 4th and 12th month postnatally.
7. Meckel's cartilage is a primary cartilage while the condylar cartilage is a secondary cartilage.
8. The condylar head increases in size by both interstitial and appositional growth.
9. The temporomandibular joint (TMJ) is considered a secondary joint both developmentally and phylogenetically. The primary joint between the malleus and incus briefly functions as a jaw joint before the formation of a definite TMJ.
10. Face develops from the five processes surrounding the stomodeum—the frontonasal process and the paired maxillary and mandibular processes.
11. The paranasal air sinuses develop as pneumatic diverticula in the lateral wall of the nose and extend into the corresponding bones.
12. The mucosa of tongue develops from the endodermal lining of the first four branchial arches (the tuberculum impar and the lingual swelling from the first arch and the copula from the second, third and fourth arches).
13. The muscle of the tongue is developed from the occipital myotome.
14. The epiglottis develops from the posterior division of the copula, the hypobranchial eminence.
15. One of the important factors contributing to the elevation and fusion of palatal shelves is the descent of the tongue from between the palatine shelves.
16. The major salivary glands develop as epithelial buds originating from the oral epithelium.
17. Persistence of the naso-optic furrow between the merging lateral nasal process (LNP) and the maxillary process may produce an oblique facial cleft.
18. Failure of fusion of the median nasal and maxillary processes results in a cleft lip.
19. The right and the left median nasal processes (MNPs) fuse to form the middle portion of the nose including the root, crest and tip of the nose.
20. The median cleft lip or harelip is due to the incomplete fusion of the right and left MNPs to form the globular process.
21. Errors in the extension of fusion of the maxillary and mandibular processes may produce a small mouth (microstomia) or a relatively wide mouth (macrostomia).

Mind Map



SECTION IV

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Multiple Choice Questions

1. The skull bone is derived from the
   (a) Ectomenix
   (b) Endomenix
   (c) Ectoderm
   (d) Endoderm
2. The first bone to ossify in the human body is the
   (a) Skull
   (b) Mandible
   (c) Maxilla
   (d) Clavicle
3. The condylar cartilage is a _____
   (a) Primary cartilage
   (b) Secondary cartilage
   (c) Both of the above
   (d) None of the above
4. During development, the condylar head increases in size by
   (a) Appositional growth
   (b) Interstitial growth
   (c) Both a and b
   (d) Chondrification
5. The TMJ is considered
   (a) A secondary joint both developmentally and phylogenetically
   (b) A secondary joint only developmentally
   (c) A secondary joint only phylogenetically
   (d) The primary joint
6. Cheeks are developed from the
   (a) Mandibular process
   (b) Maxillary process
   (c) Frontonasal process
   (d) Globular process
7. The lower lip is formed by the fusion of the
   (a) Maxillary process and mandibular process
   (b) Right and left maxillary processes
   (c) Right and left mandibular processes
   (d) Mandibular process and hyoid process
8. The bridge of the nose is developed from the
   (a) Lateral nasal process
   (b) Median nasal process
   (c) Frontonasal process
   (d) Globular process

9. The first paranasal air sinus to develop is the
   (a) Maxillary sinus
   (b) Frontal sinus
   (c) Sphenoidal sinus
   (d) Ethmoidal sinus
10. The opening of thyroid diverticulum is the
   (a) Foramen caecum
   (b) Incisive foramen
   (c) Cervical sinus
   (d) Foramen rotundum
11. The mucosa of the tongue is derived from the
   (a) Ectodermal lining of the first four branchial arches
   (b) Endodermal lining of the first four branchial arches
   (c) Endodermal lining of the first three branchial arches
   (d) Ectodermal lining of the first three branchial arches
12. The epiglottis is derived from the
   (a) Lingual swelling
   (b) Tuberculum impar
   (c) Copula
   (d) Hypobranchial eminence
13. The gustatory sensation of the anterior two-third of the tongue is supplied by the
   (a) Lingual nerve
   (b) Chorda tympani
   (c) Glossopharyngeal nerve
   (d) Vagus
14. The skeletal muscles of tongue are derived from the
   (a) Copula
   (b) Lingual swelling
   (c) Hypobranchial eminence
   (d) Occipital myotome
15. The primary palate is derived from the
   (a) Palatine process of maxilla
   (b) Lateral nasal process
   (c) Frontonasal process
   (d) Globular process
16. During the early stages of development, the palatal shelves are oriented
   (a) Vertically on either side of the developing tongue
   (b) Horizontally on either side of the developing tongue
   (c) Horizontally above the developing tongue
   (d) Diagonally on either side of the developing tongue
17. The stroma of salivary glands are of
   (a) Ectodermal origin
   (b) Endodermal origin
   (c) Ectomesenchymal origin
   (d) Mesodermal origin
18. The median cleft lip (harelip) is due to the failure of fusion of the
   (a) LNP and maxillary process
   (b) Right and left MNPs
   (c) MNP and maxillary process
   (d) LNP and MNP
19. The failure of the fusion of the LNP and the maxillary process results in
   (a) Unilateral cleft lip
   (b) Bilateral cleft lip
   (c) Harelip
   (d) Oblique facial cleft
20. The unilateral cleft lip is due to the failure of fusion of the
   (a) LNP and maxillary process
   (b) Maxillary and mandibular process
   (c) MNP and maxillary process
   (d) LNP and MNP

CHAPTER 34



Development of Teeth

Overview

The primitive oral cavity is lined by oral ectoderm with ectomesenchymal connective tissue beneath. At about 5–6 weeks of embryonic life, oral ectodermal basal cells proliferate at some regions to form a continuous band of thickened epithelium called the primary epithelial band which determines the position of the future dental arches. The primary epithelial band gives rise to two subdivisions: dental lamina and vestibular lamina. In some areas of the dental lamina, the cells undergo further proliferation to form small round structures called the enamel organ which corresponds to the future deciduous teeth. The dental lamina, which gives rise to the enamel organs of the deciduous teeth, undergoes distal and lingual extensions to give rise to the enamel organs of the permanent teeth. The enamel organ is surrounded by dental papilla and in turn by dental follicle. The enamel organ along with dental papilla and dental organ is called tooth germ. The tooth germ travels through varied stages of growth and modification such as bud stage, cap stage and bell stage to form the tooth, periodontal ligament and alveolar bone.

INTRODUCTION

When the embryo is 3½ weeks old, the primitive oral cavity or stomatodeum is bound superiorly by the forebrain and inferiorly by the cardiac bulge. The primitive oral cavity is lined by stratified squamous epithelium called the oral ectoderm and is separated from the endoderm of the foregut by a membrane called the *buccopharyngeal membrane*. This membrane ruptures when the embryo is about 4 weeks old, establishing a connection between the stomatodeum and the foregut. The oral ectoderm is made of two to three layers of epithelium and covers the embryonic connective tissue which is termed *ectomesenchyme* because of the migration of the neural crest cells in it. The ectomesenchymal cells interact with the overlying ectodermal cells to initiate tooth development.

When the embryo is about 5–6 weeks old, certain regions of basal cells of the oral ectoderm proliferate faster than the adjacent cells to form a continuous band of thickened epithelium invading the underlying ectomesenchyme. This is called the *primary epithelial band*; it is roughly horseshoe shaped and corresponds to the position of the future dental arches of the upper and lower jaws. The formation of the primary epithelial band begins in the anterior portion and proceeds posteriorly. It gives rise to two subdivisions: dental lamina first and vestibular lamina shortly later, in front of the dental lamina (**Fig. 34.1**). The dental lamina contributes to the formation of the ectodermal portion of the developing teeth. In some areas of the dental lamina where the future 10 maxillary and 10 mandibular deciduous teeth are to form, the cells undergo further proliferation to form small round structures called *dental placodes* which protrude into the underlying

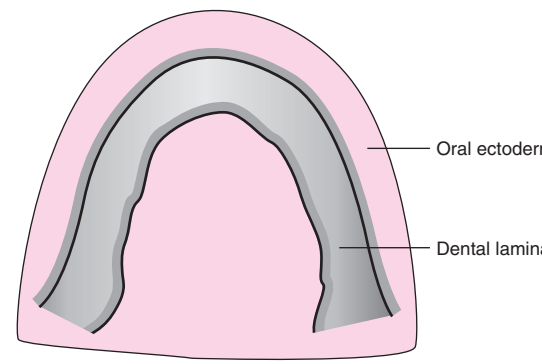


Figure 34.1 Horseshoe-shaped dental lamina.

ectomesenchyme. These round epithelial swellings form the enamel organs of the deciduous teeth.

These enamel organs do not develop at the same time; the first one appears in the anterior region in each arch and the others appear later. When the enamel organs are being formed, there is proliferation of the underlying ectomesenchymal cells, leading to condensation of the ectomesenchyme. The portion of the condensed ectomesenchyme immediately under the enamel organ is the *dental papilla,* and the portion surrounding the enamel organ and the dental papilla is the *dental follicle* or the dental sac. The enamel organ, dental papilla and dental follicle constitute the *tooth germ* from which all the parts of the tooth and its supporting structures are derived. The enamel organ gives rise to the enamel, the dental papilla gives rise to dentin (coronal and radicular) and pulp, and the dental follicle gives rise to the cementum, periodontal ligament and alveolar bone (**Fig. 34.2**).

Applied Histology

Anodontia and Oligodontia

Anodontia is the congenital absence of tooth germ of the entire dentition. Absence of single tooth germ or multiple tooth germs is termed *oligodontia*. The teeth commonly found missing are upper lateral incisors, third molars and lower second premolars.

Supernumerary Teeth

Teeth which are present in addition to the normal number of teeth are called supernumerary teeth. This occurs due to hyperactivity of the dental lamina, leading to the initiation of additional tooth buds. The most common supernumerary teeth are the mesiodens which are present between two upper central incisors and paramolars present by the side of the molars.

DEVELOPMENT OF THE ENAMEL ORGAN OF THE PERMANENT TEETH AND THE FATE OF DENTAL LAMINA

The dental lamina, which gives rise to the enamel organs of the deciduous teeth, as described earlier, undergoes distal and lingual extensions to give rise to the enamel organs of the permanent teeth. The permanent teeth can be classified into succedaneous teeth (those which have preceding deciduous teeth) and non-succedaneous teeth (those which do not have preceding deciduous teeth). The central and lateral incisors, canines and the first and second premolars are succedaneous teeth

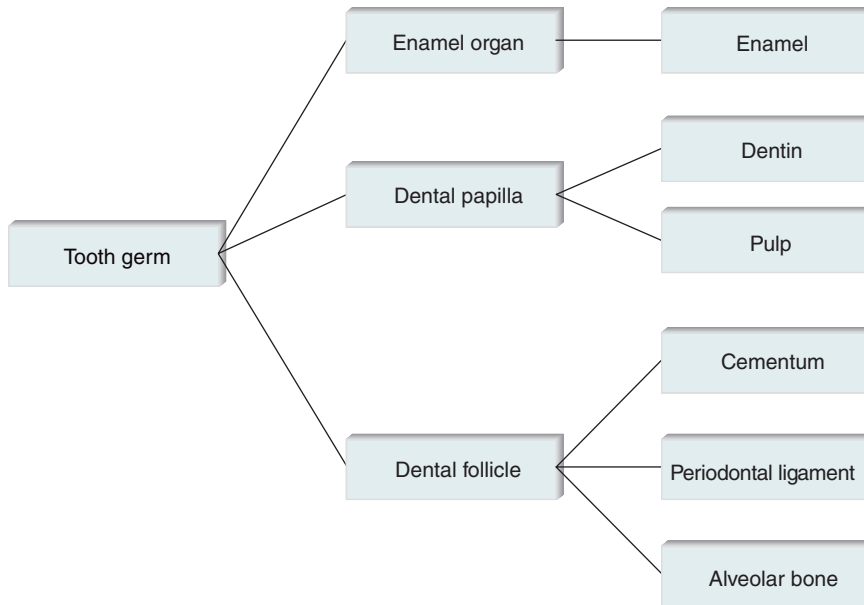


Figure 34.2 Derivatives of the tooth germ.

whereas the first, second and third molars are non-succedaneous teeth.

The dental lamina undergoes lingual extension (successional lamina) to give rise to the enamel organ of the succedaneous teeth. The first such lingual extension takes place at the 5th month in utero for the permanent central incisor, and the last lingual extension takes place in the 10th month after birth for the second premolar. The enamel organ of the non-succedaneous teeth develops from the distal extension of the dental lamina, which takes place in the fourth month in utero for the first permanent molar, first year after birth for the second molar and fifth year after birth for the third molar.

The activity of the dental lamina extends for 5 years, after which it begins to degenerate because of mesenchymal invasion. It loses connection with the enamel organ as the teeth continue to develop. Dental lamina may be active in the third molar region even after it begins to degenerate in other areas. In some areas, the mesenchymal invasion does not remove the dental lamina completely and the remnants persist as epithelial islands known as *cell rests of Serres* in the jaw or in the gingiva.

Applied Histology

Odontogenic Cysts and Tumours

Odontogenic cysts and tumours such as ameloblastoma, keratocystic odontogenic tumour and gingival cysts can originate from the remnants of dental lamina.

Vestibular Lamina

Vestibular lamina is an epithelial thickening that arises independently from the primary epithelial band and is formed labial or buccal to the dental lamina. It is also called the *lip furrow band* and its cells enlarge and degenerate. This results in the hollowing of the vestibular lamina to form a vestibule between the tooth-bearing area and the lip or cheek (**Fig. 34.3**).

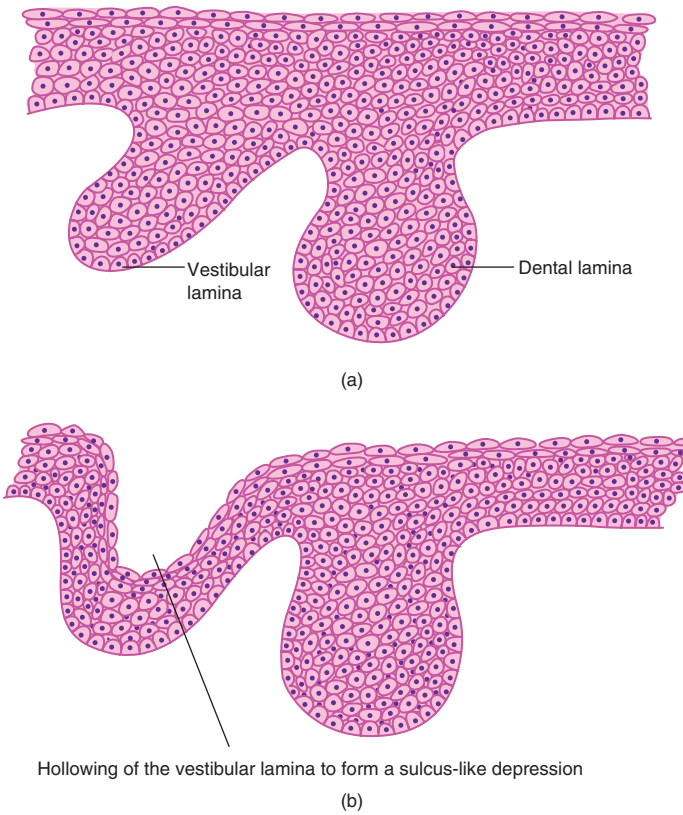


Figure 34.3 Development of vestibular lamina.

DEVELOPMENTAL STAGES

The developmental history of the tooth can be divided into the following stages on the basis of the shape of the enamel organ:

1. Bud stage
2. Cap stage
3. Bell stage
4. Advanced bell stage

Bud Stage (Fig. 34.4)

Enamel Organ

The enamel organ, which looks like a bud, consists of low columnar cells in the periphery and polygonal cells in the centre.

As a result of increased proliferation of ectomesenchymal cells and migration of neural crest cells, the cellular density of ectomesenchyme immediately adjacent to the enamel organ increases. This is referred to as *condensation of ectomesenchyme.*

Dental Papilla

The condensed ectomesenchyme immediately under the enamel organ is the dental papilla.

Dental Follicle

The condensed ectomesenchyme surrounding the enamel organ and the dental papilla is the dental follicle/sac.

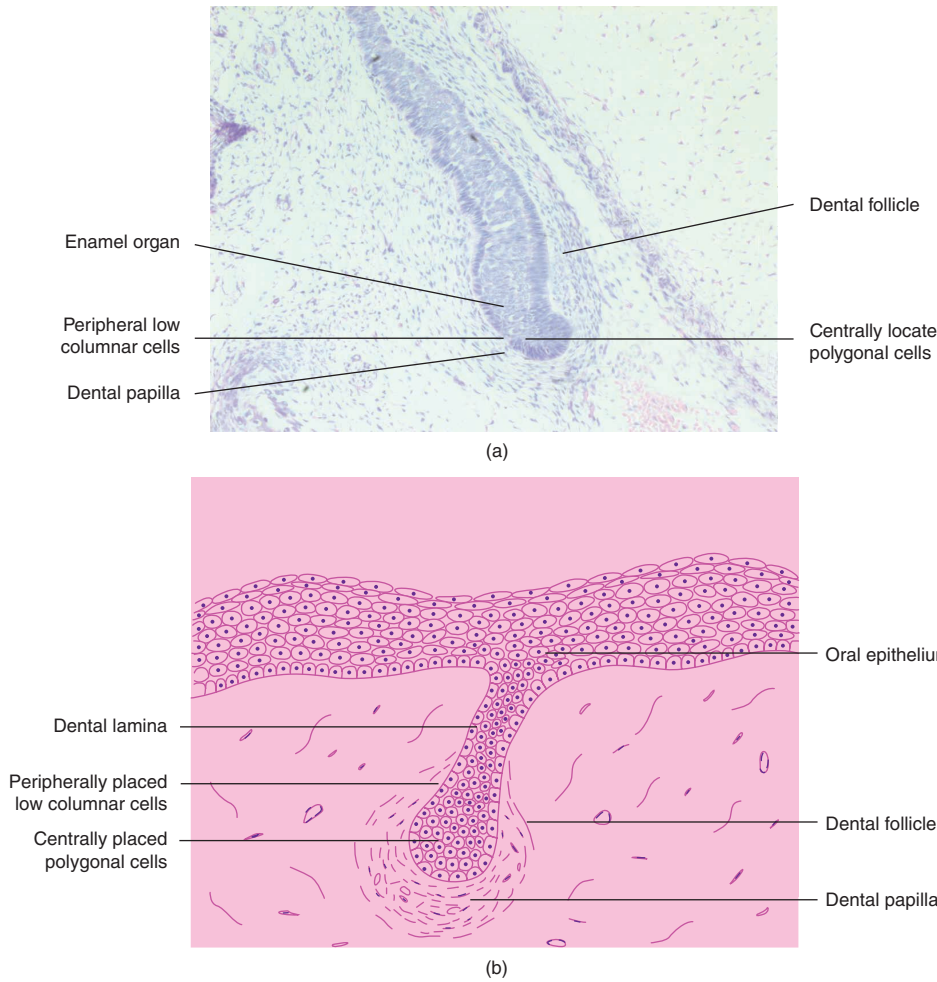


Figure 34.4 Bud stage: (a) photomicrograph (haematoxylin and eosin staining, 20X) and (b) schematic diagram.

Applied Histology

Macrodontia and Microdontia

Macrodontia is an abnormally larger tooth and microdontia is an abnormally smaller tooth. This can occur because of abnormal proliferation of the tooth germ at the bud stage and can affect a single tooth or the complete dentition.

Cap Stage (Fig. 34.5)

Enamel Organ

The enamel organ shows an unequal rate of proliferation in different parts instead of uniform expansion. This leads to a stage where the enamel organ looks like a cap.

The cells of the enamel organ in the convex portion of the cap are cuboidal in shape and form the *outer enamel epithelium*, and the cells in the concavity of the cap are columnar in shape and form the *inner enamel epithelium*. The outer enamel epithelium is separated from the dental sac and the inner enamel epithelium is separated from the dental papilla by a basement membrane.

The cells in the centre of the enamel organ, between the outer enamel epithelium and the inner enamel epithelium, synthesize glycosaminoglycans that are secreted into the extracellular compartment between the epithelial cells. Being hydrophilic, these glycosaminoglycans pull water into the enamel organ from the surrounding ectomesenchyme by osmotic force.

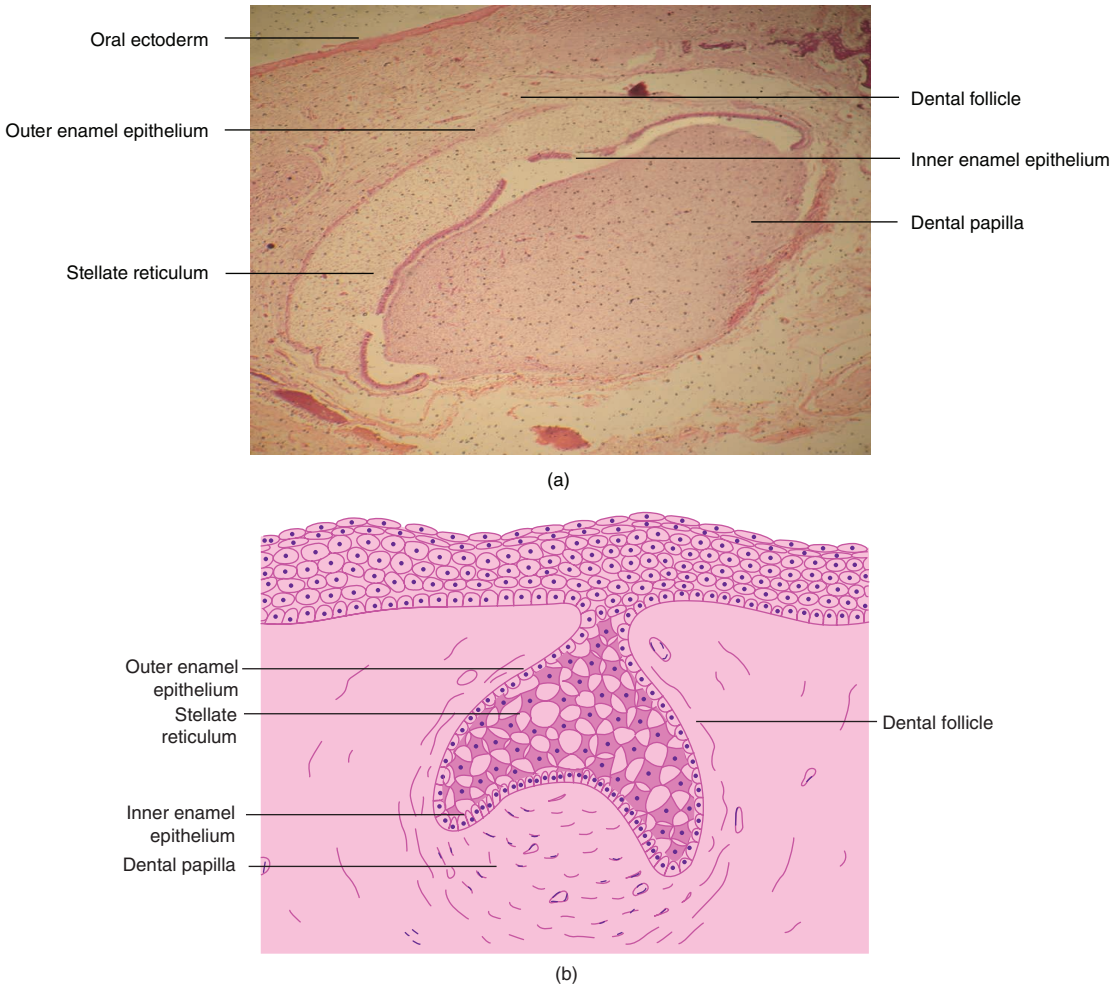


Figure 34.5 Cap stage: (a) photomicrograph (haematoxylin and eosin staining, 4X) and (b) schematic diagram.

As a result, the polygonal cells in the centre are forced apart. These cells become star shaped as they retain contact with each other because of their cytoplasmic processes. The star-shaped cells form a branched cellular network called *stellate reticulum* (stellate = star shaped; reticulum = branch-like network). The mucoid fluid that is collected between the cells of the stellate reticulum is rich in albumin and gives it a cushion-like consistency to act as a shock absorber, thus protecting and supporting the enamel-forming cells.

Transient Structures (Fig. 34.6)

The cells in the centre of the concavity of the 'cap' of the enamel organ are densely packed and form a knob-like enlargement projecting towards the underlying dental papilla. This structure is called the primary enamel knot. It acts as a centre where cell division occurs leading to progress from tooth morphogenesis to cusp formation.

A vertical extension of the enamel knot running across the centre of the enamel organ is called the *enamel cord,* and when this extension meets the outer enamel epithelium, it is called the *enamel septum.* A small depression that forms at the junction between the enamel septum and the outer enamel epithelium is called the *enamel navel.* These are transient structures which disappear before enamel formation begins.

During sectioning of the developing tooth tissue specimen, the enamel organ appears to be attached to the oral epithelium by two or more strands of dental lamina. This artefactual stalk is called *enamel niche*

Applied Histology

Enamel knots play a vital role in successful tooth formation. Gene knockout studies reveal that tooth development is arrested if there is a failure in primary enamel knot formation.

Secondary enamel knots form during the bell stage at the site of future cusp tips and play a central role in directing morphogenesis in multicuspid teeth. Differences in the location of secondary knots correspond to differences in cusp positioning. Alterations in gene expression or signalling proteins may result in anomalous tooth morphology. Even mild changes affecting secondary enamel knot timing and positioning can yield observable and quantifiable variation in final crown morphology.

Dental Papilla

Along with the development of enamel organ described earlier, the cells of the dental papilla appear more crowded in this stage. The dental papilla also shows signs of becoming more vascular. This is evident by the presence of mitotic figures and active budding of capillaries.

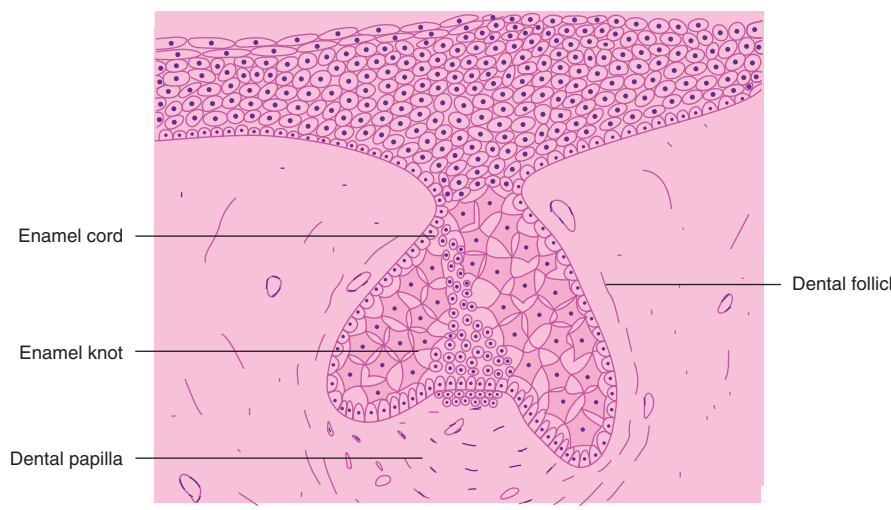


Figure 34.6 Transient structures in the cap stage.

Dental Sac

The dental sac appears more condensed and fibrous.

Applied Histology

Gemination and Fusion

Gemination is division of tooth germ while fusion is the union of the adjacent tooth germs which can occur during the cap stage of tooth development.

Dens Invaginatus

Abnormal invagination of the enamel organ into the dental papilla can cause an appearance of tooth within the tooth called *dens invaginatus or dens in dente*. This abnormality appears as a deep lingual pit which may lead to pulp exposure warranting endodontic therapy of the affected tooth.

Bell Stage (Fig. 34.7)

Enamel Organ

As the enamel organ further invaginates with growth in the margins, it takes the shape of a bell. In this stage, the crown of the tooth gets its final shape (morphodifferentiation) and the cells that form the hard tissues of the crown (the ameloblasts that form the enamel and the odontoblasts that form dentin) acquire histodifferentiation. (*Histodifferentiation* is

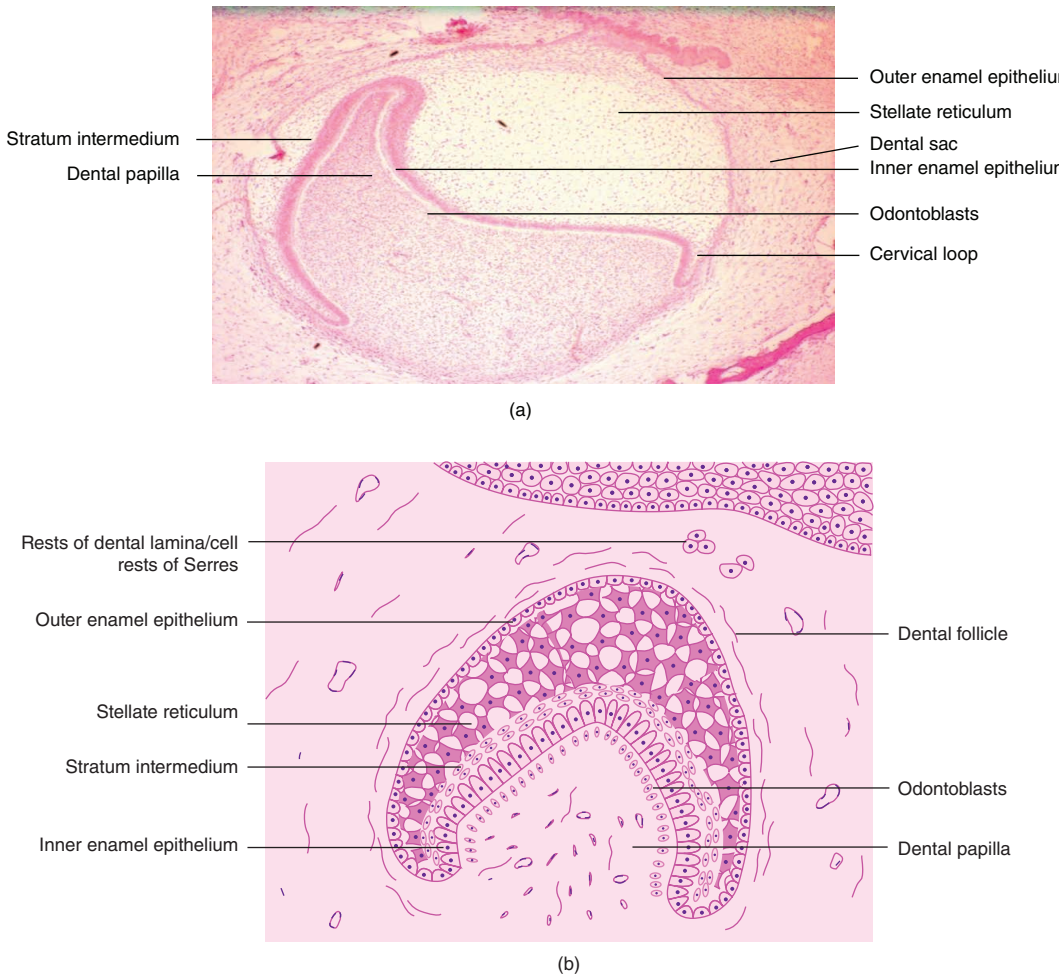


Figure 34.7 Early bell stage: (a) photomicrograph (haematoxylin and eosin staining, 4X) and (b) schematic diagram.

the process in which the cells develop distinctive characters to enact their functional role.)

Four different types of epithelial cells of the enamel organ can be identified in this stage:

1. Inner enamel epithelium
2. Stratum intermedium
3. Stellate reticulum
4. Outer enamel epithelium

The junction between the inner and outer enamel epithelia is known as the *zone of reflexion* or *cervical loop*.

1. **Inner enamel epithelium:** This single layer of columnar cells differentiates into tall columnar cells called ameloblasts before the formation of enamel (amelogenesis). The desmosomes connect these inner enamel epithelial cells with one another and with the cells of the stratum intermedium.
2. **Stratum intermedium:** Some layers of squamous cells seen between the inner enamel epithelium and stellate reticulum are called stratum intermedium. The cells of the stratum intermedium are connected to one another and to the cells of the inner enamel epithelium and stellate reticulum by desmosomes and gap junctions. They are associated with protein synthesis and transport of nutrients to the ameloblasts. They consist of a moderate number of mitochondria, bundles of filaments, well-developed Golgi apparatus, numerous ribosomes, tonofilaments, acid mucopolysaccharides and glycogen deposits. They exhibit a high enzyme alkaline phosphatase activity. This layer plays an important role in regulating the formation of enamel.
3. **Stellate reticulum:** These star-shaped cells are connected to one another and to the cells of the outer enamel epithelium and the stratum intermedium by desmosomes. These serve to protect the underlying inner enamel epithelial cells. After a layer of dentin is laid down, the inner enamel epithelial cells are deprived of their nutritional supply from the dental papilla. The stellate reticulum collapses before the formation of enamel, bringing the capillaries in the dental follicle closer to the inner enamel epithelial cells to provide nutrition.

   The collapse of the stellate reticulum is not simultaneous and does not occur completely, but begins at the deepest point of invagination of the enamel organ and progresses cervically. The collapsed stellate reticulum cannot be distinguished from the stratum intermedium.
4. **Outer enamel epithelium:** The outer enamel epithelium has cuboidal cells. They are connected to the adjacent cells by junctional complexes. The outer enamel epithelial layer is smooth in the initial stages. As the stellate reticulum collapses before enamel formation, this layer is laid into folds, bringing the capillaries present in the dental follicle closer to the ameloblasts.

Dental Papilla

Fine fibrils from the basal lamina, which separates the dental papilla from the enamel organ, extend into an acellular zone. The acellular zone is present between the basal lamina and the dental papilla and is devoid of cells. The extracellular space is occupied by few fine, scattered collagen fibrils. The dental papilla cells are undifferentiated mesenchymal cells containing usual organelles. The peripherally placed undifferentiated ectomesenchymal cells of the dental papilla increase in size before the enamel formation begins. They are initially cuboidal and later become columnar and differentiate into odontoblasts. This increase in the size of the outermost cells of the dental papilla eliminates the acellular zone between the dental papilla and the inner enamel epithelium. Experiments have established that the differentiation of the undifferentiated ectomesenchymal cells of the dental papilla takes place under the organizing influence of the cells of the inner enamel epithelium. In the absence of the inner enamel epithelial cells, differentiation of odontoblasts does not occur and dentin does not form.

The basement membrane which separates the enamel organ and dental papilla just before dentin formation is called *membrana preformativa.*

Dental Follicle

As more and more of collagen fibrils occupy the extracellular spaces between the fibroblasts of the dental follicle, these can be clearly distinguished from the more vascular dental papillae. These collagen fibrils orient themselves circularly around

the enamel organ and the dental papillae. It is these fibres of the dental follicle that later differentiate into periodontal fibres that become embedded in the cementum and alveolar bone.

Crown Pattern Determination (Fig. 34.8)

The other events that occur during the bell stage are the breaking up of dental lamina and determination of the crown pattern of the tooth (morphodifferentiation).

During the bell stage, the dental lamina, which joins the enamel organ to the oral ectoderm, is invaded by the surrounding cells of the dental follicle. It undergoes fragmentation resulting in the separation of the enamel organ from the oral ectoderm. Clusters of epithelial cells, which usually degenerate, are formed following the fragmentation of the dental lamina. Cells which persist form epithelial islands (cell rests of Serres). Sometimes, cysts are formed over the developing tooth by these cell rests, delaying the eruption of the tooth.

It has already been noted that the transition of the enamel organ from cap to bell stage was because of the invagination of the inner layer of the enamel organ and the growth of the enamel organ at its margins. Further invagination or infolding of the inner layer of the enamel organ (inner enamel epithelium) decides the shape of the crown of the tooth.

Earlier, it was thought that the infolding of the enamel organ occurs as a result of the pressure exerted by the proliferating cells of the dental papilla on the inner enamel epithelium. Now, studies have shown that this pressure is opposed equally by the fluid present in the stellate reticulum. The infolding which gives shape to the crown occurs as a result of the differential rates of mitotic division within the cells of the inner enamel epithelium as well as the difference in the time at which these cells undergo differentiation. Cells begin to differentiate after they cease to divide. Those inner enamel epithelial cells which lie in the future cusp tip region stop dividing earlier and begin to differentiate first to assume their function of producing enamel. This point at which differentiation of inner enamel epithelial cells occurs first is known as the *growth centre*.

While these cells at the cusp tip have undergone differentiation and cease to divide, the other cells of the enamel organ continue to divide, exerting pressure on the cells in the cusp tip region. This causes the cells in the region of cusp tip to be pushed up into the enamel organ towards the outer enamel epithelium.

The cells in another future cusp area begin to differentiate and form a cusp tip by a similar process. Gradually, the rest of the cells of the inner enamel epithelium at the side of the growth centre cease to divide and undergo differentiation. This process determines the shape of the area between the two cusp tips that is the extent of cuspal slopes and the cusp height.

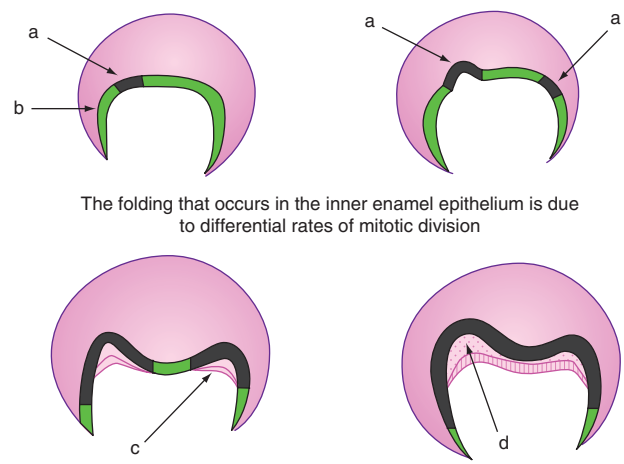


Figure 34.8 Crown pattern determination. a, zone of differentiated cells; b, zone of cell division; c, dentin; d, enamel.

Cell differentiation proceeds cervically and the cells at the cervical loop are the last to differentiate. In this way, the shape of the crown is determined.

Applied Histology

Dens Evaginatus

It is cusp-like elevation seen in the occlusal surface of premolars or molars. This aberrancy occurs due to the abnormal proliferation of inner enamel epithelium into the stellate reticulum resulting in a core of dentin with intervening pulpal tissue covered by enamel. With occlusal wear or fracture of this cusp-like structure, pulp exposure and pulpal necrosis can occur warranting endodontic therapy.

Advanced Bell Stage (Fig. 34.9)

Advanced bell stage is characterized by the beginning of mineralization and root formation.

Mineralization

As discussed earlier, the peripheral ectomesenchymal cells of the dental papilla are differentiated into odontoblasts under the influence of the inner enamel epithelial cells. The line separating the newly differentiated odontoblasts and the inner enamel epithelial cells outlines the dentinoenamel junction.

As the odontoblasts begin to differentiate, they elaborate the organic matrix of dentin along the dentinoenamel junction, initially in the region of

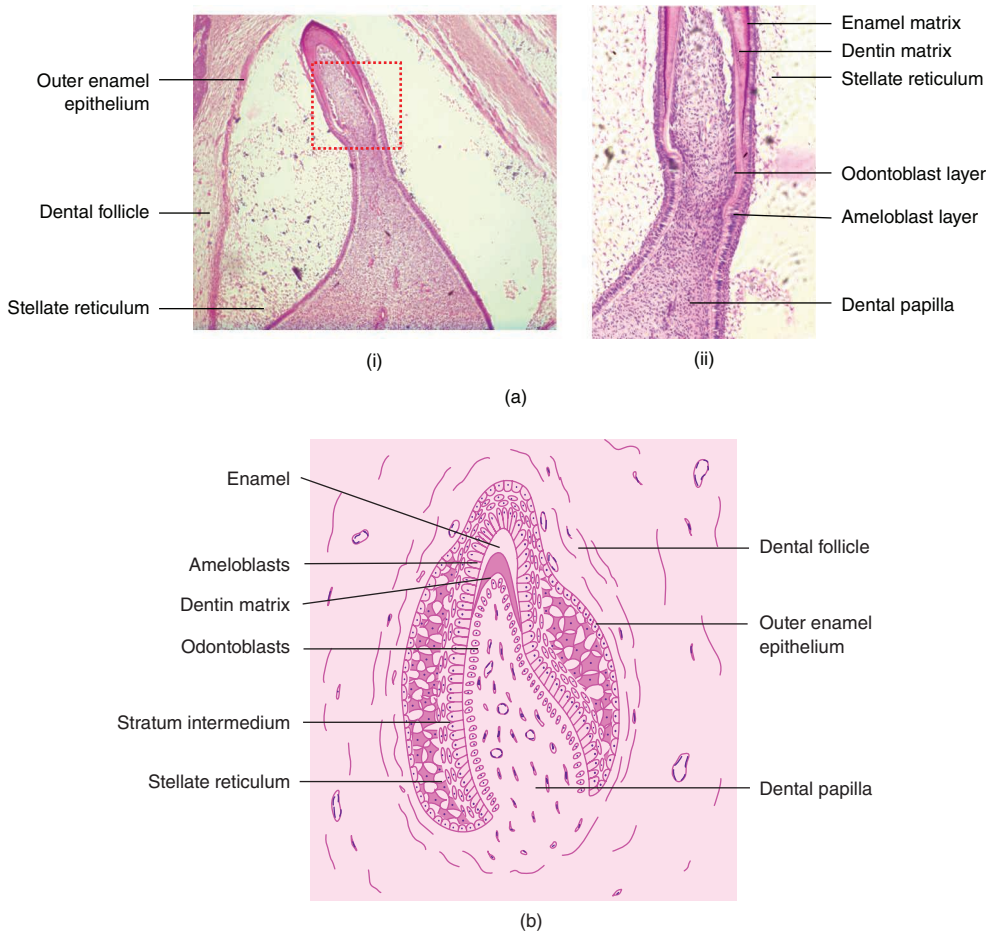


Figure 34.9 Advanced bell stage: (a) photomicrograph and (b) schematic diagram. (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin, 4X; ii—haematoxylin and eosin, 10X).

future cusp. This matrix proceeds pulpally and apically and mineralizes later.

After the first layer of dentin is formed, the short, columnar inner enamel epithelial cells elongate to become tall, columnar cells, which reverse their polarity (alignment of nuclei adjacent to stratum intermedium and Golgi complex facing dental papilla) and become functional ameloblasts. These ameloblasts produce an organic matrix of enamel against the newly formed dentin. Almost immediately, this organic matrix mineralizes to become the initial layer of enamel. As the enamel formation proceeds from the dentinoenamel junction towards the outer surface, the ameloblasts move away from dentin coronally and cervically.

Applied Histology

Tetracycline Staining

Tetracycline is an antibiotic which has high affinity for calcified tissue. Ingestion of this antibiotic during the mineralization of enamel and dentin can lead to discoloration. This consequent discoloration of enamel and dentin occurring at the time of tooth development is called tetracycline staining.

Reciprocal Induction

An important step in the development of tooth is the terminal differentiation of ameloblasts and odontoblasts and the formation of two principal hard tissues of the tooth: enamel and dentin. This process is histodifferentiation.

Experiments have shown that the differentiation of odontoblasts from the peripheral ectomesenchymal cells of the dental papilla occurs under the influence of the inner enamel epithelial cells, and in turn for these inner enamel epithelial cells to differentiate into functional ameloblasts, a single layer of dentin matrix laid down by the odontoblasts is essential.

The differentiation of ameloblasts and odontoblasts is interdependent, and this is an example of *reciprocal induction*.

HERTWIG'S EPITHELIAL ROOT SHEATH AND ROOT FORMATION

The enamel and dentin formation proceeds, as described earlier, outlining the dentinoenamel junction. When this line reaches the future cementoenamel junction, root development begins. From the cervical portion of the enamel organ arises Hertwig's epithelial root sheath (HERS), which plays an important role in the determination of the shape, length, size and number of roots (**Fig. 34.10**). In addition, it initiates radicular dentin formation. Hertwig's epithelial root sheath, arising from the cervical portion of the enamel organ, is a double layer of cells composed only

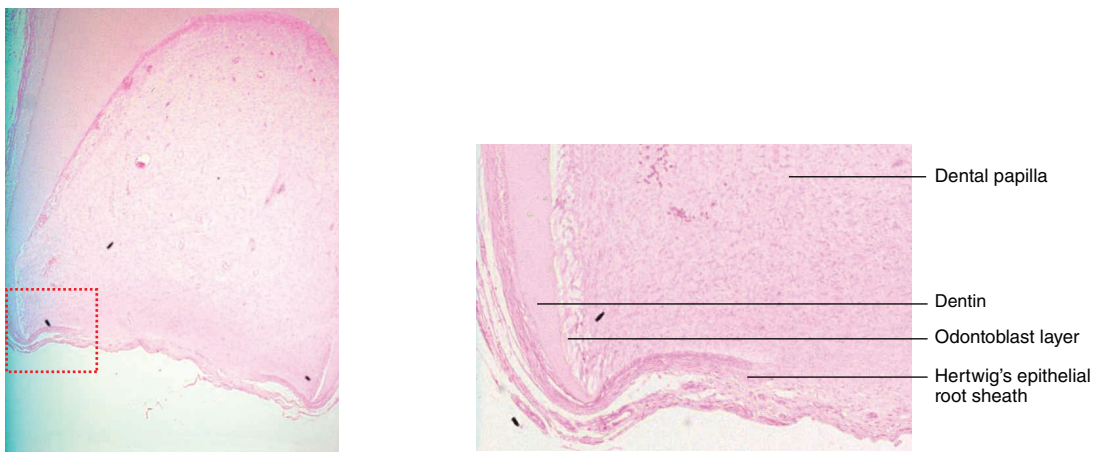


Figure 34.10 Hertwig's epithelial root sheath. (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin stain, 4X; ii—haematoxylin and eosin stain, 10X).

of the inner enamel epithelium and outer enamel epithelium. This sheath extends around the dental papilla and separates it from the surrounding dental follicle all over except in the basal portion. The cells of the inner enamel epithelial layer of the HERS influence the formation of a layer of odontoblasts from the outermost portion of radicular dental papilla. This layer of odontoblasts lays down the first layer of radicular dentin.

This is similar to the way in which coronal dentin is formed under the influence of the inner enamel epithelium of the enamel organ. In the crown portion, the cells of the inner enamel epithelium become functional ameloblasts by becoming taller and form enamel after a single layer of dentin is formed. Unlike this, in the root portion, the cells of the inner enamel epithelium of HERS remain short and do not produce enamel.

After the first layer of radicular dentin is formed, the HERS loses its continuity and at the same time the cells of the dental follicle/sac proliferate and invade the double layer of HERS, dividing it into epithelial strands. In this way, the epithelial root sheath moves away, allowing the connective tissue cells of the dental follicle to come in contact with the surface of the newly formed radicular dentin. This results in differentiation of cementoblasts from the cells of the dental follicle, which deposit cementum on the surface of the radicular dentin. Similarly, fibroblasts and osteoblasts differentiate from the cells of the dental follicle, forming the periodontal ligament and the alveolar bone, respectively. While most of the cells of HERS are removed following their invasion by the cells of the dental follicle, in some places remnants are left behind. These remnants are called *cell rests of Malassez* and they may be found as strands or clumps of epithelial cells in the periodontal ligament of erupted teeth.

Applied Histology

Radicular Cyst

Tooth decay on progression can lead to inflammation at the region of apical foramen. This inflammation can trigger the epithelial cell rests of Malasezz to proliferate and result in the formation of *radicular cyst*.

The development of HERS in teeth with one root and in those with two or three roots is different.

Formation of a Single-Rooted Tooth (Fig. 34.11a)

The outer and inner enamel epithelial layers of HERS bend at the future cementoenamel junction onto a horizontal plane before the root formation begins. This forms the epithelial diaphragm, the plane of which remains relatively fixed during further development and growth of the root. The diaphragm narrows the wide cervical opening of the tooth germ and encloses the primary apical foramen. When the cells of the epithelial diaphragm proliferate, one would expect to see the free end of the diaphragm growing into the connective tissue, causing further narrowing of the cervical opening of the tooth germ. But the proliferation of the cells of the epithelial diaphragm is accompanied by the proliferation of the connective tissue cells of the dental papilla adjacent to the diaphragm. As a result of this, lengthening of the root sheath occurs (coronal to epithelial diaphragm) and narrowing of the cervical opening does not occur.

Though there is lengthening of HERS with the onset of root formation, the root sheath does not actually grow into the jaw. It is the crown of the tooth which moves away from the bony base of the crypt. With the increase in the length of the root sheath, more root is formed with the formation of the cementum, periodontal ligament and alveolar bone, as described earlier. The HERS is not seen as a continuous layer on the root surface because of the rapid sequence of its proliferation and destruction. During the last stages of root development, the proliferation of cells of the epithelial diaphragm (HERS) lags behind that of the cells of the dental papilla. This narrows the cervical opening, which further narrows by the deposition of dentin and cementum. In this way, the apical third of the root becomes conical.

Formation of a Multirooted Tooth (Fig. 34.11b)

In case of multirooted teeth, tongue-like extensions develop on the horizontal diaphragm due to differential growth of the diaphragm. Teeth germs of the lower molars show two such extensions and

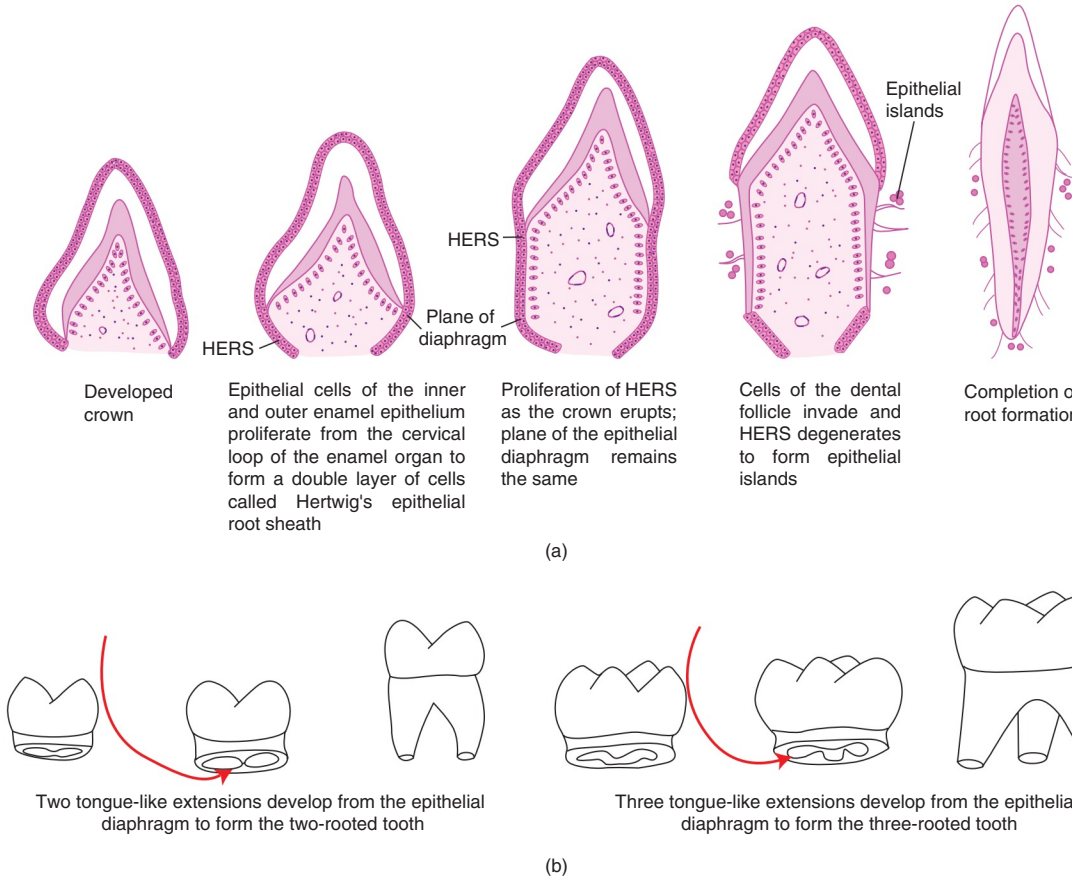


Figure 34.11 Root formation: (a) single-rooted and (b) multirooted teeth. *HERS*, Hertwig's epithelial root sheath.

SECTION IV

those of the upper molars show three such extensions, the free ends of which grow towards each other and fuse. The single cervical opening (primary apical foramen) of the tooth germ is divided into two or three openings (secondary apical foramina). Dentin formation starts on the pulpal side of these epithelial bridges. Root formation follows the same way as described for single-rooted teeth on the periphery of each opening.

Applied Histology

Aberration in HERS

The cells of HERS may differentiate into fully functional ameloblasts and form enamel if they remain adherent to the radicular dentin without becoming removed by the invading cells of the dental follicle. This may appear as a globule of enamel, called *enamel pearl*, and is sometimes seen at the furcation area of the roots of the first permanent molars. This globule of enamel can lead to periodontal problems. A defect occurs in the dentinal wall of the pulp if the continuity of HERS is broken before radicular dentin formation, and this results in the formation of *accessory root canals*. A similar type of defects can also occur when there are aberrations in the splitting of primary apical foramen, resulting in the development of *accessory roots*. Accessory root canals and accessory roots can lead to failure of endodontic therapy if left unnoticed. Distortion of HERS because of trauma or pressure can lead to angulated roots which possess difficulty during extraction. This sharp bent in the tooth root is called *dilaceration*. Union of tooth root with cementum only is termed *concrescence*. This occurs due to excessive cementum deposition. Such an event possess difficulty during extraction.

DEVELOPMENT OF A TOOTH: HISTOPHYSIOLOGICAL PROCESS

So far, the development of a tooth has been discussed under various headings on the basis of the shape of the enamel organ in various stages of tooth development. On the basis of the histophysiological process taking place, the development of a tooth can be studied under the following headings:

1. Initiation
2. Proliferation
3. Histodifferentiation
4. Morphodifferentiation
5. Apposition

Though each of the aforementioned processes predominates in one stage more than the other, they overlap considerably.

Initiation

Initiation of tooth development depends on the epithelial–ectomesenchymal interaction. The dental lamina which forms as a result of such interaction has the ability to form enamel organs of the deciduous and permanent teeth.

Lack of initiation results in the absence of a tooth, a condition called *anodontia*. This can involve a single tooth or multiple teeth (oligodontia) or the entire dentition (complete anodontia). The tooth commonly absent are the upper lateral incisors, third molars and lower second premolars. Conversely, an abnormal initiation can result in the formation of single or multiple supernumerary teeth. The most common supernumerary teeth are the mesiodens (between two upper central incisors) and paramolars (by the side of the molars). Similarly, aberration in initiation can result in the tooth developing at abnormal locations (ovary).

Applied Histology

Tooth Development at an Abnormal Site

Aberrant initiation can result in the tooth developing at abnormal locations (ovary).

Proliferation

The enamel organ formed due to initiation undergoes proliferation to give the crown of the tooth its final size and shape.

Any disturbance in proliferation will have effects on the developed tooth depending on the stage at which the disturbance occurs.

Histodifferentiation

As the cells continue to proliferate, they undergo changes (structural, biochemical, etc.) and prepare themselves to carry out their function, for example deposition of organic matrix (apposition). This is termed *histodifferentiation*. In this process, the cells may give up some of the properties they possessed earlier, like their ability to proliferate.

Histodifferentiation is seen in the bell stage just before the formation and apposition of the enamel and dentin. In the bell stage, the inner enamel epithelium influences the adjacent cells of the dental papilla to become differentiated into odontoblasts which form the dentin matrix. This constitutes the histodifferentiation of odontoblasts. Then, the inner enamel epithelial cells are differentiated into the ameloblasts which form the enamel matrix. This constitutes the histodifferentiation of the ameloblasts. The formation of the enamel and dentin are dependent on one another, and this forms the basis of reciprocal induction.

When there is vitamin A deficiency, the ameloblasts fail to differentiate properly and hence their organizing influence on the adjacent cells of dental papilla is disturbed. As a result, odontoblasts fail to differentiate properly and the dentin formed by these odontoblasts will be atypical and is known as *osteodentin*.

Morphodifferentiation

The morphological form and shape of the tooth are determined by morphodifferentiation or differential growth. The dentinoenamel junction and the dentinocemental junction are characteristic for different teeth and determine the shape of the crown and root, respectively. The dentinoenamel

junction and the dentinocemental junction are established before the formation of the hard tissue. In accordance with their shape, the formative cells deposit enamel, dentin and cementum, giving the tooth its characteristic form and size. Disturbances occurring during the morphodifferentiation can affect the morphology of the crown or root depending on the stage at which the disturbance occurs. Examples of some disturbances involving the crown are the formation of supernumerary cusp, loss of cusp and peg-shaped teeth. Formation of supernumerary root and dilaceration (abnormal curvature in the root caused due to trauma) are some examples of disturbances involving the morphology of root.

Apposition

Apposition is the deposition of the matrix of dental hard tissues, characterized by alternate periods of activity and rest. It is this regular and rhythmic appositional growth that gives the tooth its final shape.

Apposition involves formation of the organic matrix and its subsequent calcification or mineralization. Hypoplasia is the term used to indicate disturbances involving the matrix formation, while hypocalcification or hypomineralization indicates disturbances involving the calcification or mineralization of the matrix. Various genetic and environmental factors can cause disturbances in the formation of enamel matrix leading to enamel hypoplasia.

ADDITIONAL READING

Molecular Aspects of Tooth Development

Initiation

Many explanations that substantiate the initiation of tooth development have been provided. Experimentally, when the mouse's first arch epithelium is combined with cranial neural crest, the tooth develops. But epithelium from other sources, such as the second arch epithelium, does not produce this response. This shows that initially, tooth-forming potential lies with the first arch epithelium. After the 12th day of development, the first arch epithelium loses its potential, which is then assumed by the first arch ectomesenchyme. This can be understood by experiments performed after the 12th day of development, in which the first arch epithelium is combined with skin mesenchyme and the skin epithelium is combined with the first arch ectomesenchyme. The first arch epithelium loses its dental properties and assumes the properties of the skin (epidermis) whereas the skin epithelium changes its developmental direction to assume dental characteristics.

These experiments indicate that odontogenesis is initiated by factors residing in the first arch epithelium, influencing the ectomesenchyme, but with time, this potential is assumed by the ectomesenchyme. These experimental findings are substantiated by the expression pattern of growth and transcription factors in these tissues. A growth factor, FGF-8 (fibroblast growth factor), is expressed at the proper place and time in the first branchial arch epithelium and this induces the expression of transcription factors such as *Lh-6* and *Lh-7* (Lim home-box domain genes) in the neural crest–derived first arch ectomesenchyme.

Positioning of the Tooth Germs

Many factors control the positioning of tooth germs along the oral surface. Experimental data suggest that the signal for localization of tooth germs appears to originate from the oral epithelium. FGF-8 expressed in the oral epithelium plays a role in initiating tooth development and determining the position in which the tooth germs will form. This is done by inducing the expression of the *Pax-9* gene (paired box homoerotic gene) in the mesenchyme. The expression of the *Pax-9* gene in the mesenchyme coincides with the exact site where tooth germs will appear. Along with FGF-8, certain proteins such as BMP-2 and BMP-4 (bone morphogenetic protein) are also expressed in the oral epithelium in non-overlapping areas. BMP-2 and BMP-4 have a repressing effect on *Pax-9* gene expression. So the *Pax-9* gene will be expressed in areas where FGF-8 is expressed in the oral epithelium and will not be expressed in areas where BMP-2 and BMP-4 are expressed in the oral epithelium.

Determination of the Tooth Type

It is important to understand how teeth have the correct shape and how incisors are formed in the anterior region and molars in the posterior region and not vice versa. The determination of a specific type of tooth at its correct position in the jaw is called *patterning of dentition*. All the teeth are of the same shape in some animals (homodont) while in most mammals, including human beings, teeth are of different shapes (heterodont) and come under three families: incisors, canines and molars. Two hypotheses have been proposed to explain how these different shapes are determined.

Field Model (Fig. 34.12) According to this model, factors responsible for determining the shape of each tooth family reside within the ectomesenchyme in a distinct graded and overlapping field. The proof for this model comes from the fact that each of the field expresses differing combination of spatially restricted patterning homeobox genes called *odontogenic homeobox code*. Thus, a group of homeobox genes expressed in the ectomesenchyme in the presumptive incisor field will influence the formation of incisor teeth in that region whereas a group of homeobox genes expressed in the presumptive molar field will influence the formation of molar teeth in that region.

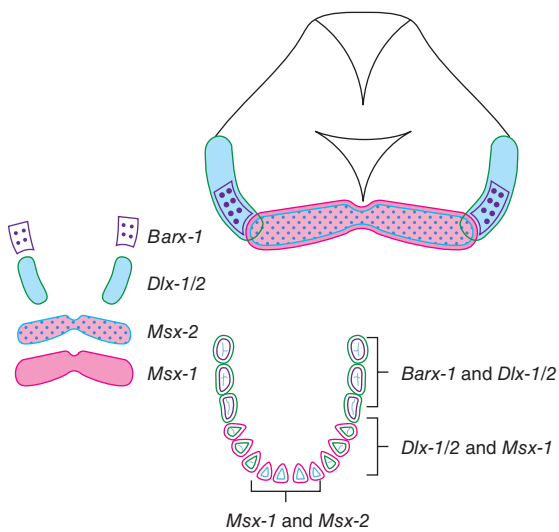


Figure 34.12 Field model for tooth type determination.

The neural crest–derived ectomesenchyme expresses *Msx-1* and *Msx-2* homeobox genes in the incisor and canine region, whereas it expresses *Dlx-1* and *Dlx-2* in the canine/premolar region and *Barx-1* in the molar region.

This field model theory can be tested by experiments manipulating the homeobox genes expressed in the incisor region to the molar region and vice versa resulting in incisor developing in place of a molar and molar developing in place of an incisor.

FGF-8 and *BMP-4*, which are expressed in the epithelium and are known to play a role in the initiation of tooth development and in determination of the position of the tooth germs, also influence the expression of homeobox genes Msx-1, Msx-2, Dlx-1, Dlx-2 and Barx-1 which determine the shape of the tooth.

Clone Model According to this model, each tooth family is derived from a clone of ectomesenchymal cells programmed by the epithelium to produce teeth of a given pattern. This theory is strengthened by the fact that when the presumptive first molar tissue was isolated, it continued its development and formed three molar teeth in a proper sequence.

Both field and clone model could probably play a role in determining the shape of the tooth. The expression of homeobox genes in the ectomesenchyme could be due to the signals from the epithelium. Similar to the initiation phase of tooth development, in the later stages, the ectomesenchyme plays a dominant role in determining the pattern of the tooth. Experiments that recombine molar papilla with the incisor enamel organ, resulting in the formation of a molar tooth, and those that recombine incisor papilla with the molar enamel organ, resulting in the formation of an incisor tooth, confirm the dominant role of ectomesenchyme.

Tissue Engineering of a Tooth

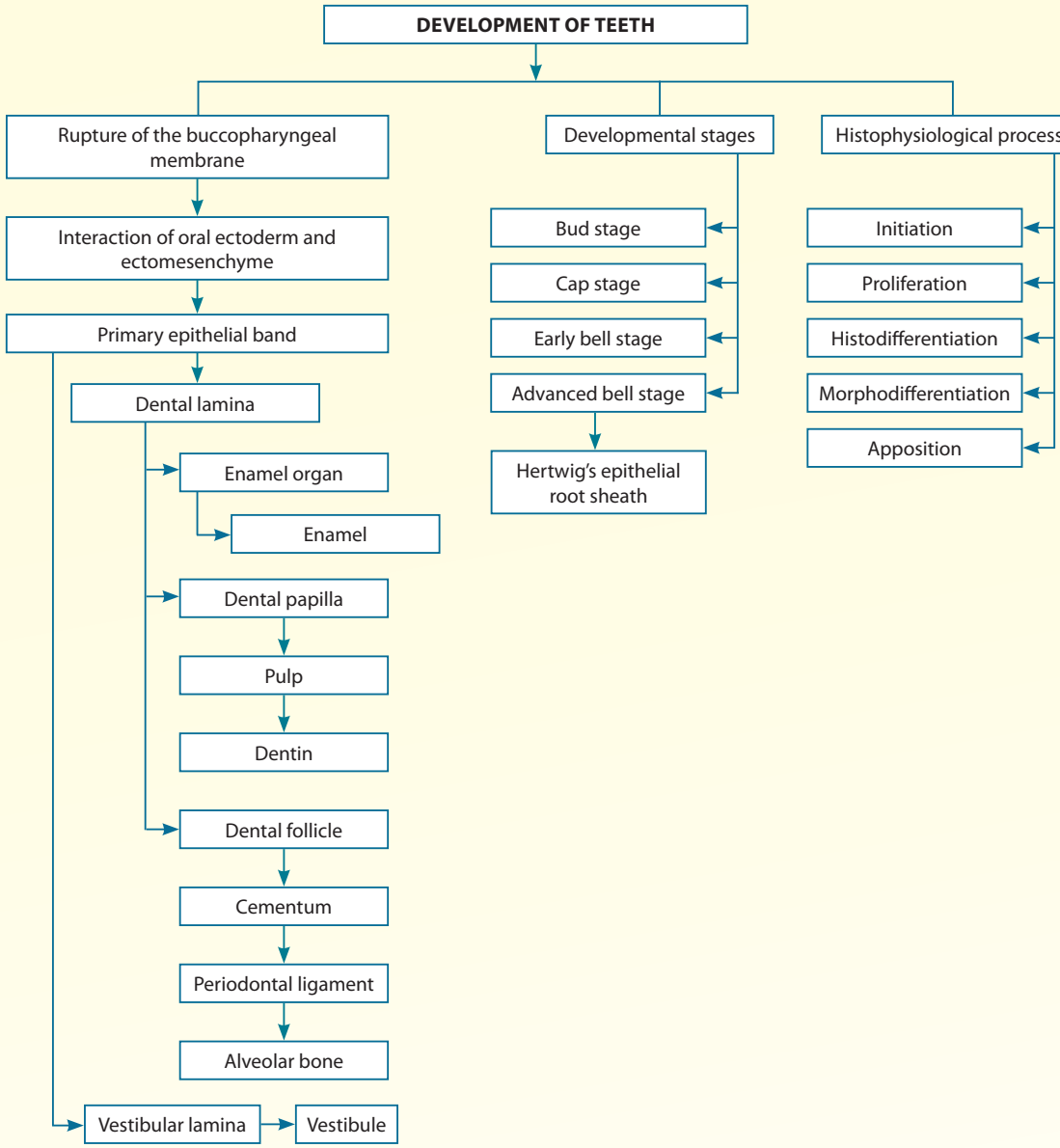
Tooth tissue engineering aims to develop a natural teeth in vivo or in vitro. It has the potential to be used as permanent restorations in dental prosthesis and as implants. Engineering of tooth involves reconstruction of the complex biological organ with its macromorphological (crown

size, tooth length) and micromorphological (cusp number and position, root formation) features. Creation of a functional engineered tooth is a major challenge in terms of exact mimicking of the oral environment with spatiotemporal expression and interactions of growth factors, cytokines and transcription factors. Various approaches to engineering the entire biological teeth have been made which include dental tissue-engineering scaffolds, stimulation of third dentition formation, cell–tissue recombination, chimeric tooth tissue engineering and gene-manipulated tooth regeneration. These strategies may gradually meet the challenge of generating bio-engineered teeth of a predetermined size and shape.

Key Points

1. The embryonic connective tissue concerned with tooth development is termed *ectomesenchyme* due to the migration of the neural crest cells in it.
2. The lingual extension of the dental lamina gives rise to the enamel organ of the successional teeth—central and lateral incisors, canines and premolars.
3. The distal extension of the dental lamina gives rise to the enamel organ of the non-succedaneous teeth—permanent molars.
4. The remnants of the dental lamina are called the *cell rests of Serres*.
5. Vestibular lamina is also known as the *lip furrow band*.
6. Stellate reticulum is also called enamel pulp and it acts as a shock absorber to protect the inner enamel epithelial cells.
7. The enamel knot acts as a signalling centre and determines the morphology of the cusp.
8. The bell stage marks the morphodifferentiation of the crown and histodifferentiation of the ameloblasts and odontoblasts.
9. The stratum intermedium exhibits a high degree of metabolic activity and synthesizes proteins essential for enamel formation.
10. After the formation of the dental matrix, the inner enamel epithelial cells (ameloblasts) receive nutrition from the capillaries of the dental follicle.
11. The basement membrane that separates the enamel organ and dental papilla just before the dentin formation is called the membrana preformativa.
12. The shape of the crown is formed by the differential mitotic division of the inner enamel epithelial cells.
13. The infolding that occurs in the inner enamel epithelium during crown pattern determination is due to the differential rates of mitotic division.
14. The reversal of polarity of the ameloblasts is the alignment of nuclei towards the stratum intermedium and the Golgi complex towards the dental papilla.
15. Hertwig's epithelial root sheath outlines the future root and is responsible for the shape, length, size and number of roots.
16. During root development, the plane of the epithelial diaphragm remains fixed and the lengthening of the root is accompanied by the movement of the crown in an axial direction.
17. The remnants of Hertwig's epithelial root sheath are called the *cell rests of Malassez*.
18. A cell becomes histodifferentiated when it undergoes functional and morphological changes and acquires its functional assignment.
19. The dentinoenamel and dentinocemental junctions are the blueprints which decide the morphology of the crown and the root, respectively.

Mind Map


DEVELOPMENT OF TEETH
Rupture of the buccopharyngeal membrane
Interaction of oral ectoderm and ectomesenchyme
Primary epithelial band
Dental lamina
Enamel organ
Enamel
Dental papilla
Pulp
Dentin
Dental follicle
Cementum
Periodontal ligament
Alveolar bone
Vestibular lamina
Vestibule
Developmental stages
Bud stage
Cap stage
Early bell stage
Advanced bell stage
Hertwig's epithelial root sheath
Histophysiological process
Initiation
Proliferation
Histodifferentiation
Morphodifferentiation
Apposition

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Multiple Choice Questions

1. The embryonic connective tissue under the oral ectoderm is termed *ectomesenchyme* because
   (a) It has both ectodermal and mesenchymal cells
   (b) It has migrated neural crest cells in it
   (c) It has characteristics similar to ectodermal cells
   (d) None of the above
2. Identify the correct statement about the primary epithelial band.
   (a) It is the same as dental lamina
   (b) It is the structure that gives rise to dental lamina and vestibular lamina
   (c) It is the same as lip furrow band
   (d) None of the above
3. Tooth germ is made up of
   (a) Ectoderm, mesoderm and endoderm
   (b) Inner enamel epithelium, outer enamel epithelium and stellate reticulum
   (c) Enamel organ, dental papilla and dental sac
   (d) None of the above
4. Development of the first permanent molar is initiated at
   (a) Birth
   (b) Fourth month, in utero
   (c) 6 years of age
   (d) None of the above
5. The last successional lamina forms at
   (a) 6th month, in utero
   (b) 4th month, in utero
   (c) 10th month after birth
   (d) 5 years of age
6. In which of the following structures does a precise expression of growth and transcription factors associated with future cusp formation takes place:
   (a) Enamel cord
   (b) Enamel knot
   (c) Inner enamel epithelium
   (d) None of the above
7. Among which of the layers of the enamel organ is the alkaline phosphatase activity high?
   (a) Stellate reticulum
   (b) Inner enamel epithelium
   (c) Outer enamel epithelium
   (d) Stratum intermedium
8. Membrane preformativa is the
   (a) Basement membrane separating dental papilla from the enamel organ before dentin formation
   (b) Basement membrane separating Hertwig's epithelial root sheath from dental papilla
   (c) Basement membrane separating dental follicle from outer enamel epithelium
   (d) Basement membrane separating enamel organ from dental papilla in the cap stage
9. Reciprocal induction is seen between the
   (a) Cementoblast and odontoblast
   (b) Cementoblast and osteoblast
   (c) Ameloblast and odontoblast
   (d) None of the above
10. Development of root begins after the
    (a) Formation of the dentin matrix
    (b) Formation of the enamel matrix
    (c) Enamel and dentin formation has reached the cementoenamel junction
    (d) None of the above
11. Cell rests of Malassez are seen
    (a) In the jaw bone
    (b) Among the layers of cementum
    (c) In the periodontal ligament
    (d) In the cementodentinal junction
12. A tooth developing in an abnormal location is due to disturbance in
    (a) Histodifferentiation
    (b) Initiation
    (c) Proliferation
    (d) All of the above

13. Formation of accessory canals is due to the
    (a) Persistence of the epithelial root sheath cells
    (b) Improper differentiation of the cementoblast in the cervical area
    (c) Earlier removal of Hertwig's epithelial root sheath cells
    (d) Improper differentiation of the odontoblast in the apical third
14. Identify the correct statement about osteodentin:
    (a) It is due to disturbance in histodifferentiation
    (b) It is seen in vitamin A deficiency
    (c) It is irregular dentin
    (d) All of the above
15. Hypoplasia is disturbance in
    (a) Matrix formation
    (b) Calcification
    (c) Maturation
    (d) All of the above



CHAPTER 35

Enamel

Overview

The enamel is an ectodermally derived structure produced by ameloblasts to form a protective covering for the teeth. It is composed of 96% inorganic content and 4% of organic matter and water. The high content of mineral salts, along with a crystalline arrangement, makes the enamel the hardest calcified tissue in the human body. Structurally, enamel is composed of enamel rods arranged in a wavy pattern and oblique direction. The other structures of enamel which can be seen in ground section are striations, incremental lines of Retzius, Hunter–Schreger bands, enamel lamellae, enamel tufts and enamel spindles. At the time of eruption, the enamel is covered by primary enamel cuticle which is also called Nasmyth's membrane. After eruption, the primary enamel cuticle is gradually lost and salivary pellicle covers the enamel surface. The process of development of enamel is called amelogenesis. Ameloblasts, the enamel secretory cells, undergo morphological and functional changes during amelogenesis. Initially, the organic matrix is laid down which is subsequently mineralized to form enamel. Enamel is devoid of vascular or neural supply and hence does not demonstrate the potential for repair when lost. Enamel undergoes wearing with age.

INTRODUCTION

The enamel is an ectodermally derived structure produced by ameloblasts to form a protective covering for the teeth. The high content of mineral salts, along with a crystalline arrangement, makes the enamel the hardest calcified tissue in the human body. This property of the enamel makes it suitable to form a resistant covering for the teeth and enables it to withstand the mechanical forces applied during mastication.

Physical Properties

1. There is considerable variation in the thickness of the enamel over different parts of the crown. It is thicker in the cusp of the molars and premolars, reaching up to a maximum of 2–2.5 mm, whereas at the cervical region, it almost thins down to a knife edge.
2. The hardness and density of the enamel varies in different parts of the crown. The hardness and density decreases from the surface of the enamel to the dentinoenamel junction (DEJ) and from the cuspal or incisal region to the cervical margin. The average value of the breaking stress of enamel is 11,000 lb/in^2. The specific gravity of enamel is 3.
3. The enamel exhibits the phenomenon of birefringence, as it has a crystalline structure. The colour of the enamel varies from light yellow to greyish white. The colour depends on the translucency of the enamel, which is mostly associated with a variation in the degree of calcification and homogeneity of the enamel. The refractive index of enamel is 1.62. Yellow teeth probably have translucent enamel through which the yellow colour of the underlying dentin is seen and greyish white teeth have a less translucent or opaque enamel. The cervical area appears slightly yellow even in greyish white teeth as a result of the thinner enamel layer in the cervical region allowing light to pass through, reflecting the yellow colour of the dentin. Thin incisal edges consisting only of a double layer of enamel without the intervening layer of dentin appear slightly blue.
4. The permeability of the enamel has been demonstrated by radioactive tracers and certain dyes. It has been found that the enamel acts like a semipermeable membrane, allowing

complete or partial passage of certain molecules. The permeability of the enamel is the result of the presence of cracks and microscopic spaces on the surface of enamel which allow the penetration of fluids. Permeability decreases and hardness increases with age.

5. The structure and hardness of the enamel makes it brittle, which is evident when the underlying layer of more resilient dentin is lost.

Chemical Properties

The enamel is made up of 96% inorganic material and 4% organic matter and water by weight. The organic matrix of enamel is made up of two types of non-collagenous protein components: amelogenins (90%) and non-amelogenins (10%). The non-amelogenins constitute the enamel proteins enamelin, ameloblastin, sulphated protein and tuftelin.

The organic matrix of the enamel, made up of enamel proteins, has to be degraded to make way for the inorganic minerals. Two enzymes, enamelysin and kallikrein-4, belonging to the proteinase family, carry out this function. Loss of function of these enzymes results in insufficient removal of the organic matrix, leading to hypomineralized enamel.

Although the organic matrix, formed mainly by the amelogenins, provides physical support, the enamel proteins do not play a major role in contributing to the structure of enamel. This is in contrast to the collagenous proteins which are the principal proteins of dentin, bone and cellular cementum, contributing to their structure. On the basis of the biochemical characteristics and their pattern of distribution, it is believed that non-amelogenins promote and guide the function of inorganic enamel crystals while amelogenins regulate the growth of the crystals.

Applied Histology

Amelogenin

Amelogenesis imperfecta is a disorder affecting the formation of enamel. The resultant enamel is either hypoplastic or hypomaturative or hypomineralized. Mutations in the human amelogenin gene located on the X chromosome are said to induce amelogenesis imperfecta (AIH1) with enamel phenotypes broadly characterized into either hypoplastic or hypomineralized. Documented cases of A1H1 with mutations in the C terminus of amelogenin have resulted in a hypoplastic phenotype whereas mutations located within the N terminus have resulted in hypomineralized enamel.

Enamelins account for about 2% of all enamel matrix proteins. Intact enamelin is only found on the enamel surface, within a micrometre of the ameloblast cell membrane, and many enamelin cleavage products appear to be rapidly degraded and are only found in the outer enamel layer. Recent in vitro evidences indicate that 32-kda enamelin and amelogenin cooperation promotes nucleation of apatite crystals. Enamel tuft proteins are called tuftelin. The function of this enamel protein remains unknown, but a predicted function is to nucleate hydroxyapatite crystal formation. Ameloblastin (also called amelin/sheathlin) is expressed by ameloblasts during amelogenesis as well as by cells of Hertwig's epithelial root sheath during cementogenesis.

Applied Histology

Ameloblastin

Ameloblastin overexpression in mice has recently been shown to influence enamel crystallite and enamel rod morphology, implicating the role of ameloblastin gene locus in the aetiology of a number of undiagnosed autosomally dominant cases of amelogenesis imperfecta.

The inorganic components of mature enamel are hydroxyapatite crystals, which are hexagonal in cross-section and have the following approximate composition: calcium—37%, sodium—0.5%, magnesium—0.5%, phosphate—55.5%, carbonate—3.5% and traces of other components. The chemical formula of these crystals is $Ca_{10}(PO_4)_2(OH_4)_2$. These hydroxyapatite crystals are arranged to form enamel rods or prisms.

Applied Histology

Fluorapatite Crystals and Caries Resistance

Incorporation of fluoride ions in the hydroxyapatite crystals of enamel makes it more resistant to dissolution by acid. This altered characteristic

(Continued)

(Continued)

of the apatite structure helps in lowering the incidence of dental caries. The replacement of hydroxyapatite by fluorapatite can occur while the enamel of the teeth is being formed or after the teeth have erupted into the oral cavity. Communal water fluoridation programme, in which the level of fluoride in drinking water is adjusted to 1 parts per million (ppm), provides the necessary fluoride ions. (However, the amount of fluoride must be carefully controlled because ameloblasts are sensitive to fluoride ions and an increased concentration can lead to the formation of enamel hypoplasia.) The semipermeable nature of enamel enables topical application to provide a higher concentration of fluoride in the surface enamel of erupted teeth. Topical application of sodium fluoride, stannous fluoride and acidulated phosphorus fluoride alters the outer surface of the enamel and makes it more resistant to decay. Incorporation of fluoride in dentifrice is a well-known and accepted method of prevention of caries. When a small portion of enamel has lost mineral, remineralization is possible if the destructive causative agent, i.e. dental plaque, is removed. This process of remineralization is enhanced by the presence of fluoride.

In terms of volume, the inorganic material constitutes 86% while organic matrix and water constitute 2% and 12%, respectively (mineral material is three times heavier than organic material).

Water is present in enamel in the following two physical states:

1. Loosely bound form or free water
2. Strongly bound form, as a part of the apatite crystals

Water determines certain physicochemical properties of the enamel such as permeability, ion exchange and elasticity.

During the formation of enamel, a distinct unmineralized pre-enamel layer such as the osteoid or predentin does not exist, because enamel matrix mineralization begins immediately after the matrix is secreted.

STRUCTURE OF ENAMEL

The structure of enamel can be studied using decalcified sections of the developing enamel. Mature enamel, being a highly mineralized structure, presents as an empty space in conventional demineralized sections. This is due to the dissolving of the mineral portion and washing away of the organic material of enamel in the process of demineralization. Adequate organic material is retained in decalcified sections of the developing enamel to reveal some details of the enamel structure.

The basic structural unit of the enamel is the enamel rod. The rods are surrounded by an inter-rod substance. The boundaries of the rod and inter-rod substance are surrounded by the rod sheath. It has been estimated that each tooth has millions of enamel rods and that the number varies from tooth to tooth.

The *enamel rods* do not follow a straight course as they pass from the DEJ to the surface of the tooth. The length of the rods is greater than the thickness of the enamel as a result of the oblique direction and wavy arrangement of the rods. It varies in different portions of the crown of the tooth, being long in the thicker portions (cuspal area) and short in the thinner portions (cervical area).

The outer surface area of enamel is greater than its inner surface area (i.e. the dentinal surface at the DEJ). The size and diameter of the enamel rods increase as they reach the outer surface. Although it is observed that the average diameter of the enamel rod is 4–5 μm, there is considerable variation along its course. It has been suggested that the diameter of the enamel rods increases in the ratio of 1:2 while passing from the DEJ to the outer surface. Enamel rods have a crystalline structure that allows light to pass through them. They have a shape similar to that of a cylinder and appear hexagonal, round or oval in cross-section. Some have described enamel rods as showing an arrangement resembling fish scales.

Studies with an electron microscope reveal that the enamel rods have a keyhole or paddle-shaped pattern with a rounded head and a narrow tail region (**Fig. 35.1**). The rounded head of each rod fits closely into the concavities between the heads and tails of the rods on either side. The region between the two enamel rods in one row, thought to be the *inter-rod substance*, actually represents the tail portion of the enamel rod in the previous row. The rods measure about 4–5 μm in breadth and 9 μm in length. Many patterns are observed regarding the arrangement of rods, but usually they are arranged with their head portion near the

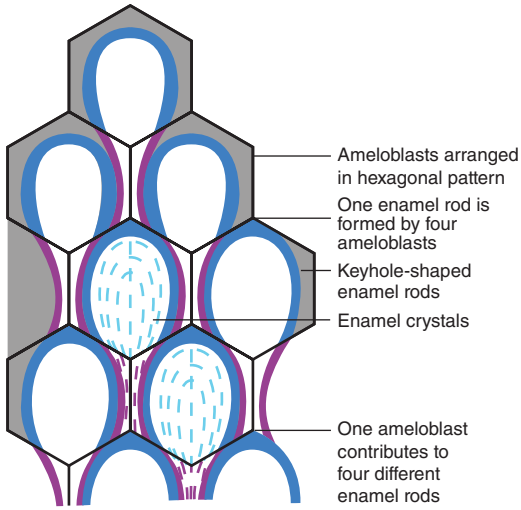


Figure 35.1 Relationship between enamel rods and ameloblasts.

occlusal or the incisal surface and their tail portion pointing cervically.

Applied Histology

Wavy Course of Enamel Rods

The wavy course, oblique direction and interlocking of the enamel rods render prevention from enamel fracture.

Each enamel rod is made up of closely packed ribbon-shaped apatite crystals, which constitute the inorganic portion of the enamel. The long axis of the crystals parallels the long axis of the rods in the head region. In the tail region, the crystal orientation deviates to 65°–70° from the axis. The greatest change in the orientation of the crystallites is found while passing from the tail of the rod to the head of the adjacent rod (**Fig. 35.2**). It is only in this region that the boundaries of the rods are seen most distinctly. When sections are examined under a light microscope, the transmitted light is deflected at these planes and shows up the boundaries of the rods. The irregularly shaped crystallites measure approximately 30 μm in thickness and 70–80 μm in width. The length of the crystal varies between 0.05 and 1 μm, but it is now believed that the crystals are extremely long. Some

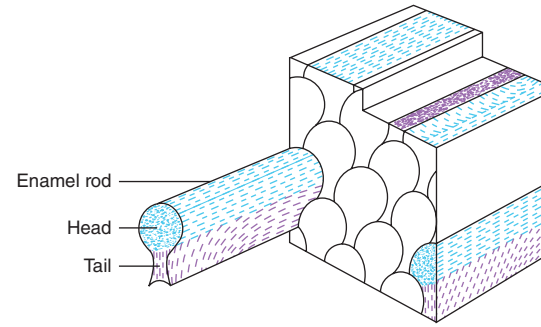


Figure 35.2 Orientation of crystals in the enamel rod.

investigations suggest that the length of the crystal spans the entire thickness of the enamel layer.

The organic matrix of the enamel is seen in the form of a network of fine fibrils enveloping each apatite crystal and forming the outer layer of each enamel rod (rod sheath) which is seen prominently in decalcified sections.

Applied Histology

Acid Etching

Acid etching of the enamel surface has become an important technique in clinical practice for the use of composite resins which require a mechanical bonding. They are commonly used as restorative material and fissure sealants and for cementing orthodontic brackets to tooth surface. This material can be mechanically bound directly to the enamel surface. In the process of acid etching, the surface of enamel is first etched with 37% orthophosphoric acid to remove plaque and other debris along with a thin layer of enamel. This produces uneven dissolution of enamel rods and their sheath, making the relatively smooth enamel surface pitted and irregular. When composite resin is applied on this irregular surface, it is able to achieve mechanical bonding with enamel. Slightly severe etching is required to obtain mechanical retention in areas of rodless enamel.

Striations

Longitudinal ground sections of enamel seen under a light microscope show that each enamel rod is composed of a series of segments separated by lines, giving it a striated appearance. These striations cross the enamel rods at intervals of about 4 μm. Each

striation is thought to represent a rest phase during the formation of the enamel. The striations are more pronounced in sections that have been etched with dilute acid. It is also thought that the striations represent variations in the width of the enamel rods.

Orientation of Enamel Rods

The general orientation of the enamel rods is perpendicular to the dentin surface. In deciduous teeth, the enamel rods lie in a horizontal plane in the cervical and middle third. They gradually become more oblique in the incisal and occlusal third and are almost vertical in the incisal edge or the cusp tip. In permanent teeth, the arrangement is similar to deciduous teeth in the occlusal and middle third; in the cervical third, the enamel rods show a rootward inclination or pass outwards (**Fig. 35.3**).

Applied Histology

Unsupported Enamel Rods

The change in the direction of the enamel rods should be given due consideration during cavity preparation (cavity preparation: a treatment modality to remove the existing dental decay and make the region conducive so as to accept a restorative material). The cavity should be prepared in such a manner that the remaining enamel rods are always supported by the adjacent rods and the underlying dentin since unsupported enamel rods are brittle and susceptible to fracture. Unsupported enamel rods can break to produce leakage at the margins. This can result in the lodging of food/bacteria in these spaces leading to secondary caries.

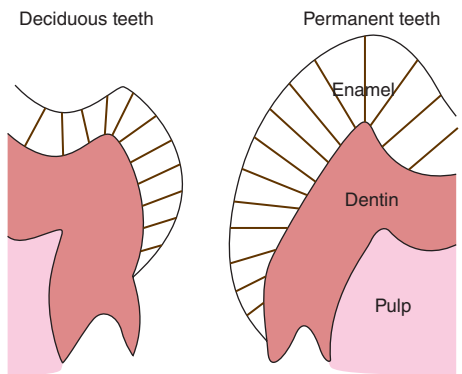


Figure 35.3 Directions of enamel rods in deciduous and permanent teeth.

As mentioned earlier, the enamel rods do not follow a straight course but have a wavy arrangement. The rods bend to right and left in the transverse plane from the DEJ to the surface, except in the cervical area, where they have a straight course. This change in the direction of rods is considered a functional adaptation that minimizes the risk of enamel fracture in the axial direction because of occlusal masticatory forces. In some areas of the enamel close to the DEJ, especially in the region of cusp, the wavy arrangement of the rods becomes marked, resulting in twisting of the rods. Such areas, known as *gnarled enamel*, are associated with increased strength. The enamel rods converge in the region of the developmental pits and fissures on the occlusal surface of molars and premolars.

Applied Histology

Pit and Fissure Caries

As the enamel rods converge in the pit and fissure region and as the enamel is thin here, the carious process which starts in these regions spreads rapidly to reach the dentin underlying the enamel. While more of the dentin is destroyed by carious processes, the patient is not aware of the cavity because the entrance to the cavity is a very tiny one. Careful examination is required to detect such cavities occurring in the enamel fissures.

Hunter–Schreger Bands

Hunter–Schreger bands are seen as alternating light and dark bands of varying width when longitudinal ground sections of the enamel are viewed under oblique reflected light. These are curved bands, with the concavity facing rootwards, commencing near the DEJ. They are seen in the inner two-third of the enamel thickness and disappear as the outer part of the enamel is approached. It has been suggested that these alternating light and dark bands may represent portions of enamel having variations in calcification, differing slightly in their permeability or having different organic material content. However, the opinion that the Hunter–Schreger bands are an optical phenomenon as a result of a change in the direction of enamel rods is widely accepted and is explained as follows (**Figs 35.4** and **35.5**).

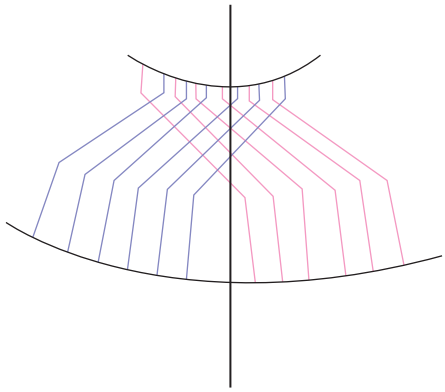


Figure 35.4 Directions of enamel rods from the dentinoenamel junction to the enamel surface.

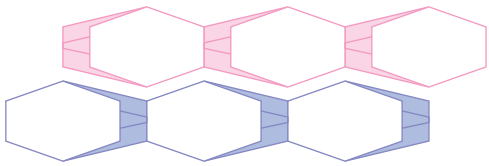


Figure 35.5 Vertical section showing the cut surface of the two layers of prisms. The prisms are directed at different angles.

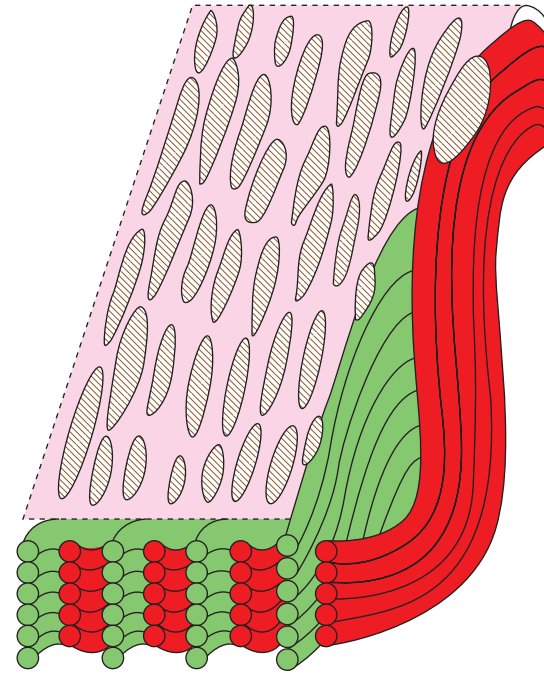


Figure 35.6 Sinusoidal direction of the enamel rods.

It has already been stated that the enamel rods do not run in a straight direction from the DEJ to the surface, but follow a wavy course (**Fig. 35.6**). The basic pattern made by the enamel rods in their course can be best understood if the enamel is imagined as being constituted of a series of horizontal discs. In each disc, the rods start by running out from the DEJ at right angles for a short distance and then turn to the left or to the right, the direction of the turning alternating in each disc. The outer part of the enamel has rods running straight to the surface.

If an oblique section is made by cutting the middle part of the rods, they pass from the cut surface to the right and to the left in alternating discs. The discs which coincide with the obliquely directed light allow light to pass through the rods. These areas absorb light and appear as dark bands known as *para zones*. In those discs where the rods run in the opposite direction, light is reflected from the sides of the rods, producing the lighter bands known as *dia zones*. While viewing the ground sections, if the light is allowed to fall on the opposite side, the position of the light and the dark bands is reversed, which confirms that it is purely an optical phenomenon.

Incremental Lines of Retzius

Incremental lines of Retzius are a series of dark lines seen in enamel when the ground sections of teeth are observed. In longitudinal sections, these are seen extending from the DEJ to the outer surface of the tooth in an upward and outward direction (deviating occlusally). The lines run obliquely in the cervical region to reach the surface (**Fig. 35.7**). In the incisal and cuspal portion, the incremental lines do not reach the surface and surround the tip of dentin. They are more numerous and close together in the cervical region. In cross-sections, they appear as concentric circles similar to the growth rings seen on the cut surface of a tree trunk. The enamel is formed by an incremental or appositional growth pattern where the lines actually represent the periods of quiescence/rest and the space between the lines represents periods of active enamel formation. Moderate intensity of the lines is considered normal.

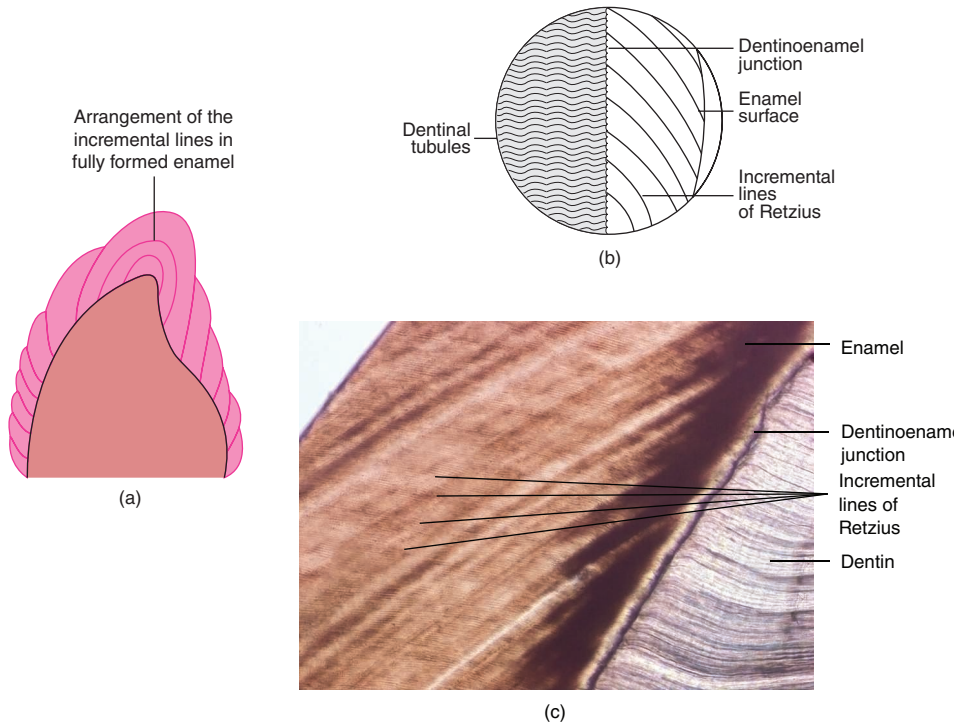


Figure 35.7 (a) Schematic diagram of a longitudinal section of the tooth showing incremental lines of Retzius. (b) Schematic diagram of a cross-section of the tooth showing incremental lines of Retzius. (c) Photomicrograph of the incremental lines of Retzius (ground section, 10X).

Applied Histology

Physiological and Pathological Accentuated Incremental Lines

The rhythmic pattern of enamel formation can be altered, causing a prolonged resting period. This leads to the broadening of the incremental lines making them more prominent or accentuated. The *neonatal line* is one such accentuated incremental line seen in deciduous teeth and in the first permanent molars, separating the enamel formed before and after birth. This is due to the physiologic changes in nutrition and environment occurring at birth. The prenatal enamel is more homogenous than the postnatal enamel, probably because of more constant surroundings and nutrition of the foetus.

Accentuated incremental lines can also be pathological, caused by metabolic and systemic disturbances such as exanthematous fever that affects enamel formation.

Surface Enamel

The surface layer of the enamel is unique when compared with the rest of the enamel. It is much harder, less soluble and has higher mineral content. It is seen in all deciduous teeth and in 70% of permanent teeth and measures approximately 30 μm in width. This layer, in contrast with the bulk of the enamel, is devoid of enamel prisms (prism-less enamel) and is made up of only apatite crystals which lie parallel to one another.

Perikymata

Perikymata are transverse wave-like grooves lying parallel to each other and to the cementoenamel junction and run circumferentially across the surface of the crown. These are seen in regions where the incremental lines of Retzius reach the outer surface of the enamel, and they are thought to be the external

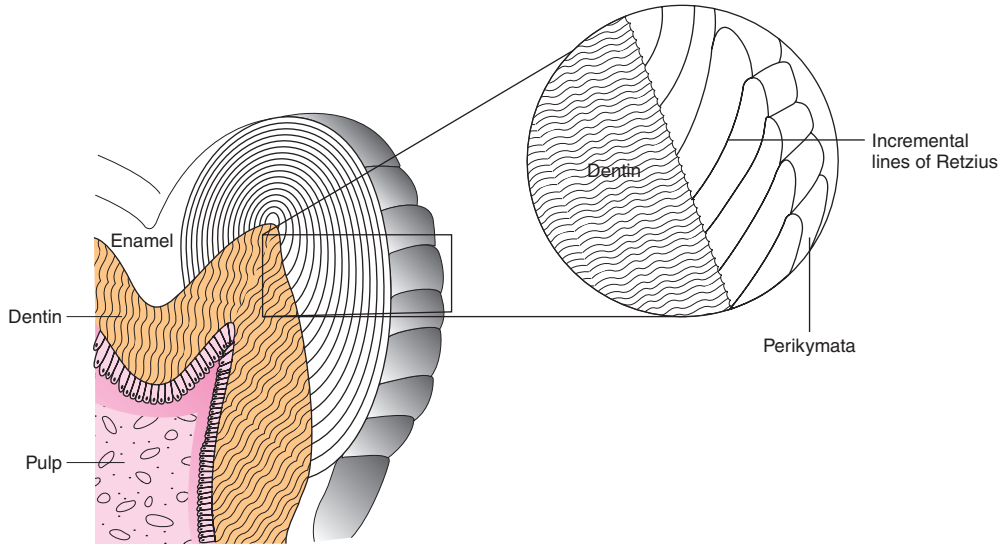


Figure 35.8 Perikymata.

manifestations of the lines of Retzius (**Fig. 35.8**). They are more in number in the cervical region (30/μm) than in the occlusal or the incisal edge (10/μm). They are sometimes referred to as *imbrication lines of Pickerill* and can be demonstrated by rubbing graphite on the surface of the teeth.

Enamel Caps and Brochs

The surface of enamel is not even and shows pits and elevations. The pits are about 1–1.5 μm in depth and represent the ends of the ameloblasts lost after the formation of enamel. Elevations occur as a result of the deposition of enamel and debris of the enamel organ. Smaller elevations are called *enamel caps* (**Fig. 35.9**), which measure about 10–15 μm in width, and larger elevations are called *enamel brochs* (**Fig. 35.10**), which measure about 30–50 μm in width.

Enamel Lamellae and Cracks

Enamel lamellae are thin, sheet-like hypocalcified structures arranged in longitudinal and radial directions of a tooth, best demonstrated in horizontal sections. They extend from the surface of the enamel to the DEJ and some may even reach the dentin (**Fig. 35.11**). Short segments of enamel rods on encountering planes of tension may not fully calcify leading to the formation of enamel lamellae. Enamel lamellae are formed due to severe disturbance causing a crack in the newly formed enamel and are filled with organic matter. Enamel lamellae can be differentiated into three types:

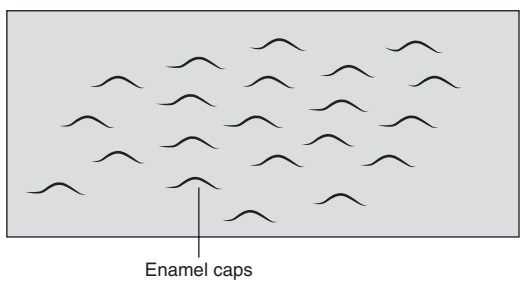


Figure 35.9 Enamel caps.

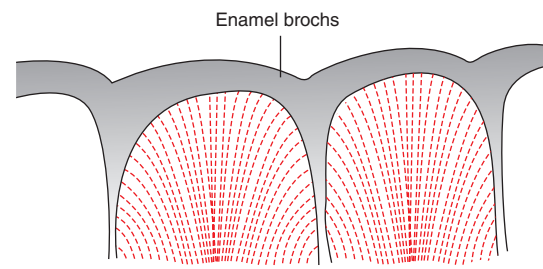


Figure 35.10 Enamel brochs.

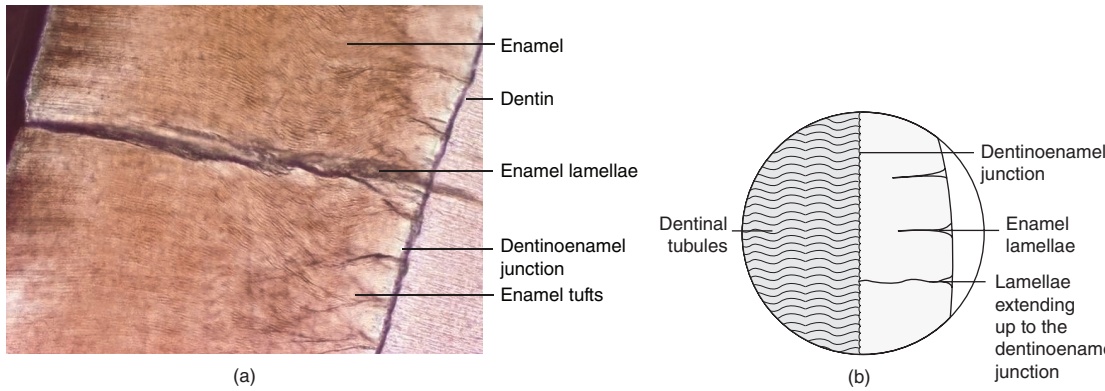


Figure 35.11 Enamel lamellae and enamel tufts: (a) photomicrograph (ground section, 10X) and (b) schematic diagram.

1. **Type A enamel lamellae:** They are poorly calcified rod segments that occur when a section of the enamel rod fails to calcify when occlusal forces are applied on it while crossing a plane of tension.
2. **Type B enamel lamellae:** They contain degenerated cells only and are defects in enamel filled with organic material
3. **Types B and C enamel lamellae:** They are defects in enamel filled with organic material.
4. **Type C enamel lamellae:** They occur in erupted teeth where the cracks are filled with organic matter from the connective tissue surrounding the teeth or from saliva. Cementum may be formed in these lamellae.

Type A enamel lamellae are restricted to enamel while types B and C may extend up to the dentin.

Enamel lamellae should not be confused with cracks, which can occur during the preparation of the ground sections of the enamel. These cracks look very much like lamellae and can be distinguished by careful decalcification of the section. While cracks, which do not contain organic material, disappear after decalcification, lamellae persist.

Applied Histology

Enamel Lamellae are Sites of Weakness

It is suggested that an enamel lamella can be a weak site, providing a pathway for the bacteria to enter and cause caries.

Enamel Tufts

Enamel tufts are thin, wavy, ribbon-like structures arising from the DEJ. They reach a short distance into the enamel, usually up to one-third of the thickness (**Fig. 35.12**). When thick ground sections are viewed under low magnification, enamel tufts, lying in different planes and curving in different directions, are projected in one plane making them appear like a tuft of grass, hence the name. However, they do not arise from a single stem as it appears. These structures are arranged in a longitudinal direction and hence best seen in a horizontal or transverse section. When traced through the enamel, the wavy course of the tufts exactly parallels the change in the direction of the rods at succeeding levels of the enamel.

Like the enamel lamellae, these structures are made up of hypocalcified enamel rods and have more organic components in them. Enamel tufts are much more numerous than enamel lamellae and both the structures persist even after decalcification.

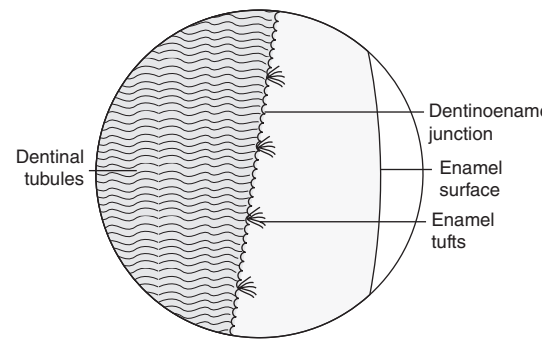


Figure 35.12 Enamel tufts.

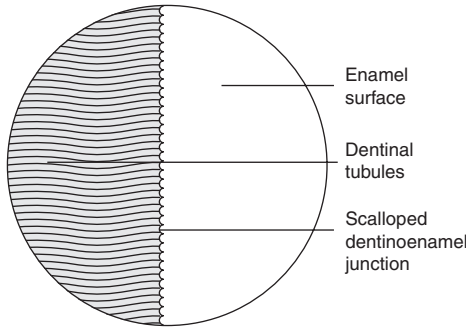


Figure 35.13 Dentinoenamel junction.

Dentinoenamel Junction

The dentinal surface of enamel is formed by a series of dome-shaped elevations arranged closely, fitting into the shallow depressions of the dentin. In sections, the DEJ appears as a scalloped line, and not straight, the convexities of which are directed towards the dentin (**Fig. 35.13**). This irregular shape of the junction helps strengthen the union between the enamel and the dentin and prevents shearing of the enamel during function. The scalloped arrangement of the junction is more marked in the occlusal area, where the masticatory stresses are the greatest.

Enamel Cuticle

Primary enamel cuticle or *Nasmyth membrane* is a delicate membrane-like structure covering the entire crown of newly erupted teeth except in the cervical area. It is soon lost due to mastication. This organic covering is about 1 μm thick and resembles the basal lamina seen beneath the epithelium. Enamel cuticle is thought to be secreted by the ameloblasts after the enamel formation is completed. A layer of afibrillar cementum secreted by the adjacent mesenchymal cells of the dental follicle covers the cervical area of the newly erupted crown. This structure forms during tooth development, when the enamel organ retracts from the cervical region, and is of the mesodermal origin (refer to 'Protective Stage' in the life cycle of ameloblasts).

In addition, the enamel of an erupted tooth is covered by a membrane-like structure called *pellicle*. This organic structure is a precipitate of salivary protein and forms within hours after the surface of enamel is mechanically cleaned.

Applied Histology

Pellicle

Salivary pellicle must be removed from the tooth surface periodically. If not removed, the pellicle can get colonized by microbes to form plaque which subsequently lead to caries.

Enamel Spindle

In some areas, the odontoblastic processes from the dentin pass across the DEJ into the enamel for a short distance. These processes may be pointed or rounded or may have a noticeably thickened end, in which case they are known as enamel spindles (**Fig. 35.14**). They presumably must have originated from those odontoblastic processes which had insinuated themselves between the

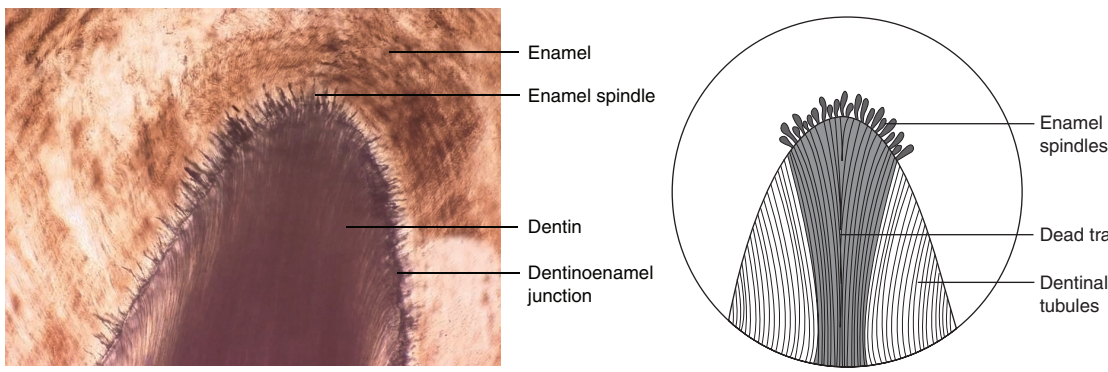


Figure 35.14 Enamel spindles: (a) photomicrograph (ground section, 10X) and (b) schematic diagram.

cells of the inner enamel epithelium of the enamel organ before either the dentin or the enamel was laid down.

The impression that this organic structure could be another hypocalcified segment of the enamel rod is dispelled by observing the direction of the spindle and enamel rods. The enamel spindle is perpendicular to the surface of the dentin and in line with the odontoblastic processes and ameloblasts. But the enamel rods are formed at an angle to the ameloblasts and are arranged in a direction divergent to that of enamel spindles.

The highest number of enamel spindles is found in the region of cusps. In ground sections, the organic structure of the spindle disintegrates and is replaced by air and thus enamel spindles appear dark in transmitted light.

DEVELOPMENT OF THE ENAMEL

During tooth development, before the formation of the enamel and dentin, the enamel organ which takes its origin from the oral ectoderm is made of four layers: outer enamel epithelium, stellate reticulum, stratum intermedium and inner enamel epithelium (discussed in Chapter 34). The border between the inner enamel epithelium and the underlying dental papilla outlines the future DEJ and determines the occlusal or incisal pattern of the crown.

The distinct morphological changes that take place in various layers of the enamel organ just before amelogenesis are discussed in the following sections.

Outer Enamel Epithelium

Initially, the outer enamel epithelium is made up of a single layer of cuboidal cells separated from the connective tissue of the dental sac by a basement membrane. Before the hard tissues start forming, the cells of the outer enamel epithelium become irregular, except in the cervical layer, and are indistinguishable from the outer portion of the stellate reticulum.

Just before the formation of the enamel, the capillaries in the connective tissue of the dental sac start proliferating and protruding towards the outer enamel epithelium, and some may even indent the stellate reticulum. The capillaries of the dental sac and the cells of the outer enamel epithelium undergo structural modifications such as thinning of the walls of the capillaries protruding towards the outer enamel epithelium and development of villi, cytoplasmic vesicles and large number of mitochondria in the cells of the outer enamel epithelium, indicating cell specialization for active transport of nutrients. When the nutrition supply of the inner enamel epithelium from the dental papilla is cut off after the first layer of dentin is laid, these structural modifications facilitate easy transport of nutrition to the inner enamel epithelium, ensuring rich metabolism in that layer.

Stellate Reticulum

Stellate reticulum is present between the outer and the inner enamel epithelium. The cells are star shaped and form a branched cellular network. Mucoid fluid, rich in albumin, is present between the cells. It gives a cushion-like consistency and acts as a shock absorber, thus protecting and supporting the enamel forming cells.

Stratum Intermedium

Stratum intermedium is made up of one or two layers of flat cells and is present between the inner enamel epithelium and the stellate reticulum. Desmosomes connect the cells of stratum intermedium with one another and with the cells of stellate reticulum and inner enamel epithelium. Stratum intermedium plays an important role in the formation of the enamel by producing necessary substances and enzymes.

Cervical Loop

The zone at the free end of the enamel organ where the cells of the outer enamel epithelium are continuous with those of the inner enamel epithelium is the cervical loop. The cells show a transition between the cuboidal outer enamel epithelium and the columnar inner enamel epithelium. The cells of this cervical loop give rise to Hertwig's epithelial root sheath after the formation of the crown of the tooth.

Inner Enamel Epithelium and Life Cycle of Ameloblasts

The cells of the inner enamel epithelium, which differentiate into ameloblasts to form enamel, undergo changes in their shape and structure as discussed in the following paragraphs.

On the basis of function, the life cycle of the cells of the inner enamel epithelium can be divided into the following six stages. Differentiation of the cells of the inner enamel epithelium takes place earlier, in the region of the incisal edge/cuspal tip rather than in the cervical region. So, a single tooth germ shows inner enamel epithelial cells in different stages of their life cycle.

1. **Morphogenic stage:** In this stage, the cells of the inner enamel epithelium interact with the adjacent mesenchymal cells of the dental papilla and determine the shape of the DEJ and hence the morphology of the crown of the tooth. The cells are low columnar with a large centrally located nucleus (**Fig. 35.15**). Golgi apparatus and centrioles are seen in the proximal/basal end of the cells (facing stratum intermedium). Mitochondria and other cytoplasmic organelles are seen scattered throughout the cell. A basal lamina is present between the cells of the inner enamel epithelium and the underlying dental papilla. Towards the dental papilla, a narrow cell-free zone is seen containing fine fibres and cytoplasmic processes of the superficial cells of the dental papilla.
2. **Organizing stage:** The cells of the inner enamel epithelium interact with the adjacent superficial cells of the dental papilla which differentiate into odontoblasts. In this stage, the inner enamel epithelial cells elongate on the distal side (side facing dental papilla) and their nuclei shift proximally (i.e. towards the stratum intermedium) (**Fig. 35.16**). The Golgi complex and centrioles migrate to the distal end. This is known as *reversal of polarity*. Most of the mitochondria cluster in the proximal part of the cell. The inner enamel epithelial cell becomes a polarized cell and it can no longer divide.

A junctional complex (terminal bar) develops in the proximal/basal side, between the adjacent inner enamel epithelial cells, bringing a close contact between the cells and helping them to maintain alignment. Because of the elongation of the inner enamel epithelial cells on the distal side, the cell-free zone between the inner enamel epithelium and the dental papilla disappears and the epithelial cells come in contact with the outermost connective tissue cells of dental papilla which differentiate into odontoblasts.

During the later part of the organizing stage, formation of dentin by the newly differentiated

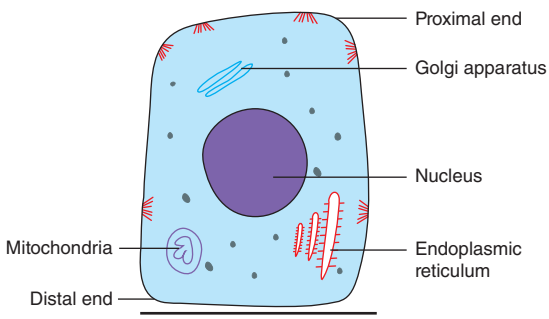


Figure 35.15 Inner enamel epithelial cell in the morphogenic stage.

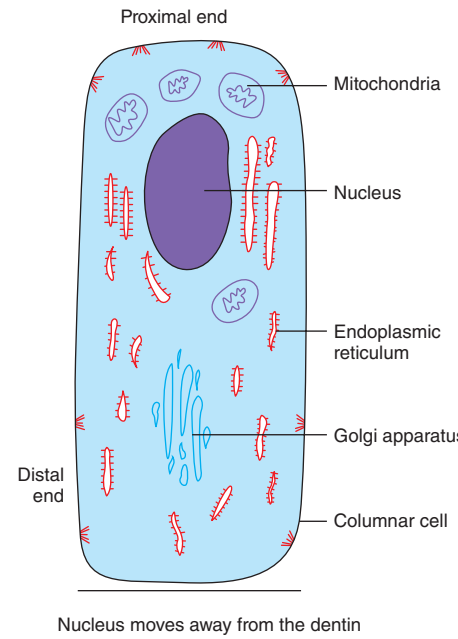


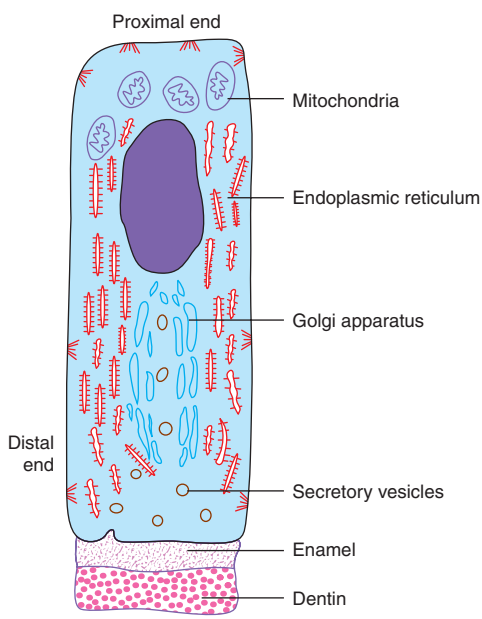
Figure 35.16 Inner enamel epithelium in the organizing stage.

odontoblasts begins, and this is the critical phase in the life cycle of the inner enamel epithelium. The inner enamel epithelial cells, which were receiving their nutrition from the blood vessels of the dental papilla so far, are deprived of it. They start depending on the capillaries of the dental sac surrounding the outer enamel epithelium for their nutrition, as mentioned earlier. This reversal of nutritional supply is facilitated by the proliferation of the capillaries of the dental sac (some may even penetrate the outer enamel epithelium) and by the disappearance of the stellate reticulum, which reduces the distance between the capillaries of the dental sac and the inner enamel epithelial cells.

3. **Formative stage/secretive stage:** The differentiated inner enamel epithelial cells (now called ameloblasts) (**Fig. 35.17**) begin the formation of the enamel matrix after the first layer of dentin is formed. The presence of dentin is necessary for the beginning of enamel matrix formation. This is similar to the necessity of the inner enamel epithelial cells coming in contact with the connective tissue cells of dental papilla for the differentiation of the odontoblast and the beginning of dentin formation. This reciprocal interaction and induction between groups of cells forms the basis of histodifferentiation (refer to Chapter 34).

   In the formative stage, the ameloblasts retain the same length, but there are changes in the organization and the number of cytoplasmic organelles which reflect their intense synthetic and secretory activity. A second junctional complex (terminal bar) develops at the distal side of the ameloblast, compartmentalizing the ameloblast into the body and a distal extension called *Tomes' process*, against which the enamel forms. The two junctional complexes—proximal (towards the stratum intermedium) and distal (towards the dentin)—encircle the ameloblast at their ends. They have actin-containing filaments extending into the cytoplasm of the cells, forming webs at both the ends. These junctional complexes serve to align the adjacent ameloblasts and play an important role in amelogenesis by tightly holding the ameloblasts together and controlling the passage of substances between the ameloblasts and the enamel. The processes involved in the formation of enamel matrix are discussed under the heading 'Amelogenesis'.

4. **Maturative stage**: After the formation of most of the enamel matrix, ameloblasts undergo morphological changes to prepare for their next function—the maturity of enamel. In this stage, the ameloblasts become shorter and are attached to the enamel matrix. Maturative stage occurs in two substages: transition and modulation.
   (a) *Transition stage*: This stage reflects the changes occurring in ameloblast after the formative change and before the onset of maturation. The shortened ameloblasts completely stop secretion. About 25% of the ameloblasts undergo apoptosis (programmed cell death), and the process of removal of enamel proteins begins.
   (b) *Modulation stage*: In this stage, the ameloblasts remove the organic material from the enamel and add more inorganic material. The ameloblasts cyclically alternate between having a ruffle end/border (**Fig. 35.18**) and a smooth end/border.



Secretory organelles appear at the end of the cell and become the site of secretion of enamel matrix

Figure 35.17 Ameloblast.

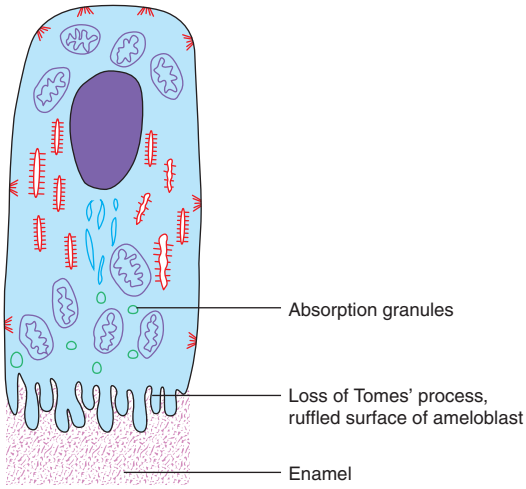


Figure 35.18 Ameloblast—modulation stage.

The ruffle-ended ameloblasts allow the incorporation of inorganic material while the smooth-ended ameloblasts allow the exit of protein (organic material) and water. The processes of mineralization and maturation are discussed in detail under the section 'Amelogenesis'.

5. **Protective stage**: After the enamel has completely calcified, the ameloblasts lose their columnar shape and become cuboidal. They become indistinguishable from the cells of the outer enamel epithelium (**Fig. 35.19**). These cell layers form the epithelial covering of the enamel called *reduced enamel epithelium*. The reduced enamel epithelium protects the surface of the mature enamel from the connective tissue of the follicle till the eruption of the tooth. Just before eruption, when the enamel organ retracts from the cervical portion of the crown, the adjacent connective tissue cells come in contact with enamel and deposit afibrillar cementum, as mentioned earlier.

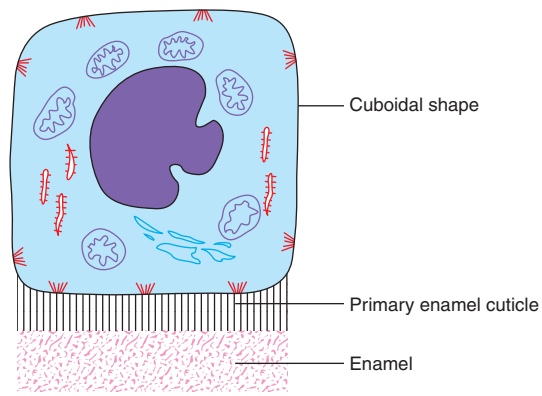


Figure 35.19 Ameloblast—protective stage.

Applied Histology

Anomalies such as resorption of enamel or a layer of cementum covering the enamel may occur if connective tissue comes in contact with enamel.

6. **Desmolytic stage:** The reduced enamel epithelium produces enzymes to destroy the overlying connective tissue by desmolysis. This brings about the fusion of reduced enamel epithelium with the oral epithelium and provides an epithelium-lined pathway for the tooth to erupt into the oral cavity without bleeding.

Applied Histology

If reduced enamel epithelium is destroyed prematurely, eruption of tooth is prevented.

AMELOGENESIS (DEVELOPMENT OF ENAMEL)

There are two major processes involved in the development of enamel: organic matrix formation and subsequent calcification (mineralization). Though the beginning of mineralization starts before the matrix formation is completed, these two processes are discussed separately.

Organic Matrix Formation

The structure of ameloblasts during matrix formation is already described under the formative stage in the life cycle of ameloblasts.

Development of the Tomes' Process

The Tomes' process is a small, pyramidal, cytoplasmic extension at the distal end of each ameloblast that is partly delineated from the rest of the cell by the distal junctional complex (distal terminal bar apparatus) (**Fig. 35.20**). It consists of secretory

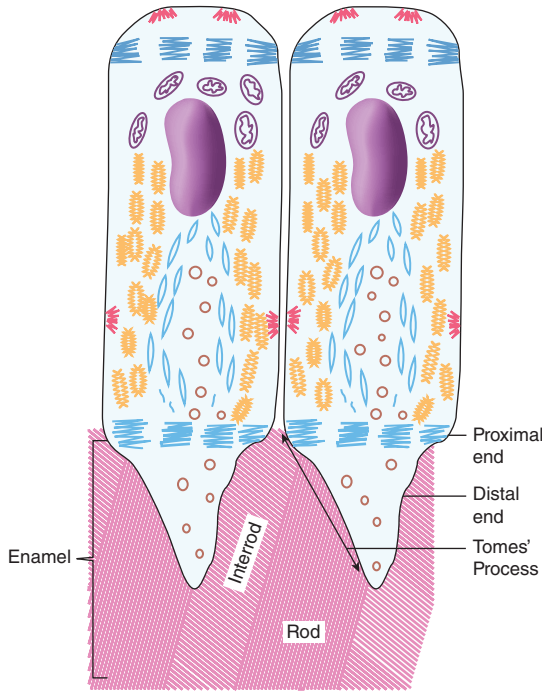


Figure 35.20 Ameloblasts showing the Tomes' process and the pattern of rod and inter-rod formation.

granules, microfilaments, microtubules, lysosomes and mitochondria. Enamel secretion occurs at two sites in the Tomes' process: the proximal end of the Tomes' process contributes to the formation of inter-rod enamel and its distal end contributes to the formation of the rod. When the first layer of enamel is laid, the Tomes' process consists only of the proximal portion and the initial enamel is rodless. As the first layer of enamel forms, ameloblasts move away from the surface of the dentin. This leads to the development of the distal portion of the Tomes' process. The extension from the distal terminal bar apparatus to the surface enamel is the proximal portion of the Tomes' process while the distal portion is an outgrowth of the proximal portion. The distal portion of the Tomes' process penetrates into the enamel formed so far and extends up to the first layer of enamel. (This is the portion of the Tomes' process embedded in the forming enamel.) The cytoplasm of the Tomes' process is continuous with that of the body of ameloblasts. The formation of the inter-rod substance occurs first by the proximal end of the Tomes' process. The inter-rod substance surrounds the pit into which the distal portion of the Tomes' process secretes the rod. As more of enamel is being formed, the distal portion of the Tomes' process lengthens, as do the enamel rods. The long axes of the ameloblasts lie at a considerable angle to the direction of rods.

When the surface of the developing enamel is visualized under a scanning electron microscope, it shows the presence of pits which represent the space occupied by the distal portion of the Tomes' process of ameloblasts. Though the rod and inter-rod enamel are identical in their composition, they differ in the orientation of their crystallites (**Fig. 35.21**). This arrangement means that no enamel rod is related to a single ameloblast. A roughly hexagonal ameloblast forming a keyhole-shaped enamel rod can be explained by the fact that the bulk of the head of the enamel rod is formed by one ameloblast and the tail of the rod is formed by three other ameloblasts. Thus, it could be understood that each enamel rod is formed by four ameloblasts and each ameloblast contributes to four different enamel rods. The shape of the distal end of the Tomes' process

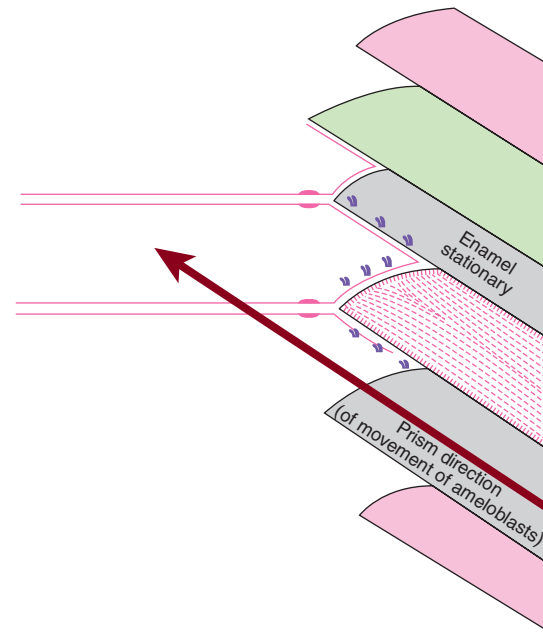


Figure 35.21 Relationship of crystal orientation and direction of ameloblast.

changes during the formation of the outer portion of enamel. The orientation of the distal end to the body of ameloblast becomes straight. Because of this alteration, the enamel rods in the outer third have a different profile. In the final phases of amelogenesis, the ameloblasts lose the distal portion of the Tomes' process and become shorter. The ameloblast at this stage appears the same as it did during the initial formation of the enamel. Enamel rods are absent in the first-formed or initial enamel as well as in the final increment of the enamel deposited. This is because the presence of the enamel rod depends on the distal portion of the Tomes' process. The distal portion of the Tomes' process is formed after the first enamel is laid and lost before the final increment of enamel is laid. So the enamel is composed of rods in the areas between the initial and the final thin rodless layers of enamel.

Mineralization and Maturation

When first laid down, the enamel matrix is completely organic and made up of proteins and water, but it very quickly begins to calcify. This requires the removal of the organic material and water from the enamel matrix and the introduction of the inorganic material. Calcification (mineralization) occurs in two stages: immediate partial mineralization and maturation.

Each increment of the organic matrix gets mineralized partially after deposition in the immediate partial mineralization stage. Calcium is deposited (seeded) in the form of apatite crystals, and this initial deposition accounts to 25% of the total mineral content. This is immediately followed by the second stage in which final mineralization (maturation) takes place. This involves growth of the apatite crystals deposited in the initial stage and requires bulk removal of the organic matrix (enamel proteins and water) to yield a final layer of enamel consisting of more than 95% minerals. Both these processes are under cellular control and are associated with morphological changes involving ameloblasts (described in the life cycle of ameloblasts under 'Maturative Stage'). During the transition stage, where the ameloblasts are shorter, the secretion of enamel matrix stops and the process of removal of enamel protein begins. Calcium crystals in the form of crystalline apatite are deposited against the mantle dentin. The first-formed crystals are ribbon shaped and have a thickness of 1.5 μm.

As the ameloblasts complete the transitional phase and go to the maturation phase, they secrete a basal lamina at their distal side (the side where the Tomes' process existed previously) and are attached to it by hemidesmosomes. The basal lamina at the other side adheres to the enamel surface. In addition to an adhesive role, the basal lamina helps regulate the movement of the material into and out of the enamel layer.

The maturation stage involving the growth of calcium apatite crystals is a slow process and takes more time than the secretory phase. During the phase of modulation, the ameloblasts show cyclic morphological changes between possessing a ruffle-ended border and a smooth-ended border (discussed under the life cycle of ameloblasts) (**Table 35.1**).

Ruffle-ended ameloblasts play an important role in incorporating minerals into maturing enamel as they allow calcium ions to pass through. Secretion of bicarbonates maintains alkalinity at the mineralizing front, aiding in the continuation of the mineralization process (acidification interferes with mineralization).

Organic components such as enamel proteins are acted upon by degrading enzymes extracellularly,

Table 35.1 Characteristics of Ruffle-Ended and Smooth-Ended Ameloblasts

Ruffle-Ended Ameloblasts	Smooth-Ended Ameloblasts
Leaky proximal and tight distal junctions	Tight proximal and leaky distal junctions involved in exchange of molecules
Numerous lysosomes exhibit considerable endocytosis	Little endocytic activity
Presence of organelles which promote pumping of calcium ions into maturing enamel	No calcium-pumping activity

which digest them into small polypeptide fragments. The leaky distal junctions of the smooth-ended ameloblasts allow the exit of these protein fragments and water. About 90% of the initially secreted enamel proteins are lost in this way and the remaining are seen around the individual apatite crystals and in the region of rod/prism sheath.

The maturation process begins from the height of the crown and progresses cervically, from the dentinal end towards the outer surface. Maturation and mineralization can be appreciated in the same tooth at different places, maturation occurring at the inner first-formed matrix and mineralization occurring at the outer recently formed matrix. Both the processes occur parallel to the DEJ initially and parallel to the outer enamel surface later. The incisal and occlusal regions reach maturity ahead of the cervical region by following the aforementioned pattern of mineralization and maturation.

Applied Histology

Enamel Hypoplasia

As ameloblasts are cells that are very sensitive to changes in their environment, any disturbances occurring during the development of enamel produce defects in the enamel of the erupted teeth which are visible clinically. The disturbances that occur during the period of enamel matrix formation result in enamel hypoplasia and the disturbances that occur during calcification/mineralization result in hypocalcification of enamel.

Enamel hypoplasia is manifested by pitting, furrowing or even total absence of enamel while hypocalcification of enamel is manifested in the form of an opaque/chalky area on a normally contoured enamel surface. The causes of enamel hypoplasia can be classified into systemic, local and genetic (hereditary).

Enamel hypoplasia of the systemic origin is called chronological hypoplasia. Enamel formation extends over a long period whereas the systemic disturbance is usually of a shorter duration. When a systemic disturbance occurs, the defects are seen in areas of those teeth where the enamel is being formed during that period. A narrow zone of hypoplasia in the enamel formed during the period of systemic disturbance represents chronological enamel hypoplasia. Exanthematous fever, hypoparathyroidism and rickets (vitamin D deficiency) are some of the most frequent causes of such hypoplasia.

The most likely causes of a single-tooth hypoplasia are local factors such as sepsis of the pulp, with subsequent periapical infection in the deciduous tooth. This affects the developing enamel of the underlying permanent tooth.

Amelogenesis imperfecta refers to the hereditary type of enamel hypoplasia which causes generalized disturbance of the ameloblasts. Unlike in the systemic cases, where only a zone of enamel in a group of teeth is affected, here the enamel of all the teeth (deciduous and permanent) are affected. The enamel is very thin or relatively absent.

A high fluoride content in the drinking water (more than 1 ppm) can cause hypocalcification of enamel called mottled enamel, which presents as unsightly white patches on the crown of the tooth. However, teeth with mottled enamel show increased resistance to caries.

Administration of antibiotics such as tetracycline during childhood can result in the incorporation of this drug into the forming enamel, resulting in a band of brown pigmentation or total discoloration of the affected teeth.

AGE CHANGES IN ENAMEL

With the advancement in age, the enamel undergoes wearing because of masticatory forces and this phenomenon is termed *attrition*. Further, the enamel becomes more resistant to decay with ageing which may be attributed to the increased thickness of dentin and changes in the composition. The permeability of enamel decreases with ageing.

ADDITIONAL READING

The enamel is a composite bioceramic composed largely of hydroxyapatite, carbonated hydroxyapatite (carbonate ion + hydroxyapatite) and very small amounts of protein remnants. It rarely undergoes catastrophic mechanical failure despite a lifetime of repeated masticatory parafunctional and occasional impact loading in a hostile wet environment. Mature enamel reflects certain unique molecular and cellular activities as a result

of its formation during development. The hardness of the enamel is intermediate between that of iron and carbon steel, and it displays very high elasticity for a material of such hardness.

Incremental Features of the Enamel

In addition to the lines of Retzius and cross-striations, intradian lines and laminations occur as a result of incremental deposition of enamel:

1. **Intradian lines:** They are thin bands that subdivide the daily lines, resulting from a 12-hour rhythm in enamel production. Intradian lines are generally difficult to resolve clearly, as they may be very closely spaced and require higher magnification.
2. **Laminations:** They are closely spaced bands that follow the course of the developing enamel front and show a daily periodicity. Laminations were observed to be most common in the enamel over dentin horn, along the DEJ in the cervical region and in the outer enamel in association with aprismatic enamel and Retzius lines. The development of laminations in specific regions may be related to aprismatic enamel production. Laminations result from the circadian rhythm manifesting across the entire enamel-forming front.

Molecular Mechanism of Enamel Formation

Regulated gene expression assembles an extracellular proteinaceous matrix to control biomineralization and the resultant biomechanical function of the tooth enamel.

Certain important determinants of enamel formation are as follows:

1. Enamel matrix proteins (amelogenin, ameloblastin and amelotin)
2. Dentin sialoprotein
3. Electrogenic sodium bicarbonate cotransporter (NBCe1)
4. Serine proteases (kallikrein-4 [Klk4] and enamelysin)

The *amelogenin gene* is a tooth-specific gene expressed in preameloblasts, ameloblasts and epithelial root sheath remnants. Human amelogenin is expressed by genes located in the X and Y chromosomes. It regulates the initiation and growth of hydroxyapatite crystals during the mineralization of enamel. In addition, amelogenins appear to aid in the development of cementum by directing cells that form cementum to the root surface of teeth. Mutations in the amelogenin gene (*AMELX*) cause amelogenesis imperfecta.

Ameloblastin (also called sheathlin or amelin) has been suggested to play a role in crystal growth. The suggested function of ameloblastin was based on its location relative to the Tomes' process, the secretory end of the ameloblast and the site of crystal growth initiation. It has been shown that the overexpression of ameloblastin in mice significantly alters the enamel crystal habit and enamel rod morphology in a fashion resembling amelogenesis imperfecta. Ameloblastin is a cell adhesion molecule that facilitates the attachment of ameloblasts to the enamel matrix. This factor may be essential for the maintenance of the ameloblasts in their differentiated state, which is ultimately required for proper enamel deposition.

Amelotin (AMTN) is a recently identified enamel matrix protein with an expression apparently limited to late-stage enamel formation. The outer layer of the last-formed enamel is believed to be softer than the bulk enamel and lacks its regular organization. As amelotin expression is seen only in the late stage of amelogenesis, it is thought to play a role in producing the final thin layer of the softer outer surface enamel. It may play a function in diverse activities such as biomineralization, calcium transport, pH balance and/or cellular differentiation/dedifferentiation.

Dentin sialophosphoprotein (DSPP) is transiently expressed at an early stage in the secretory ameloblasts at the time of DEJ formation. DSPP has a role in producing specialized first-formed harder enamel adjacent to the DEJ. The expression of DSPP is short lived in ameloblasts but continues in odontoblasts until dentin formation is complete.

After the formation of a competent proteinaceous scaffold to guide mineralization, the ameloblasts secrete the mineral component of enamel in an environment conducive to crystallite precipitation. *Electrogenic sodium bicarbonate cotransporters* (NBCe1) in ameloblasts help maintain the

pH buffering system required during the mineralization of hydroxyapatite.

Mature functional enamel contains very minimal amounts of protein. These minimal remnants may act as plasticizing agents, allowing some slippage of enamel rods over one another to relieve stress and provide some toughening. However, almost all of the enamel scaffold must be removed before mineralization can be completed. Amelogenin, the dominant enamel protein, is a known substrate of *kallikrein-4* (Klk4), the proteolytic enzyme. Kallikrein-4 is a secreted serine protease found primarily in prostate and enamel. Amelogenin is secreted by ameloblasts through early and mid-enamel formation. In contrast, Klk4 is normally secreted from these same ameloblasts later in enamel formation. Overexpression of Klk4 in a spatiotemporal pattern simultaneous to endogenous amelogenin expression has been found to display soft hypomineralized enamel.

Mineralization

Mineralization in the initial stages (secretory stage) of enamel formation appears as long, thin ribbons which are formed almost immediately when the ameloblast lays down enamel matrix proteins.

Although these mineral ribbons are extremely long (>100 m) and may extend to the full thickness of the enamel layer, they are only a few unit cells thick (i.e. in the order of 10 nm). The initial mineral phase consists of hydroxyapatite (HA) or octacalcium phosphate (OCP). The mineral phase of secretory enamel is approximately 10–20% by volume, with the remaining portion occupied by matrix protein and water. These ribbon-like crystals are organized in parallel arrays that ultimately dictate the highly ordered arrangement of bundles of enamel crystals (i.e. enamel rods) found in mature enamel. The enamel proteins ensure proper alignment of successive mineral increments on the tips of enamel ribbons deposited in the previous cycle, causing the crystallites to lengthen with each secretory cycle.

During the maturation stage, there is almost complete removal of enamel proteins by resident proteases. The mineral ribbons grow rapidly in thickness and width as mineral deposition occurs onto the sides of the existing crystallites.

In Vitro Enamel

Enamel: A Bionanocomposite

Enamel is a bionanocomposite as it has a hierarchical organization at the nano to macromolecular scales. Proteins interact to form a matrix that guides the individual crystallites to produce long, thin crystallites. They are mechanically superior to other simple mineral structures. Fabricating structures similar to dental enamel through the in vitro preparation method is of great interest in the fields of dentistry and material sciences. To prepare a material mimicking such composition requires a novel approach of simultaneous assembly of amelogenin and calcium phosphate precipitates. It is achieved by the process of electrolytic deposition. It was found that recombinant full-length amelogenin self-assembled into nanochain structures during electrolytic deposition and had significant effect on the induction of parallel bundles of calcium phosphate nanocrystals grown on semiconductive silicon wafer surface. The formation of organized bundles in amelogenin–apatite composites is mainly driven by amelogenin nanochain assembly and highlights the potential of such composites for future application as dental restorative materials.

Abiotic Tooth Enamel

The tooth enamel structure consists of microscale and nanoscale ceramic columns or prisms which are parallely arranged amidst a soft protein matrix. The core structural motif is almost the same and is consistent across all species from early geological eras. Mimicking enamel ex vivo involves formation of enamel-inspired columnar nanocomposites which are constructed through layer-by-layer deposition of zinc oxide nanowire carpets in a polymeric matrix. The nanocomposites were found to have similar mechanical properties, including hardness, to those of enamel despite the nanocomposites having a smaller hard-phase content. The viscoelastic figures of merit (VFOM) and weight-adjusted VFOM abiotic enamels were similar to, or higher than, natural tooth enamels. VFOM values describe resistance to vibrational damage and help in designing light-weight materials of unusually high resistance to structural damage from shocks, environmental vibrations

and oscillatory stress. Combinations of high stiffness, damping and light weight were achievable due to efficient energy dissipation in the interfacial portion of the organic phase. Materials with columnar composites could be used for development of high-performance load-bearing materials (excerpts from Yeom et al. 2017).

Ameloblast Modulation and Transport

Cyclic transformation of ruffle-ended (RE) ameloblasts facing slightly acidic enamel into smooth-ended (SE) ameloblasts near pH-neutral enamel involves a process called modulation (or pH cycling). Regulation of pH is critical for modulation and for completion of enamel mineralization. This happens due to transmembrane molecules that ameloblasts express to transport calcium to form crystals and bicarbonates. The types of transporter involved varies with the developmental stage. pH cycling occurs due to the compositional and/or physicochemical changes of the fluid present in enamel where increased acidity may turn RE ameloblasts into the SE mode. The intercrystalline space is kept open for diffusion of mineral ions into complete depth of enamel by amelogenins. This is executed by delaying the outgrowth of crystals. Stage-wise removal of amelogenins from the crystal surface, their degradation and removal from the enamel is an important function of modulation. Degradation of the matrix also slows down the expansion of crystals (excerpts from Bronckers et al. 2015).

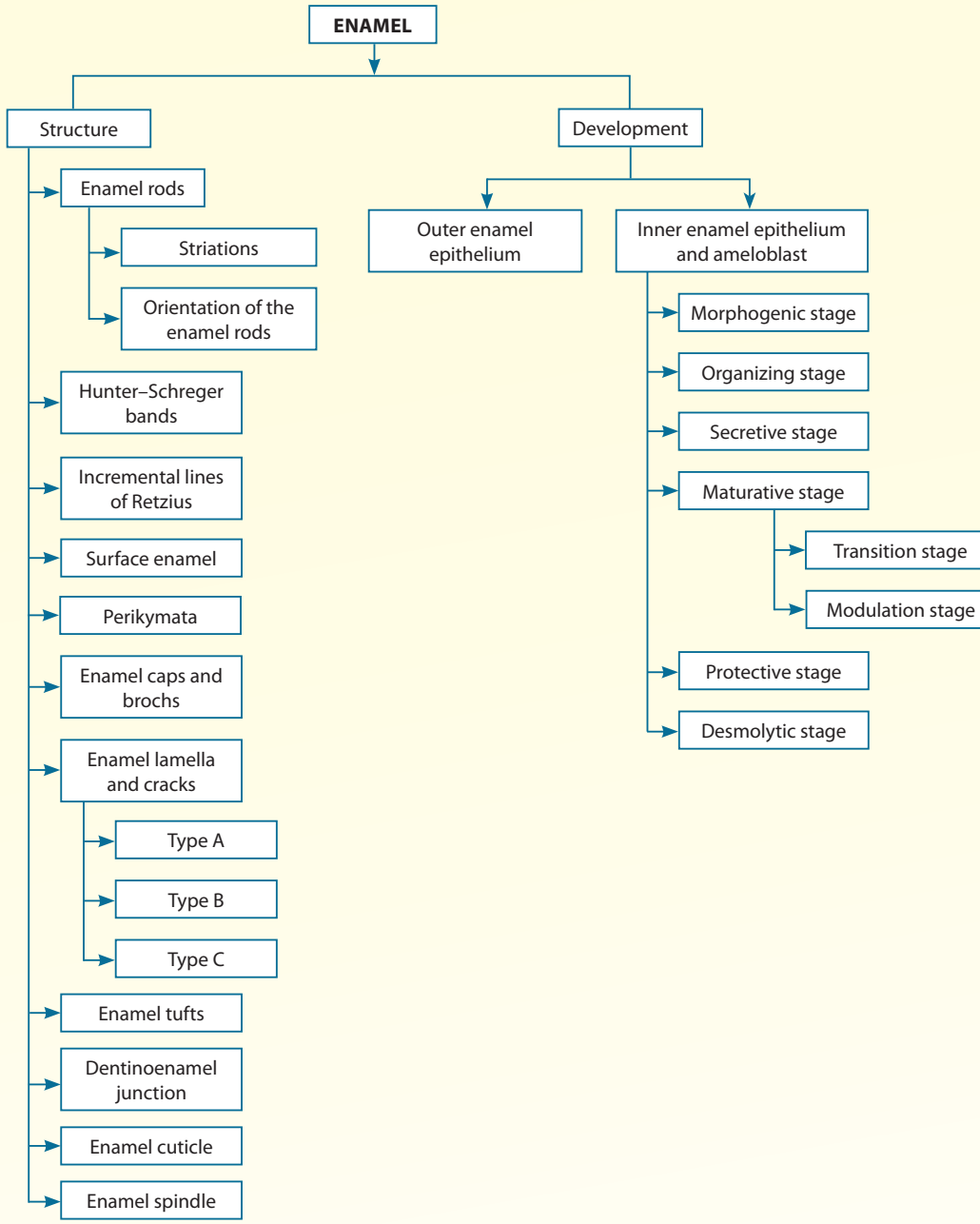
Enamel Matrix Derivative

Enamel matrix derivative (EMD) has been proven to have an inductive role. It has been widely researched and is extracted enamel matrix from a porcine tooth. EMD is used for regenerating periodontal tissue. Adjunctive application of EMD regenerates about 1 mm more tissue than surgical treatment alone. The clinical outcomes are similar to guided tissue regeneration; however, it is simpler to use and presents with less complications..

Key Points

1. Enamel is the hardest calcified structure in the human body and is derived from ectoderm.
2. The formative cells of enamel are ameloblasts.
3. Enamel is made up of 96% inorganic material and 4% organic matter.
4. The enamel rod is keyhole shaped with an average diameter of 4–5 μm.
5. Hunter–Schreger bands are alternating light (dia zones) and dark bands (para zones) of varying width. They are the result of an optical phenomenon seen when the longitudinal ground sections of enamel are viewed under oblique reflected light.
6. Incremental lines of Retzius result due to the rhythmic formation of enamel, with alternating forming and resting periods.
7. External or surface manifestations of incremental lines of Retzius are called perikymata or imbrication lines of Pickerill.
8. Enamel brochs and caps are surface elevations seen under the electron microscope.
9. The life cycle of ameloblasts consists of six stages: morphogenic, organizing, formative, maturative, protective and desmolytic.
10. The dentinoenamel junction (DEJ) is scalloped, and the convexities of the scallops are directed towards the dentin. The shape of the DEJ is determined at the morphogenic stage.
11. Reversal of polarity is seen in the organizing stage.
12. The inner enamel epithelial cells differentiate into ameloblasts during the formative stage.
13. Tomes' process is a small, pyramidal cytoplasmic extension at the distal end of each ameloblast. It is partly delineated from the rest of the cell by the distal junctional complex (distal terminal bar apparatus).
14. Mineralization of the enamel begins at the maturative stage.

Mind Map


ENAMEL
Structure
Development
Enamel rods
Striations
Orientation of the enamel rods
Hunter–Schreger bands
Incremental lines of Retzius
Surface enamel
Perikymata
Enamel caps and brochs
Enamel lamella and cracks
Type A
Type B
Type C
Enamel tufts
Dentinoenamel junction
Enamel cuticle
Enamel spindle
Outer enamel epithelium
Inner enamel epithelium and ameloblast
Morphogenic stage
Organizing stage
Secretive stage
Maturative stage
Transition stage
Modulation stage
Protective stage
Desmolytic stage

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Multiple Choice Questions

1. The hardest calcified tissue in human body is
   (a) Bone
   (b) Cementum
   (c) Enamel
   (d) Dentin
2. The thickness of enamel is
   (a) Greatest at the buccal surface
   (b) Greatest at the lingual surface
   (c) Greatest at the cusp tip
   (d) Uniform
3. The maximum thickness of the enamel at the cusp of molars and premolars is
   (a) 1–1.5 mm
   (b) 2–2.5 mm
   (c) 3 mm
   (d) 3.5 mm
4. The inorganic content in enamel is
   (a) 90%
   (b) 96%
   (c) 95%
   (d) 92%
5. The diameter of enamel rods averages at
   (a) 2 μm
   (b) 3 μm
   (c) 4 μm
   (d) 6 μm

6. The direction of enamel rods in a permanent tooth is
   (a) Vertical at the cusp tip
   (b) Tangential to the outer enamel surface
   (c) Horizontal in the cervical region
   (d) All of the above
7. Gnarled enamel is
   (a) Enamel formed due to deficiency
   (b) Optical appearance of enamel due to its wavy course
   (c) Enamel present at the furcation of teeth
   (d) None of the above
8. The alternate dark and light strips of varying width seen in the longitudinal ground section under reflected light are
   (a) Dental bands
   (b) Perikymata
   (c) Incremental lines
   (d) Hunter–Schreger bands
9. External manifestation of striae of Retzius are
   (a) Enamel cracks
   (b) Rods
   (c) Perikymata
   (d) None of the above
10. The direction of the enamel rods at the cervical region is
    (a) Horizontal
    (b) Vertical
    (c) Oblique
    (d) None of the above
11. The _____ extends over the full thickness of enamel from DEJ
    (a) Enamel lamella
    (b) Enamel spindles
    (c) Enamel tufts
    (d) None of the above
12. The dentinoenamel junction is a
    (a) Straight line
    (b) Scalloped line with convexities towards dentin
    (c) Scalloped line with concavities towards dentin
    (d) None of the above
13. Odontoblastic processes which pass into the enamel through the dentinoenamel junction are called
    (a) Enamel tufts
    (b) Perikymata
    (c) Enamel spindles
    (d) Enamel extensions
14. All are hypomineralized except
    (a) Enamel spindles and tufts
    (b) Enamel lamellae and tufts
    (c) Enamel prism and surface layer
    (d) Neonatal line of Retzius
15. Which is true about enamel prisms?
    (a) They are arranged perpendicular to the enamel surface
    (b) They show a keyhole pattern on cross-section
    (c) They are apatite crystals arranged parallel to the long axis of the body
    (d) All of the above

CHAPTER 36



Dentin

Overview

Dentin is the mineralized connective tissue that forms the bulk of the tooth. It is covered by enamel in the crown portion and by cementum in the root portion. Dentin is secreted by odontoblasts, the cells differentiated from the undifferentiated mesenchymal cells of dental papilla. Organic matrix is laid down initially which is mineralized subsequently forming the dentin. The newly laid yet to mineralize organic dentin matrix is known as predentin. The odontoblasts demonstrate a long cytoplasmic process called the odontoblastic process. This process traverses the entire thickness of dentin inside a tubular structure known as the dentinal tubule. The dentin that is present immediately next to the tubules is called peritubular dentin while the dentin between the tubules is called intertubular dentin. The dentin deposited before root completion is called primary dentin while the dentin deposited after root completion is called secondary dentin. Dentin is innervated by nerve endings which are responsible for dentin sensitivity and pain.

INTRODUCTION

Dentin is the mineralized tissue that forms the bulk of a tooth. It is present in the crown and in the root portions of the tooth. It is covered by enamel in the crown portion and cementum in the root portion. It is made up of a mineralized collagen matrix consisting of closely packed dentinal tubules which extend the entire thickness of the dentin. The tubules contain the long cytoplasmic processes of the cells which are responsible for forming dentin, odontoblasts and a small amount of dentinal fluid. The cell bodies of the odontoblasts line the innermost portion of the dentin defining its junction with the pulp.

PHYSICAL PROPERTIES

1. Dentin, which is pale yellow, contributes to the colour of the crown of the tooth because light readily passes through the thin, translucent enamel.
2. Dentin is harder than bone and cementum but softer than enamel. The hardness of dentin varies slightly depending on its location in the tooth and between different teeth. The dentin in the central part of the tooth is harder than that in the periphery; the dentin of permanent teeth is slightly harder than that of deciduous teeth.
3. Even though dentin is rigid, it is elastic in nature, which permits slight deformation. This property of flexibility of dentin is important for the proper functioning of teeth. Since enamel is hard and unyielding, it may fracture during mastication if the underlying dentin is not elastic in nature.
4. The tubular structure of dentin makes it permeable; this permeability, however, decreases with increasing age.
5. Dentin differs from enamel in that it is sensitive and forms throughout life at the expense of the pulp. Dentin has a higher compressive strength than enamel while the tensile strength of enamel is more than that of dentin.
6. Dentin is more radiolucent than enamel because of its reduced mineral content.
7. Even though dentin closely resembles the bone physically and chemically, a morphological difference exists between the two. Bone-forming cells (osteoblasts) may become

enclosed within the matrix to form osteocytes. But the bodies of the cells that form dentin (odontoblasts) remain external to the dentin matrix and only their processes are enclosed inside the dentinal tubules.

CHEMICAL PROPERTIES

Dentin is made up of approximately 70% inorganic material, 20% organic material and 10% water by weight and 50% inorganic material, 30% organic material and 20% water by volume. The inorganic portion is in the form of calcium hydroxyapatite crystals made up of several thousand unit cells with each unit cell having the formula $3Ca_3(PO_4)_2 \cdot Ca(OH)_2$. Though the crystals are similar in shape to those of enamel, they are smaller in size, rich in carbonate and poor in calcium when compared with those in enamel. The crystals are embedded in the organic matrix.

The organic matrix is made up of collagen fibres in an amorphous ground substance consisting of mucopolysaccharides (proteoglycans and glycosaminoglycans). The collagen fibres, constituting 90% of the organic matrix, are mainly made up of type I collagen. The ground substance is made up of the non-collagenous matrix proteins listed in **Table 36.1**.

Table 36.1 Components of the Ground Substance of Dentin

Dentin phosphoproteins	Dentin phosphoproteins, γ-carboxyglutamate–containing proteins (Gla proteins)
Glycoproteins	Dentin sialoprotein
Proteoglycans	Chondroitin sulphate, decorin
Growth factors	Insulin growth factor 2 (IGF-2) Transforming growth factor β (TGF-β) Bone morphogenetic protein 2 (BMP-2)
Lipids	Phospholipids
Acidic proteins	Osteonectin, osteopontin

The components of the organic matrix play an important role in regulating the mineralization of dentin.

HISTOLOGY OF DENTIN

Dentinal Tubules

Odontoblasts form the dentin matrix and move towards the pulp. Each odontoblast gives rise to one process that traverses the entire thickness of dentin inside a tubular structure known as the *dentinal tubule*. These appear circular in transverse sections. The dentinal tubules account for the permeability of dentin.

The dentinal tubules start at right angles to the surface of the pulp. They follow a gentle S-shaped (sigmoid) curvature from the pulpal surface, with the convexity directed towards the root (*primary curvatures*), and end perpendicular to the dentinoenamel junction in the crown and to the dentinocemental junction in the root (**Fig. 36.1**). The primary curvatures are less pronounced in the root. The tubules run a straighter course in the root tip, incisal edges and beneath the cusps. The curvature of the dentinal tubules is said to occur because of the movement of the odontoblasts with dentin deposition. During the development of the tooth, the follicle enlarges during crown formation which demands the pulp and the odontoblasts to retreat more within the tooth leading to pronounced curvature of the tubules in the bulk of the crown. On the contrary, the follicle elongates more during root formation minimizing the distance required by the odontoblasts to retreat

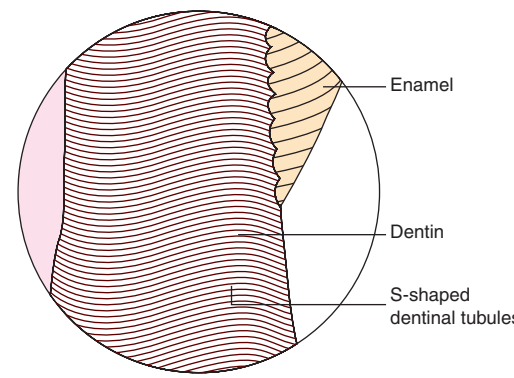


Figure 36.1 Shape of dentinal tubules.

leading to almost straight dentinal tubules in the apical end of the tooth. Minute secondary curvatures are exhibited along the entire length of the tubules. The secondary curvatures are said to be seen because of the undulations of the odontoblastic process per se. The length of the tubule is greater than the thickness of dentin due to these curvatures. The thickness of dentin ranges from 3 to 10 mm and varies from surface to surface in a tooth, with the buccal and lingual surfaces being thicker than the mesial and distal surfaces. The ratio of the outer surface (towards the dentinoenamel and dentinocemental junction) to the inner surface (pulpal surface) of dentin is about 5:1. Hence, the tubules are closely packed towards the pulp and widely separated near the dentinoenamel and dentinocemental junction. The number of dentinal tubules per unit area varies depending on the location within the tooth, ranging from 25,000–30,000/mm^2 in the periphery to 50,000–60,000/mm^2 in the pulpal surface. They are tapered structures measuring 2.5 μm in diameter in their pulpal end and 1 μm in the periphery.

Applied Histology

Dentinal tubules' distribution towards pulpal surface and its clinical implications: On cutting into dentin during various dental procedures, deeper cuts expose more dentinal tubules owing to the increase in the number and size of dentinal tubules towards the pulp.

Generally, the crown has more tubules per unit area than the root.

Dentinal tubules show branching both in their terminal portion and along their length (**Fig. 36.2**). These branches are more in the root dentin than in the coronal dentin. The branches seen in the terminal portion are called *terminal branches*. These probably represent the numerous processes the odontoblasts had in the earlier stage of dentinal matrix formation. Some of the terminal branches that extend through the dentinoenamel junction into the enamel are called enamel spindles. The branches seen on the lateral aspect along the length of the tubules are 1 μm in diameter and originate at right angles to the main tubule. These are called *lateral branches* or *canaliculi* or *microtubules*. While some of them end in the intertubular dentin (portion between dentinal tubules), others enter the adjacent tubules.

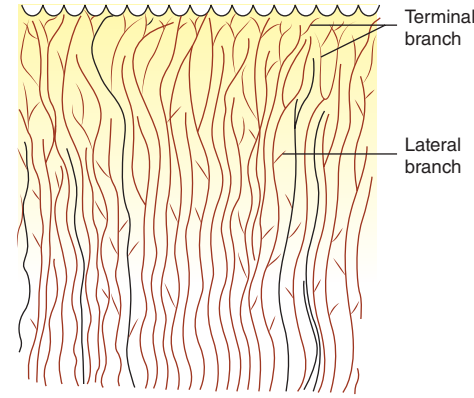


Figure 36.2 Lateral and terminal branches of dentinal tubules.

Applied Histology

Dentinal tubules as a pathway for pulpal irritants: The tubular structure of dentin may allow substances placed on the outer surface of dentin to pass through them and reach the pulp. The effect on the pulp may depend on the nature of these substances. Bacteria of dental caries, toxins produced by bacteria, etchants used for placement of restoration and components of dental restorative materials are some of the substances that pass through dentinal tubules and produce their effect in the pulp. However, occlusion of dentinal tubules by deposition of per tubular dentin or calcium or formation of tertiary dentin may prevent these substances from reaching the pulp.

Predentin

Predentin is the newly laid, yet-to-be mineralized dentin matrix. It is the innermost layer of dentin, close to the pulp. The width of this layer varies from 6 to 10 μm, but this depends on the rate at which dentin is deposited. When demineralized sections are stained with haematoxylin and eosin, the predentin takes up a pale stain when compared with mineralized dentin. This is attributed to the difference in the composition of its matrix. When the matrix of predentin starts undergoing mineralization, it becomes a part of mineralized dentin and new predentin forms pulpally.

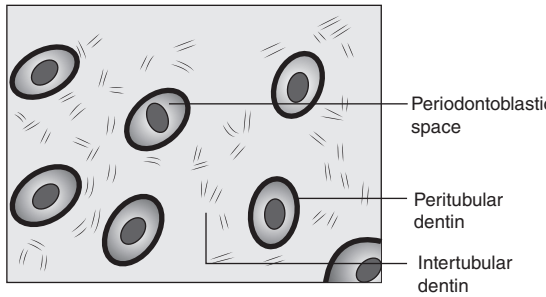


Figure 36.3 Cross-section of dentinal tubules

Peritubular Dentin

The dentin that is present immediately next to the dentinal tubules is the peritubular dentin (**Fig. 36.3**). It is seen in almost the entire dentin except in that portion of dentin close to the pulp. Peritubular dentin differs from intertubular dentin in that it is 5–12% more mineralized and lacks a collagenous fibrous matrix. The minerals are deposited in the inner wall of the tubule for the formation of peritubular dentin. So, it is referred to as *intratubular dentin* as well.

The thickness of peritubular dentin is twice (0.75 μm) more in the outer dentin near the periphery than in the inner dentin close to the pulp (0.4 μm). The growth of the highly mineralized peritubular dentin narrows the lumen of the tubules to about 1 μm in diameter in the region of the dentinoenamel junction. This narrowing can be appreciated while viewing the demineralized dentin with a light microscope. Because of the loss of peritubular dentin following demineralization, the diameter of the tubule appears similar in both the outer and the inner dentin.

The main protein of the peritubular dentin has a high molecular weight and a different amino acid composition when compared to the protein found in the intertubular dentin. Similarly, the apatite crystals of the peritubular dentin are more compact and smaller than those of the intertubular dentin.

A thin organic membrane (lining) rich in glycosaminoglycans called the *lamina limitans* is seen on the inner aspect of the peritubular dentin.

The space between the odontoblastic process and the peritubular dentin is the *periodontoblastic space*. This space contains the dentinal fluid, the movement of which forms the basis of dentin sensitivity.

Intertubular Dentin

The dentin situated between the dentinal tubules is the intertubular dentin which forms the major bulk of dentin. It is made up of type I collagen fibrils of diameter 50–200 nm arranged approximately at right angles to the dentinal tubules. Hydroxyapatite crystals are deposited with their long axis oriented parallel to the collagen fibrils.

Odontoblastic Processes

Odontoblastic processes are the cytoplasmic extensions of the odontoblast which extend into the dentinal tubules (**Fig. 36.4**). The process has a diameter of 3–4 μm when it enters the dentinal tubule and tapers to about 1 μm as it extends further into the tubule.

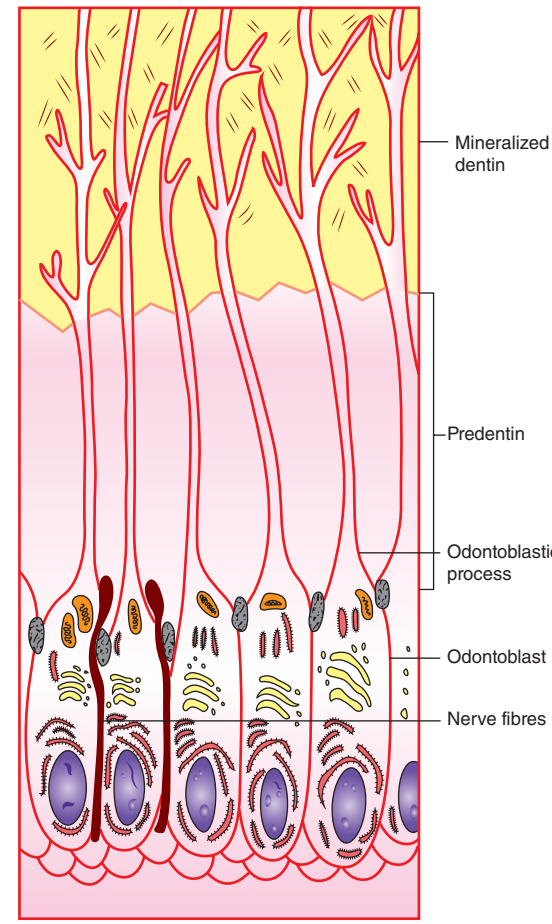


Figure 36.4 Odontoblastic process.

The structure of the odontoblastic process varies at different levels of dentin with more organelles present in the region of predentin than in the mineralized dentin. The process is composed of microtubules and intermediate filaments running longitudinally. These are made up of proteins such as actin, tubulin and vimentin. Mitochondria, vesicles, strands of rough endoplasmic reticulum and structures resembling lysosomes are also seen. Tubulin is an intercellular protein of microtubule identified by immunofluorescent studies.

The details of how far the odontoblastic process extends into the tubules is not known clearly. The presence of tubulin throughout the thickness of dentin implies that the odontoblastic process extends throughout the dentin. Some investigators feel that the organic lining of the peritubular dentin (lamina limitans) could have been mistaken for the process and that the odontoblastic process does not extend beyond the inner dentin.

Similar to the dentinal tubules, the odontoblastic processes also have terminal and lateral branches. Some of these lateral branches extend further into the adjacent tubules.

Primary Dentin

Mantle Dentin

Mantle dentin is the first-formed dentin in the crown. It is a 20 μm thick layer below the dentinoenamel junction (**Fig. 36.5**). It is composed mainly of type III collagen fibres which are argyrophilic (stain with silver) and are called Vankorff's fibres. It differs from the remaining portion of the primary dentin (circumpulpal dentin) in the following ways:

1. It is less mineralized.
2. It is composed of larger collagen fibres oriented perpendicular to the dentinoenamel junction.
3. It undergoes mineralization in the presence of matrix vesicles.
4. It shows branching of dentinal tubules.
5. It shows fewer defects than circumpulpal dentin.

These properties of mantle dentin prevent the cracks developing in the enamel near the dentinoenamel junction from spreading into dentin.

Circumpulpal Dentin

Circumpulpal dentin constitutes the remaining primary dentin. It is the bulk of the dentin formed before root completion. When compared with mantle dentin, the circumpulpal dentin is slightly more mineralized and has collagen fibres which are smaller and closely packed (**Figs 36.6** and **36.7**).

Incremental Lines

Odontoblasts deposit organic matrix of the primary dentin in daily increments of 4 μm. A minute change in the orientation of collagen fibres can

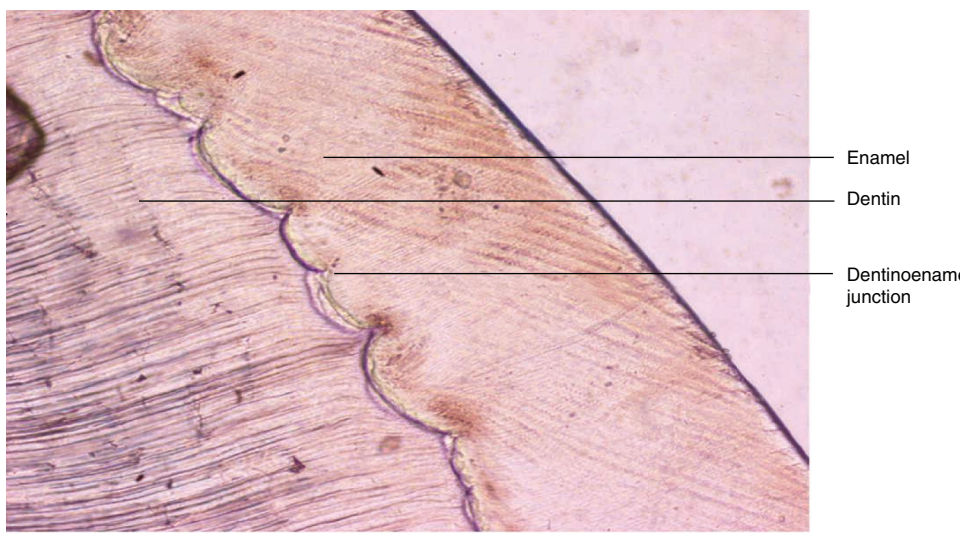


Figure 36.5 Dentinoenamel junction (ground section, 10X).

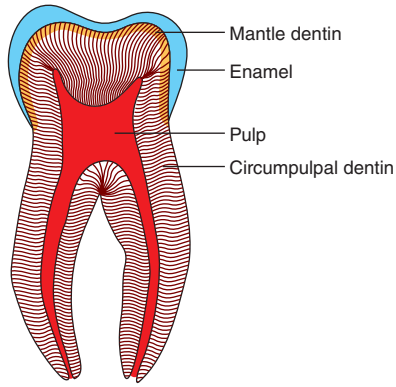


Figure 36.6 Mantle and circumpulpal dentin.

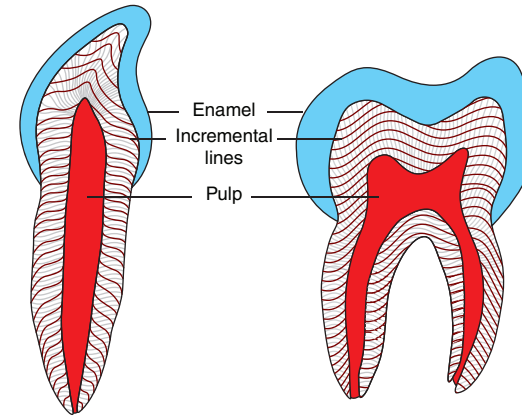


Figure 36.8 Incremental lines

be observed at the boundary between these daily increments. They appear as fine lines or striations in dentin known as *incremental lines of von Ebner* (**Fig. 36.8**). These lines reflect the normal, daily, rhythmic, linear pattern of deposition of dentin matrix. The incremental lines run at right angles to the dentinal tubules and the distance between these lines varies from 4 to 8 μm in the crown. It is lesser in root. The change in the orientation of the collagen fibres is more exaggerated at the end of the fifth-day increment. This leads to a belief that the incremental lines of von Ebner are 20 μm apart representing a 5-day interval in dentin formation.

Sometimes, disturbances during matrix formation or mineralization of dentin cause accentuation of these incremental lines; these are called *contour lines of Owen*. The longer the period of disturbance (illness or nutritional deficiency), the wider these lines appear.

The *neonatal line* is one such accentuated contour line reflecting the abrupt change in environment at birth, separating the prenatal and postnatal dentin. It is seen in deciduous teeth and the first permanent molars where dentin is formed partly before and partly after birth. Better quality of dentin matrix is seen in prenatal dentin.

Interglobular Dentin

During the mineralization of dentin matrix, the minerals are deposited as globules or calcospherites.

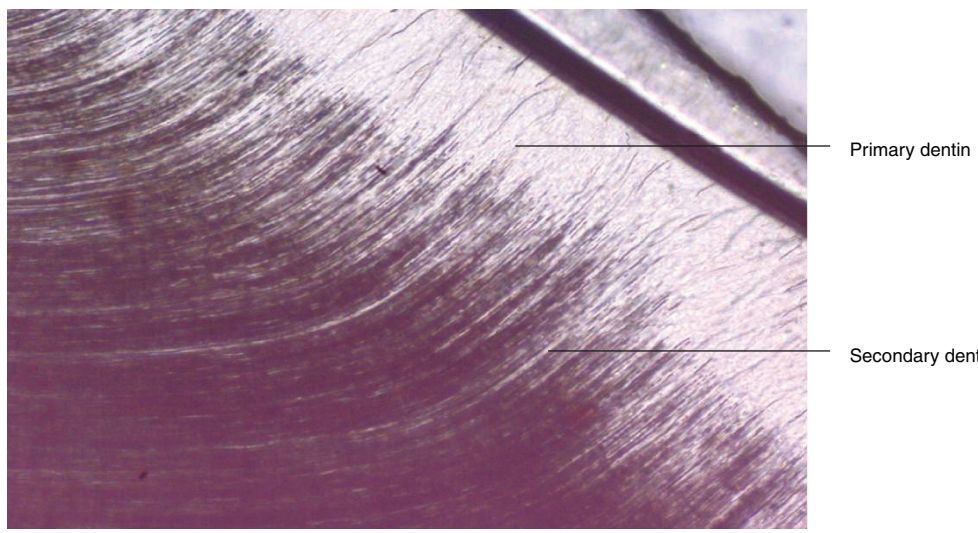


Figure 36.7 Primary and secondary dentin (ground section, 10X).

In most of the areas, these globules fuse to form a uniformly calcified tissue. When some of these globules fail to fuse into a homogenous mass, hypomineralized areas form. These areas are known as interglobular dentin (**Fig. 36.9**). Most often, it occurs in the crown in the circumpulpal dentin just below the mantle dentin, where the pattern of mineralization is mainly globular. Vitamin D deficiency or exposure to high levels of fluoride during dentin formation is thought to be responsible for the failure of fusion of the globules. In areas of interglobular dentin, the architectural pattern of the tubules does not change and the tubules pass through interglobular areas without deviation. This confirms that the formation of interglobular dentin is because of a defect in mineralization and not because of matrix formation. Peritubular dentin is absent in the tubules passing through interglobular dentin. When ground sections are viewed in transmitted light, interglobular areas appear dark.

Tomes' Granular Layer

A layer having a granular appearance is seen in the radicular dentin, just beneath the cementum. This layer is known as Tomes' granular layer (**Fig. 36.10**). There is a progressive increase in the granular area from the cementoenamel junction to the root apex. Though various explanations have been given for this granular appearance, the most widely accepted reason is that the dentinal tubules in this area branch more profusely leading to coalescing and looping of the terminal branches. The air spaces thus created appear dark and granular in ground sections because of internal reflection of transmitted light. This granular layer is hypomineralized when compared with circumpulpal dentin. The granular appearance is seen only in the root because coalescing and looping of the terminal branches of the dentinal tubules occur in the root and not in the crown.

Applied Histology

Dentin Loss and Exposure

Unlike enamel, dentin is living tissue and hence exposure or loss leads to sensitivity and pain followed by pulpal death. Dentin can be lost due to fracture of tooth, attrition, gingival recession or dental decay. Coronal dentin is exposed due to enamel attrition or trauma leading to fracture of tooth while root dentin is exposed with gingival recession as cementum is lost swiftly with exposure. Dental decay leads to demineralization and dissolution of dentin on progression.

Dehydration of dentin follows the death of pulp or root canal treatment. It weakens the tooth structure and may result in the fracture of the tooth. This underlines the importance of fixing of a crown on a root canal–treated tooth.

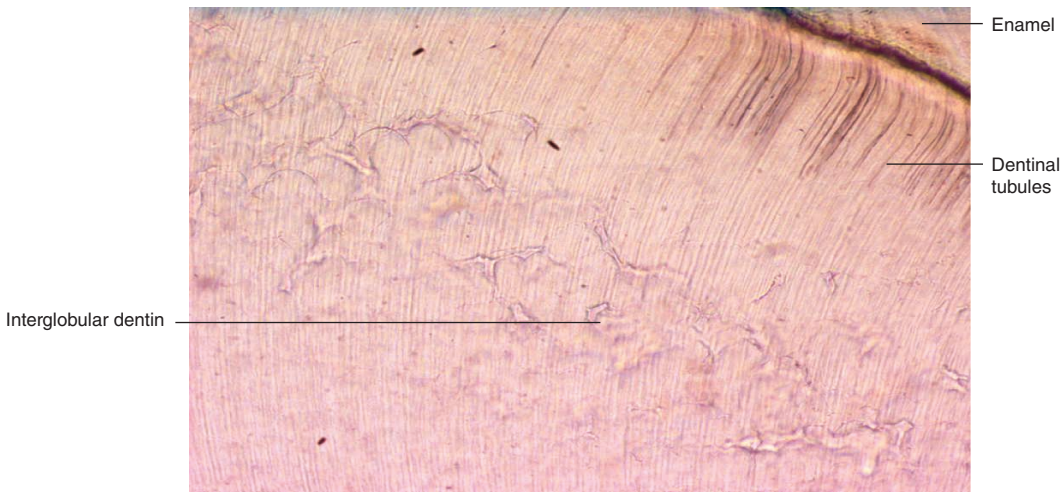


Figure 36.9 Interglobular dentin (ground section, 10X).

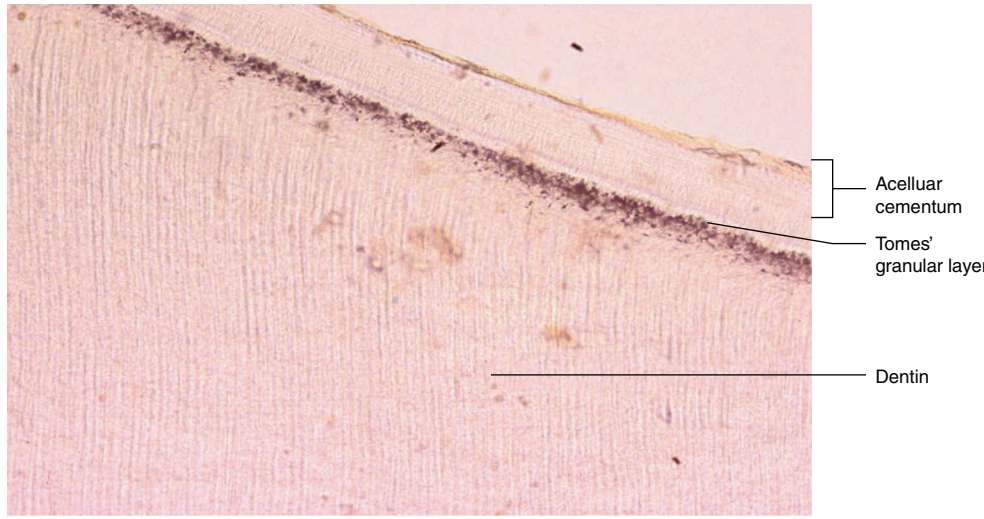


Figure 36.10 Tomes' granular layer (ground section, 10X).

AGE AND FUNCTIONAL CHANGES

Dentin undergoes changes throughout life even after the tooth is erupted and fully formed. These changes are either related to age or a response to a stimulus applied to the tooth. Secondary dentin and translucent dentin occur due to physiologic age changes. Tertiary dentin, sclerotic dentin and dead tracts occur as a result of responses to stimuli.

Secondary Dentin

The most important age-associated change in dentin is the formation of secondary dentin. This is the dentin formed after root completion. This narrow band of secondary dentin bordering the pulp is formed by continuous but slow deposition of dentin by the odontoblasts. Though the structure of secondary dentin is similar to that of primary dentin, it contains fewer tubules and is slightly less regular than primary dentin. There is usually a bend in the tubules at the junction of primary and secondary dentin. Secondary dentin is not deposited evenly around the periphery of the pulp. More deposition occurs near the roof and floor of the coronal pulp chamber leading to an asymmetrical reduction in the size and shape of the pulp. Continuous deposition of secondary dentin leads to a smaller pulp chamber and narrow root canal in older patients and protects the pulp from exposure (Fig. 36.7).

Applied Histology

Secondary Dentin and Change of Pulp Morphology

As age advances, deposition of secondary dentin occurs leading to reduction in the size of the pulp. Occasionally, the pulpal space might be completely obliterated also. This should be anticipated while treating the root canals of an older tooth.

Translucent Dentin

As a result of physiologic ageing, dentinal tubules become completely occluded with peritubular dentin, especially in the root. The contents of the occluded tubules have the same refractive index as that of the intertubular dentin. The occluded tubule appears translucent in a ground section. This is translucent dentin. The remaining portion of the tubules appears opaque. Translucent dentin formation starts at the root apex and proceeds cervically with age.

Applied Histology

Translucent Dentin—Application in Forensic Dentistry

The amount of translucent dentin increases linearly with age, and this aspect is used in forensic dentistry to estimate the age of teeth.

Tertiary Dentin

Tertiary dentin is the dentin formed in response to various stimuli such as attrition, caries or restorative dental procedure. It is also referred to as *reactionary dentin*, *reparative dentin* or *osteodentin*. The primary dentin and secondary dentin are formed along the entire pulpal surface of the dentin. But the appearance of tertiary dentin varies as it is formed only by cells directly affected by the stimulus and depends on the intensity and duration of the stimulus.

Reactionary Dentin

Reactionary dentin is formed by the existing odontoblasts which have survived severe damage caused to them by the insult/stimulus. This type of dentin has an irregular appearance with fewer tubules.

Reparative Dentin

Reparative dentin is formed by the newly differentiated odontoblast-like cells that replace the original odontoblasts that have been destroyed by insult/stimulus. The newly differentiated odontoblast-like cells are thought to arise from deeper regions of the pulp, either from the cell-rich zone or from the undifferentiated perivascular cells. The reparative dentin is irregular and has fewer and more twisted tubules. Normally, odontoblasts move away from the matrix they form (tubular dentin), but the newly differentiated odontoblast-like cells may get entrapped in the matrix they form to produce *osteodentin* (similar to bone). Sometimes, a combination of tubular dentin and osteodentin is formed (**Fig. 36.11**).

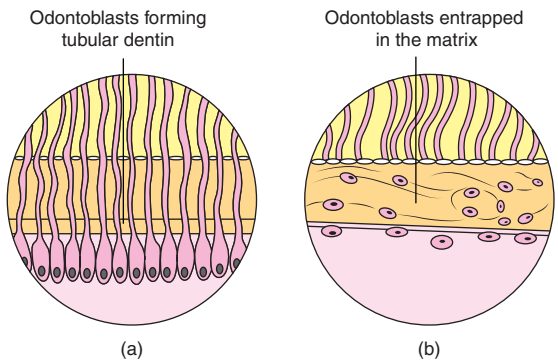


Figure 36.11 Reparative dentin formation: (a) tubular dentin and (b) osteodentin.

The differentiation of odontoblast-like cells from the pulp is thought to be a pulp response, which in turn occurs as a result of the migration of stimulants (bacteria, toxic products or chemical substances from restorative material) through the dentinal tubules into the pulp.

It was noted that, during normal tooth development, differentiation of odontoblast from the dental papilla took place under the influence of the inner enamel epithelial cells—epithelial–mesenchymal interaction. If so, how did the odontoblast-like cells arise from the pulp in the absence of an epithelial stimulus? It is thought that during initial dentin formation, the epithelial–mesenchymal interaction would have guided some cells on the path to become odontoblasts. These cells remain dormant in the pulp awaiting a stimulus. When stimulated as a result of a pulp response, they complete their life cycle, become functional odontoblasts and form reparative dentin. The other explanation given for the differentiation of odontoblast-like cells is that they arise from the stem cell population without any epithelial–mesenchymal interaction. Bioactive molecules, such as cytokines and growth factors, synthesized locally could play a role in the differentiation of odontoblast-like cells from the stem cells.

Sclerotic Dentin

Sclerotic dentin refers to the filling up of the dentinal tubules with calcified material in response to external stimuli such as slowly progressing caries, attrition or erosion. This is considered a defensive reaction because it reduces the permeability of dentin and keeps the pulp vital for a prolonged period. The initial sporadic laying down of apatite crystals later forms a fine meshwork, thereby obliterating the lumen of the tubule completely. When the lumen of the tubule is completely filled with mineral, the refractive indices are equalized and this area becomes transparent; it appears light in transmitted light and dark in reflected light.

The deposited mineral is different from that in peritubular dentin. Though the mineral concentration is higher, the size of the crystals in sclerotic dentin is smaller than that in normal dentin. Sclerotic dentin is harder and has reduced fracture toughness but same elastic properties as normal dentin.

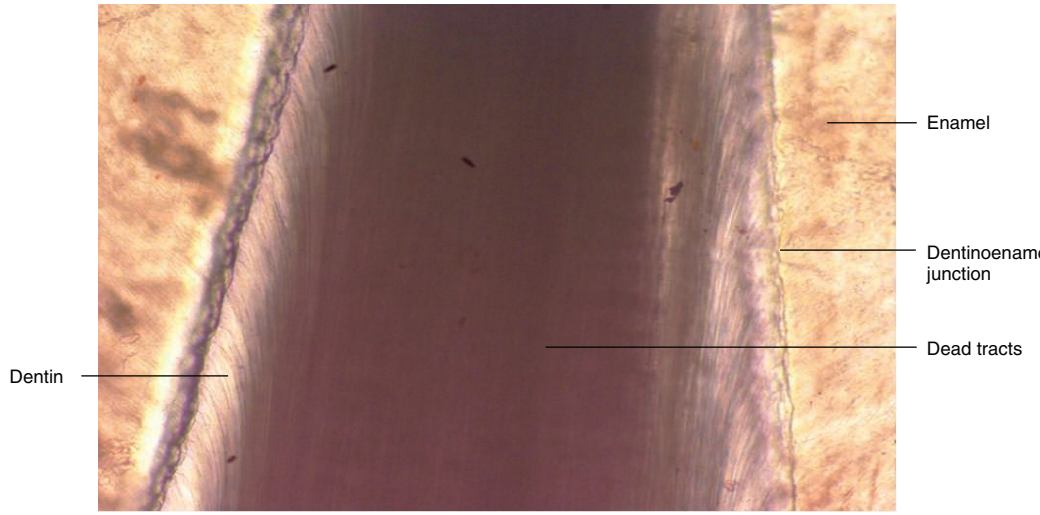


Figure 36.12 Dead tracts (ground section, 10X).

Dead Tracts

Dentinal tubules can become empty following the retraction of the odontoblastic process or death of odontoblast. Stimuli such as caries, attrition or erosion can result in emptied dentinal tubules, which are then sealed by reparative dentin at their pulpal ends. In ground sections, these empty, air-filled tubules appear dark in transmitted light and white in reflected light because of internal reflection (**Fig. 36.12**). This appearance is termed *dead tracts* and is more often seen in the region of narrow pulp horns in coronal dentin. Dead tracts are seen more commonly in older teeth and demonstrate reduced sensitivity.

Applied Histology

Sclerotic dentin and dead tracts association with progress of dental caries: Because of the obliteration of the tubules caused by sclerotic dentin formation, the caries process is confined from reaching pulp while dead tracts lead to enhanced progression of caries into the pulp.

INNERVATION OF DENTIN

Numerous nerve endings pass between the odontoblasts to enter the dentinal tubules in the predentin and the innermost circumpolar dentin. These are the terminal processes of the myelinated nerve fibres of the pulp from the subodontoblastic plexus. The nerve endings are mostly located in the coronal portion in relation to the pulp horns. They contain mitochondria and many small vesicular structures and are in close proximity to the odontoblastic process. The primary afferent somatosensory nerves of the dentin and pulp relay to the descending trigeminal nuclear complex present in the subnucleus caudalis.

DENTIN SENSITIVITY

Exposed dentin is very sensitive. Three main theories have been proposed to explain dentin sensitivity (**Fig. 36.13**):

1. Direct neural stimulation theory
2. Fluid or hydrodynamic theory
3. Transduction theory

Direct Neural Stimulation

This theory states that the nerve endings inside the dentinal tubules are directly stimulated and cause sensitivity/pain.

The arguments against this theory are as follows:

1. Even though nerve endings are seen inside the dentinal tubule, they are confined to the inner dentin and are absent in the outer dentin.

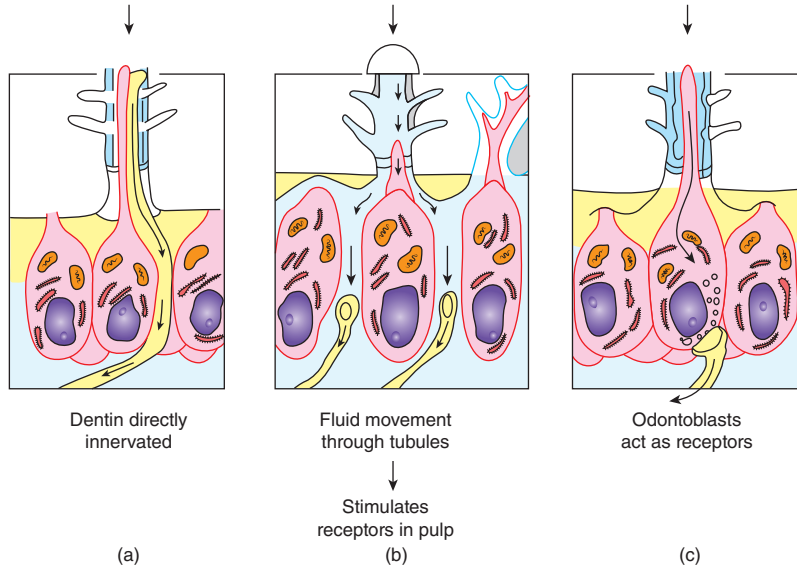


Figure 36.13 Theories of dentin sensitivity: (a) direct neural stimulation theory, (b) fluid or hydrodynamic theory and (c) transduction theory.

2. Topical application of the local anaesthetic to the surface of dentin does not eliminate dentin sensitivity.

Fluid Or Hydrodynamic Theory

This theory states that dentin sensitivity is due to the movement of fluid inside the dentinal tubules. Various stimuli such as heat, osmotic pressure and drying can cause outward movement of fluid, whereas cold stimulus causes inward movement of fluid. Movement in either direction causes mechanical disturbance of the nerve endings which are present in the inner dentin and are close to the odontoblasts and their process. The free nerve endings in the plexus of Raschkow sense these disturbances, resulting in sensitivity/pain. This widely accepted theory proposes that nerve endings act as mechanoreceptors.

Transduction Theory

This theory states that various stimuli stimulate the odontoblastic process which conducts the impulses to the nerve endings located in the inner dentin.

The arguments against this theory are as follows:

1. Neurotransmitter vesicles are absent in the odontoblastic process.
2. There is no synaptic relationship between the odontoblastic process and the nerve endings.

DENTINOGENESIS

Dentin formation begins when the tooth germ has reached the bell stage of development. Under the influence of the inner enamel epithelium, the outermost ectomesenchymal cells of the dental papilla differentiate into odontoblasts (**Fig. 36.14a**). Initially, the cells of the dental papilla are small, undifferentiated and have few organelles. These are separated from the inner enamel epithelium by an acellular zone. The expression of signalling molecules and growth factors in the cells of the inner enamel epithelium causes differentiation. Inner enamel epithelium releases transforming growth factor, insulin growth factor and bone morphogenetic protein to play an important role in the differentiation of odontoblasts. Fibronectin, decorin, laminin and chondroitin sulphate are essential for this differentiation. Differentiation begins adjacent to the deepest invagination of the enamel organ, the portion of the future cusp tip.

Later, the cells of dental papilla immediately adjoining the acellular zone enlarge to become preodontoblasts, which change their shape from ovoid to columnar and differentiate into odontoblasts (**Fig. 36.14b**). The nucleus is oriented towards the base (away from the inner enamel epithelium), and increased amounts of protein-synthesizing organelles appear in the cytoplasm.

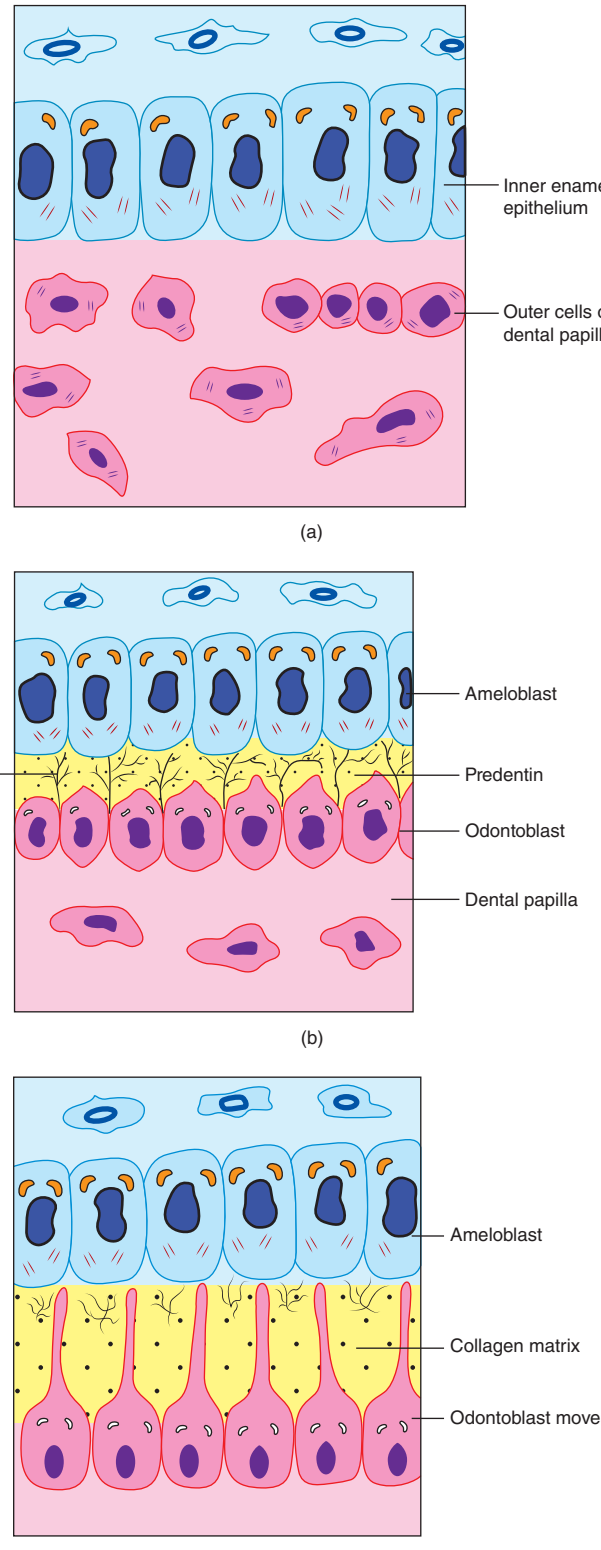


Figure 36.14 Dentinogenesis—predentin formation from the odontoblasts.

The acellular zone between the dental papilla and the inner enamel epithelium is narrowed down and finally eliminated as the odontoblasts increase in size (40 μm) and occupy this zone.

Dentin genesis occurs in a two-phase sequence. Collagen matrix is formed first and then calcified (**Fig. 36.14c**). Several processes arise from the apical end of the odontoblast. Collagen I and precursors of phosphorin are found in the endoplasmic reticulum, Golgi complex and secretory granules. These migrate into the processes and are emptied into the extracellular matrix. Matrix formation begins with the appearance of large diameter collagen fibrils (0.1–0.2 μm) known as *Vonkorff's fibres*. These fibres are laid down at right angles to the future dentinoenamel junction. They show a corkscrew appearance in sections stained with silver. Once the mantle dentin is laid, the remaining collagen fibres are laid parallel to the dentinoenamel junction. As the odontoblast forms the matrix and moves towards the pulp, several fibres join to form the processes that are embedded in the dentinal tubules. With the continuation of matrix formation, the length of the odontoblastic processes and the tubule increases. Dentin is formed at a rate of about 4 μm/day till the crown is formed and the tooth erupts. As each increment of the matrix is formed, it remains for a day before it is calcified and the next increment of the matrix forms. The rate of matrix formation is slower in the radicular dentin and it contains collagen fibres which are parallel to the cementodentinal junction.

Applied Histology

Dentin Matrix—Application in Forensic Dentistry

The amino acids present in the non-collagenous protein of dentin convert from one raceme form to another with advancing age, and measuring these changes is an accurate way of determining the age of human remains.

Mineralization

As the odontoblasts give off processes, they also bud off several membrane-bound vesicles called matrix vesicles, which are involved in the mineralization of the mantle dentin. These vesicles contain the enzyme alkaline phosphatase, which increases the concentration of phosphates. The phosphate combines with calcium (taken up from the tissue fluid) to form apatite. These apatite crystals grow and rupture from the confines of the vesicles to form a cluster of crystallites which fuses with the adjacent clusters to form a continuous layer of mineralized matrix.

Proteins such as dentin phosphoproteins (DPP) osteonectin, osteopontin Gla-containing proteins, chondroitin sulphate and phospholipids regulate deposition of minerals.

Initially, the apatite crystals are deposited on the surface of collagen fibrils and in the ground substance. Later, the crystals are laid down within the fibrils with their long axes parallel to the long axes of fibrils and in rows restricted to the 64-nm banding pattern of the collagen fibres.

Pattern of Mineralization

In dentin genesis, the continuous deposition of mineral occurs initially in the matrix vesicle (mantle dentin) and later at the mineralization front (circumpulpal dentin). Depending on the rate of dentin formation, there are two mineralization patterns: globular and linear.

Globular calcification occurs when the crystals are deposited in several discrete areas. Globular masses are formed as the crystals grow. They enlarge and fuse to form a single calcified mass. This type of globular calcification is seen in mantle dentin. The mineralization in circumpolar dentin is of either the globular pattern (if the rate of dentin deposition is fast) or the linear pattern (if the rate of dentin deposition is slow).

In addition to non-collagenous matrix, various genes—*MAP1B* (odontoblast differentiation) and *PHEX* (dentin mineralization)—are involved in dentin genesis.

CLINICAL CONSIDERATIONS

1. The tubular structure of dentin may allow substances placed on the outer surface of dentin to pass through it and reach the pulp. The effect on the pulp may depend on the nature

of these substances. Bacteria of dental caries, toxins produced by bacteria, etchants used for placement of restoration and components of dental restorative materials are some of the substances that pass through dentinal tubules and produce their effect in the pulp. However, occlusion of dentinal tubules by deposition of per tubular dentin or calcium or formation of tertiary dentin may prevent these substances from reaching the pulp.

2. Dehydration of dentin follows the death of pulp or root canal treatment. It weakens the tooth structure and may result in the fracture of tooth. This underlines the importance of fixing of a crown on a root canal–treated tooth.

ADDITIONAL READING

Induction and Regulation of Dentinogenesis

Close regulation of odontoblast differentiation and subsequent secretory activity is critical for dentinogenesis during both embryogenesis and tissue repair. Dental papilla cells achieve commitment and specific competence to respond to epithelially derived inductive signals during the process of odontoblast differentiation. Temporospatial regulation of odontoblast differentiation is dependent on matrix-mediated interactions involving the basement membrane (BM). Regulation of functional activity of odontoblasts allows ordered secretion of the primary dentin matrix and maintenance of vitality and downregulation of secretory activity throughout secondary dentinogenesis.

After injury to the mature tooth, the fate of the odontoblasts can vary according to the intensity of the injury. Mild injury can result in upregulation of functional activity leading to focal secretion of a reactionary dentin matrix while greater injury can lead to odontoblast cell death. Induction of differentiation of a new generation of odontoblast-like cells can lead to reparative dentinogenesis. Many similarities exist between development and repair, including matrix mediation of the cellular processes and the apparent involvement of growth factors as signalling molecules despite the absence of epithelium during repair. While some of the molecular mediators appear to be common to these processes, the close regulation of primary dentinogenesis may be less orderly during tertiary dentinogenic responses.

Molecules such as bone morphogenic proteins 2 and 4 (BMP), transforming growth factor (TGF), fibroblast growth factor, insulin growth factor (IGF) and follistatin help in signalling and odontoblast differentiation. IGF stimulates the cytological polarization of odontoblast-like cells, while BMPs allow for functional differentiation in restricted areas. TGF stimulates gradients of odontoblast-like functional differentiation.

Dentin Matrix Proteins and Dentinogenesis

Dentinogenesis consists of highly controlled events occurring at a short distance from the periphery of odontoblasts. It involves formation of extracellular collagen fibrils that act as a scaffold for deposition of plate-like carbonate apatite crystals. Odontoblasts also form a set of matrix proteins that are probably secreted at the mineralization front. Although most of the proteins are similar to those of bone, they differ from soft-tissue proteins. The mineral phase is essentially the same in these two tissues and primarily consists of a carbonated hydroxyapatite; the difference lies in the crystal size and shape. Three components are necessary for proper mineralization: proper synthesis and secretion of the non-collagenous proteins (NCPs), self-assembly of the collagenous matrix and delivery of calcium and phosphate ions to the extracellular matrix.

Three major NCPs present in the dentin matrix are as follows:

1. **Dentin matrix protein 1 (DMP1):** DMP1, an acidic protein, is present predominantly at the mineralization front and in the nucleus of undifferentiated preodontoblast cells.
2. **Dentin phosphophorin (DPP):** DPP, the major NCP, is present in large amounts at the mineralization front and regulates the size of the growing hydroxyapatite crystals. The localization of DPP in the nucleus of preodontoblast cells suggests a signalling function during the odontoblast differentiation process.

3. **Dentin sialoprotein (DSP):** DSP is localized predominantly in the dentinal tubules at the site of peritubular dentin, which is highly mineralized in nature.

The temporal and spatial localization of these NCPs correlate their expression with the presence of collagenous matrix and calcified deposits. The precise localization of DMP1, DPP and DSP in the dentin tissue suggests that a concerted effort between several NCPs is necessary for dentin formation.

Dentin Permeability

Permeability refers to the state or quality of being open to passage, especially passage of fluids, ions, bacteria and minute particles. It is the ease of passage and/or the rate of diffusion through a tissue under standard conditions. Many factors affect this passage, including the area exposed, the structure and chemistry of the involved tissue, the thickness of the tissue and the pressure exerted on the process of permeability. The dentinal tubules form the major channels for diffusion of various substances across dentin. Dentin permeation is proportional to the product of tubule number and diameter, both of which increase as the tubules converge at the pulp; dentin permeability increases rapidly as the pulp chamber is approached. Intratubular materials such as mineral deposits, collagen fibrils, proteoglycan linings and bacteria can greatly reduce dentin permeability.

Bacterial invasion of dentinal tubules commonly occurs when dentin is exposed following a breach in the integrity of the overlying enamel or cementum. Bacterial products diffuse through the dentinal tubule towards the pulp and evoke inflammatory changes in the pulpdentin complex. These changes may eliminate the bacterial insult and block the route of infection. Unchecked invasion results in pulpitis and pulp necrosis, infection of the root canal system and periapical disease. The streptococci group of bacteria colonize the dentinal tubules. Streptococci recognize components such as collagen type I present in the dentinal tubules which stimulate bacterial adhesion and intratubular growth.

The components of dental restorative materials also tend to diffuse through the tubules and reach the pulp. Restorative materials which are incompatible to the pulp may damage the pulp tissue. Considering the permeable nature of dentin, the choice of restorative materials should be given due importance.

Role of DSPP in the Normal Development of the Dental-Craniofacial Complex

The craniofacial complex is predominantly derived from both neural crest cells and mesodermal cells, but the neural crest contributes more by formation of bone, cartilage and connective tissue. Dentin sialophosphoprotein (DSPP) is a progenitor protein that is expressed by the connective tissues of the bone of the craniofacial region. DSPP is found to be intensely expressed in the dentin matrix. Mutations in the *DSPP* gene affects dentin, calvarial bones and sutural development. This has been proven through gene ablation studies with *DSPP* mutant mice. *DSPP* has also been found to influence craniofacial mineralization directly or indirectly through transcription factors, matrix molecules and serum phosphate levels (excerpts from Chen et al. 2016).

Fracture Toughness of Dentin

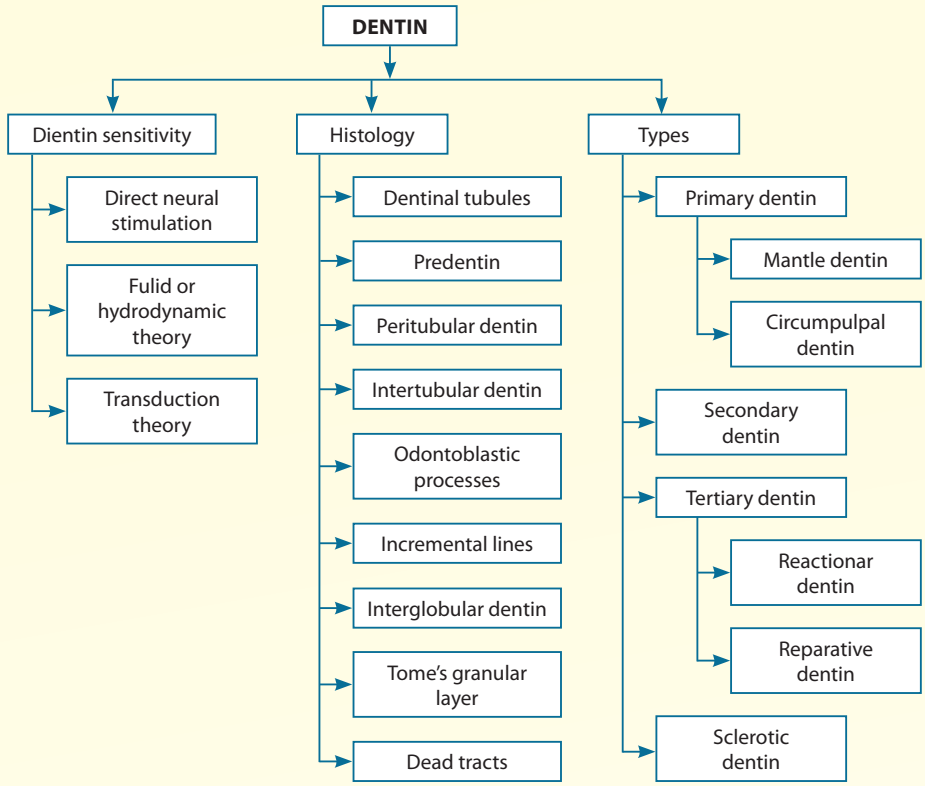
Human dentition is subjected to a variety of cyclic stresses, including those of mastication and other para-functional activities. Resistance to such forces is hugely derived from dentin due to its spatial variations in terms of tubule orientation. The network of tubules (approximately 0.5–1.5 μm in diameter) that radiate outwards from the pulp cavity to the dentinoenamel junction (DEJ) makes it a unique structure. Dentin tubules are covered by a collagen-free, hypermineralized cuff of peritubular dentin. Intertubular dentin consists of a collagen fibril matrix reinforced by nanoscale crystals of apatite and is present between the peritubular dentin. This complex microstructure is regarded as a biological composite. Substantial spatial variations in the number, diameter and orientation of the tubule lumens in the tooth crown have been visualized in microscopical evaluations. The mechanical property of dentin has zonal variance due to a difference in tubule density and tubule

diameters near the pulp and DEJ. Spatial variations in mechanical behaviour have found that there is a decrease in hardness and toughness with proximity to the pulp. Fatigue resistance of coronal dentin is more than in other regions of dentin (excerpts from Ivancik and Arola 2013).

Key Points

1. Dentin is harder than bone and cementum but softer than enamel.
2. Dentin has the property of deformability or elasticity, which prevents fracture of the hard overlying enamel.
3. Dentin is permeable because it is tubular in structure. The permeability decreases with increasing age.
4. The number of dentinal tubules per unit area varies depending on the location within the tooth, ranging from 25,000 to 30,000/mm^2 in the periphery and from 50,000 to 60,000/mm^2 in the pulpal surface.
5. Per tubular dentin differs from intertubular dentin in that it is 5–12% more mineralized and lacks a collagenous fibrous matrix.
6. Lamina limitans is a thin organic membrane on the inner aspect of peritubular dentin (lining) rich in glycosaminoglycans.
7. The intertubular dentin forms the major bulk of dentin.
8. Odontoblastic processes are cytoplasmic extensions of the odontoblast which extend into the dentinal tubules.
9. The periodontoblastic space seen between the odontoblastic process and the peritubular dentin contains the dentinal fluid, the movement of which forms the basis of dentin sensitivity.
10. Predentin is the newly laid dentin matrix which is not yet mineralized; it forms the innermost layer of dentin close to the pulp.
11. Mantle dentin is the first-formed dentin in the crown below the dentinoenamel junction. It is about 20 μm thick.
12. Incremental lines of von Ebner are seen at regular intervals in the dentin; the distance between these lines varies from 4 to 8 μm.
13. The accentuated incremental lines are known as *contour lines of Owen*.
14. Secondary dentin contains fewer tubules and is less regular than primary dentin.
15. Tertiary dentin is formed only by odontoblasts that are directly affected by stimuli.
16. Vonkorff's fibres are large-diameter collagen fibrils which are present at right angles to the future dentinoenamel junction.

Mind Map



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Multiple Choice Questions

1. The composition of dentin by weight is
   (a) 35% inorganic + 65% organic
   (b) 20% organic + 70% inorganic
   (c) 50% organic + 50% inorganic
   (d) 60% organic + 40% inorganic
2. Dentinal tubules are
   (a) S shaped
   (b) Y shaped
   (c) Straight
   (d) Parallel
3. Which of the following is true of dentinal tubules?
   (a) They are highly branched in root dentin when compared with crown
   (b) Pulpal surface has increased dentinal tubules than peripheral dentin
   (c) There are more tubules per unit area in crown than in root
   (d) All of the above
4. Interglobular dentin is
   (a) Dentin surrounding the tubules
   (b) Dentin present between odontoblastic processes
   (c) Dentinal tubules which cross over to enamel
   (d) None of the above
5. Dentinal tubules contain
   (a) Nerve fibre terminal
   (b) Collagen
   (c) Odontoblastic processes
   (d) All of the above
6. The type of collagen seen predominantly in dentin is
   (a) Type II
   (b) Type III
   (c) Type I
   (d) Both a and b
7. Mantle dentin differs from the rest of the dentin in the following aspects:
   (a) It is more mineralized
   (b) It is less mineralized
   (c) It shows fewer defects than circumpulpal dentin
   (d) Both b and c
8. Incremental lines of dentin are called
   (a) Lines of Retzius
   (b) Lines of Salter
   (c) Lines of von Ebner
   (d) None of the above
9. Tomes' granular layer
   (a) Is seen in radicular dentin
   (b) Is seen in coronal dentin
   (c) Represents coalescing and looping of dentinal tubules
   (d) Both a and c
10. Secondary dentin is
    (a) Dentin formed after root completion
    (b) Dentin formed before root completion
    (c) First-formed dentin
    (d) Found only in permanent dentition

11. The dentin which is deposited throughout life, reducing the size of the pulp chamber, is
    (a) Primary dentin
    (b) Secondary dentin
    (c) Tertiary dentin
    (d) Predentin
12. The changes occurring in transition from primary to secondary dentin are
    (a) Decrease in number of dentinal tubules
    (b) Change in direction of dentinal tubules
    (c) Crowding of dentinal tubules in pulp
    (d) All of the above
13. Tertiary dentin is formed due to
    (a) Dental caries
    (b) Attrition
    (c) Irritation due to cavity procedure
    (d) All of the above
14. Dead tracts
    (a) Appear white in transmitted light and dark in reflected light
    (b) Appear white in reflected light and dark in transmitted light
    (c) Do not exhibit difference under reflected and transmitted light
    (d) None of the above
15. The type of mineralization seen in dentin is
    (a) Globular
    (b) Linear
    (c) Both a and b
    (d) None of the above



CHAPTER 37

Pulp

Overview

Once the first layer of calcified matrix is deposited during the bell stage of tooth development, the dental papilla is referred to as the dental pulp. The dental pulp is a soft connective tissue which is surrounded by dentin and confined within the pulp chamber and root canal of the tooth. Through the apical foramen the blood vessels and the nerves enter the pulp. Histologically, pulp is composed of odontoblastic zone at the periphery followed beneath by the cell-rich zone of Weil, cell-free zone and the pulp core. The pulp remains as an excellent source of multipotent stem cells. The pulp is involved with inductive, formative, protective, nutritive and reparative functions of the tooth. As age advances, the cellularity, vascularity and size of the pulp chamber get reduced while the fibres of the pulp become denser.

INTRODUCTION

Dental pulp is a soft connective tissue surrounded by the hard dentin, enamel and cementum. Rigid confinement of pulp in a hard chamber that cannot expand makes the tissue unique in terms of function and response during injury. The pulp chamber is present in both the crown and root of tooth. It consists of ground substance, cellular components and interstitial fluid in addition to blood vessels and nerves. Pulp is richly innervated and vascular. It contributes to the vitality of the tooth structure. Loss of pulp tissue due to inflammation can make the existing hard tissues brittle.

Applied Histology

Management and Preservation of Pulp Vitality

Management and preservation of pulp vitality is the main concern of any clinician since the vitality of the pulp determines the life of the tooth and the regenerating potential (reparative dentin formation) of the tooth. During every dental procedure, utmost care should be taken to maintain the vitality of the tooth. The vitality of the pulp can be determined by using an instrument called pulp vitalometer.

MORPHOLOGY OF THE PULP (Fig. 37.1)

The shape of the dental pulp is similar to that of the tooth. It has coronal and radicular parts. The *coronal pulp* resembles the morphology of the crown. It has six sides, namely the buccal, lingual, mesial, distal and occlusal aspects and the floor. The extension of the coronal pulp high into the cusps is known as pulp horn. *Pulp horns*, one into each cusp, are very high in young age. As age advances, the surrounding dentin is deposited all around the pulp, thus reducing the size and causing recession of the pulp horns.

The *radicular portion* of the pulp is seen in the innermost part of the roots, where it is called the *root canal*. Each root has one or more root canals. There are lateral branches to these canals called the *accessory canals*. At the apical end of the root canal is the opening called the *apical foramen*. Through the apical foramen, the pulp communicates with the periapical tissues. The average size of the apical foramen of maxillary teeth is 0.4 mm and mandibular teeth is 0.3 mm. During the formation of the root, the epithelial diaphragm is at the apical end; the size of this end gradually decreases as root dentin and cementum get deposited. The formation of the accessory canal may be because

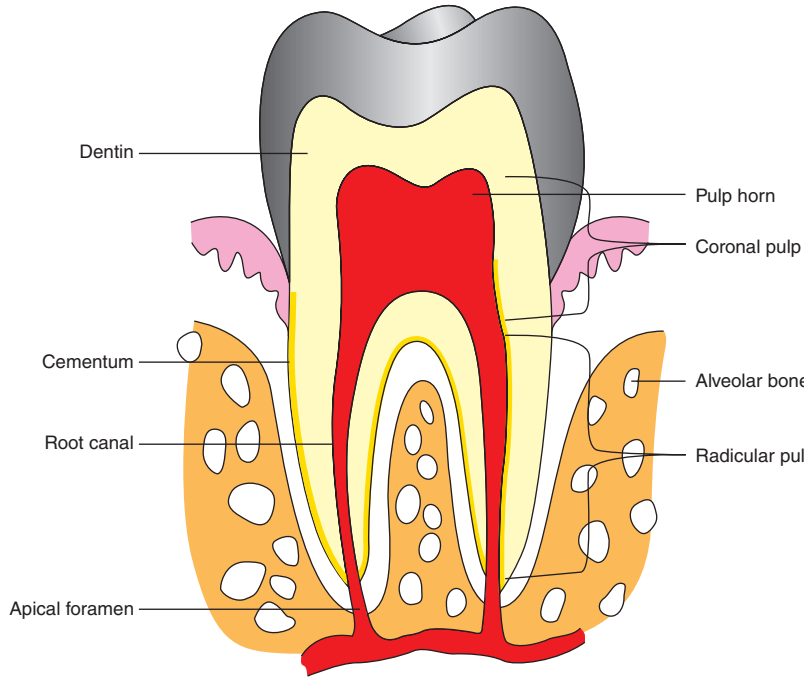


Figure 37.1 Parts of the pulp organ.

of the premature rupture of Hertwig's epithelial root sheath cells or because the root dentin encounters a blood vessel in its path during its formation.

Applied Histology

Spread of Pulpal Infection Through Apical Foramen and Accessory Canals

Pulp communicates with the periapical (peri—around; apical—apex of tooth) and periodontal (peri—around; dontal—tooth) tissues through the apical foramen. So the infection of the pulp may lead to periapical as well as periodontal problems and vice versa which warrants the combined management of pulp as well as periodontal region.

If accessory canals are present in the bifurcation areas or close to the coronal portion of the root, it can lead to the spread of infection from the pulp to the outer periodontal region of the tooth. The presence of accessory canals and pulpal remnants in these canals can complicate endodontic treatment and may lead to failure of treatment at times.

The volume of the pulp is very little—on an average, 0.02 cc per tooth. The total pulp volume of all the teeth is 0.38 cc.

The pulp of primary and permanent teeth differs in some aspects (**Fig. 37.2**). The primary pulp is present for a shorter time period than permanent pulp. Different stages such as formation, maturation and regression can be identified in the life cycle of pulp. The primary pulp shows shorter periods for all the stages compared with permanent pulp.

The neural development of primary teeth is of lesser extent than permanent teeth. This could be the reason why children suffer less pain in case of pulpal injuries.

Applied Histology

Clinical Implications of the Morphology of Pulp

1. **Endodontic treatment:** Each tooth of the dentition has unique pulp morphology and pulp horns position. Hence, the knowledge of the same is highly essential for understanding as well as explicit performance of endodontic treatment (endo—within; dontic—tooth: within

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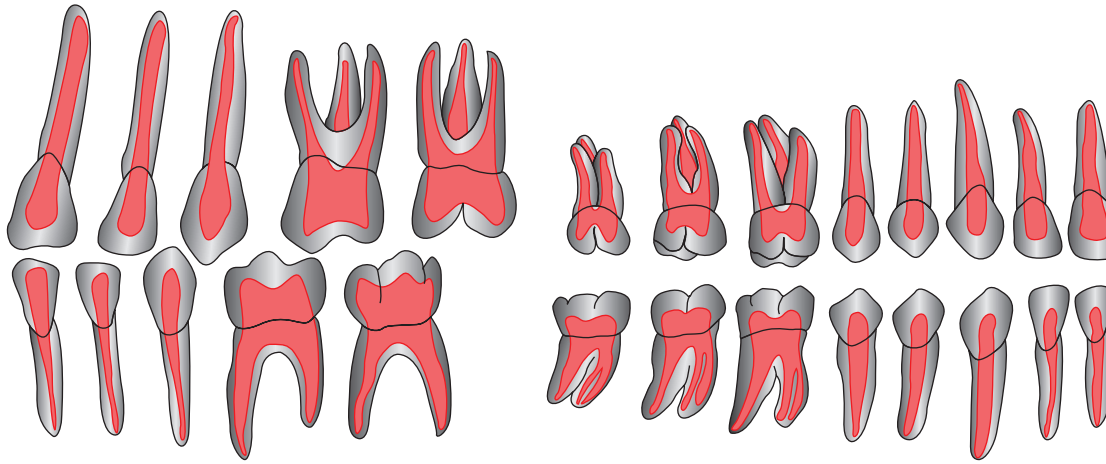


Figure 37.2 Pulp organs in (a) deciduous and (b) permanent dentition.

(Continued)

tooth which indicates the management of the diseases of pulp and pulpal space). Further, the knowledge of the morphology of the pulp is also essential while performing any dental procedure.

2. **Radiographic assessment:** Dental radiographs (X-ray) play a vital role in the diagnosis of dental diseases. Hence, it is imperative to know the morphology of the tooth so as to interpret the normality or pathosis in the tooth and associated structures.

HISTOLOGY OF THE PULP

As the pulp is a soft tissue, the tooth has to be decalcified to prepare the microscopic section. Acids such as 5% nitric acid may be used for faster decalcification.

Formic acid and other weak acids may also be used; they cause slower decalcification. After decalcification, the tooth is washed in water and subjected to routine tissue-processing techniques. A thin section is prepared and stained. The histology of the pulp is described as follows:

The coronal pulp when viewed under the microscope shows the following zones (**Fig. 37.3**):

1. Odontoblastic zone
2. Cell-free zone of Weil
3. Cell-rich zone
4. Pulp core

The distinction into these zones is less evident in the radicular pulp.

Odontoblastic Zone

As the name suggests, this zone shows the presence of *odontoblasts* arranged in a palisading manner. These cells are seen at the periphery of the pulp, adjacent to unmineralized dentin called predentin. On an average, they measure 5–7 μm in width and 25–40 μm in length. The process of these odontoblasts extends into the dentinal tubules. Although these cells are arranged in a single row, sometimes they crowd and appear as if arranged in two to three rows. The crowding of the odontoblasts is seen because of the reduction in surface area when the odontoblasts move inwards and produce the secondary dentin. The number of the odontoblasts may range from 59,000 to 76,000/mm^2.

There is some variation in the morphology, size and number of odontoblasts in different parts of the tooth. The number and size of the odontoblasts is greater in the coronal pulp as compared with the root. The cells are columnar in the crown, cuboidal in the mid portion and flat in the apical part.

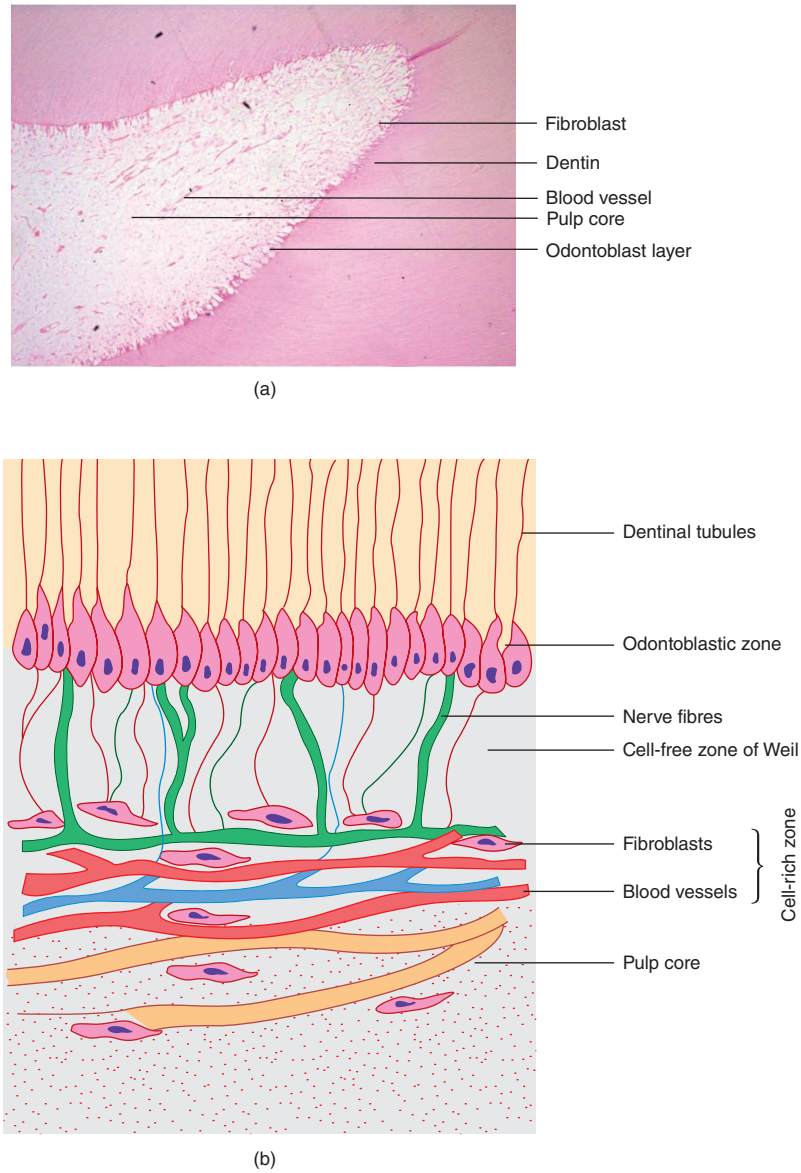


Figure 37.3 Histology of pulp: (a) photomicrograph (haematoxylin and eosin, 4x) and (b) schematic diagram.

Cell junctions such as gap junction, tight junction and junctional complex are seen between odontoblasts. The lifespan of the odontoblasts is till the tooth is viable. Since the odontoblasts are highly differentiated cells, they do not divide. Thus, the formation of the reparative dentin happens by the differentiation of undifferentiated mesenchymal cells into the odontoblasts. The inductive mechanism in the absence of the epithelial cell is not yet clear. Odontoblasts synthesize collagen and some non-collagenous proteins.

Depending on the function, the odontoblasts may be in an active, transitional or resting phase. The electron microscopy of these cells shows the variations accordingly:

1. The active cell is elongated, the nucleus is basally placed and the cytoplasm is basophilic. In this cell, the Golgi apparatus is prominent,

the rough endoplasmic reticulum is abundant and numerous mitochondria are present throughout the cytoplasm. Numerous vesicles are also seen in the process.

2. The resting cell is devoid of organelles. It has a more basophilic nucleus than the active cell. This cell contains lipid-filled vacuoles.
3. In the transitional or intermediate stage, the cells are narrower, have fewer organelles and contain autophagic vacuoles.

Odontoblastic Process

The odontoblastic process is an extension of the odontoblast cell. The process measures about 3–4 μm and is present inside the dentinal tubule. Junctional complexes are present at this zone. The extent of odontoblastic process into the dentinal tubule is not yet clear, although the majority extends to the entire length of the tubule up to the dentinoenamel junction. The odontoblastic process is devoid of major cell organelles. There are numerous microtubules and filaments arranged along the length of the process.

The ultrastructure of the odontoblastic process reveals that synthetic organelles are absent and the microtubules and microfilaments are composed of tubulin, vimentin and actin which are responsible for transporting dentin precursors. Few mitochondria and fragments of endoplasmic reticulum are found. Vesicles of various sizes are present in the periphery. These vesicles produce bud-like protuberances on the surface of the process. The vesicles contain proteoglycans. The dentin matrix is synthesized by the odontoblast cell body and transported to the predentin region through the process.

The space between the odontoblastic process and the dentinal tubule contains the fluid called the *dentinal fluid*. Studies have suggested that the contents of the dentinal tubule exist in the form of a hydrogel, which is a complex mixture of proteoglycans, tenascin, fibronectin, albumin, alpha-2-HS glycoprotein and transferrin.

Cell-Free Zone of Weil

Cell-free zone of Weil appears as a space between the odontoblastic zone and the cell-rich zone. There are no cells in this zone. However, there are a few fibres which run through this zone.

Some researchers feel that the appearance of a cell-free zone is an artefact; others opine that this zone permits the movement of the odontoblasts inwards in the pulp.

Cell-Rich Zone

Cell-rich zone contains numerous cells, fibroblasts being the highest population. Undifferentiated mesenchymal cells, mast cells and macrophages are also seen.

1. **Fibroblasts:** These cells form the predominant group of cells in the pulp. They are structurally similar to the fibroblasts in other parts of the body, but exhibit phenotypical differences. They are found in the cell-rich zone. Pulpal fibroblasts are responsible for maintenance of pulp matrix.

   The shape of the fibroblasts varies from round to stellate/star shaped. Fibroblasts contain long cytoplasmic processes and an oval nucleus with smooth contours. They secrete Types I, III, V and VI collagen and a wide range of non-collagenous extracellular matrix components, such as proteoglycans and fibronectin. They synthesize and degrade collagen. An active secretory fibroblast contains abundant rough endoplasmic reticulum and Golgi complex. The size of these cells decreases as age advances.
2. **Undifferentiated mesenchymal cells:** These cells are in a good number in a young pulp. These are totipotent cells which can differentiate into odontoblasts, fibroblasts or macrophages when the need arises. They are found throughout the cell-rich area and the pulp core and are present in proximity to blood vessels. They appear as large polyhdedral cells with a centrally placed nucleus. The number of these cells decreases with age.

Applied Histology

Pulp as a Rich Source of Stem Cells and Stem Cell Banking

Pulp tissue contains totipotent cells which may act as stem cells. The deciduous tooth pulp and third molar pulps stem cells can be extracted and preserved in stem cell banks.

3. **Defence cells:** The pulp shows a variety of defence cells. They are histiocytes, macrophages, dendritic cells, mast cells and plasma cells. In addition, neutrophils, eosinophils, basophils, lymphocytes and monocytes are also seen. The defence cells are normal resident cells of the pulp matrix and respond to situations that induce inflammation such as dental caries, mechanical and chemical irritation, trauma from occlusion, etc. They provide protection even in aged pulp tissue.

   The B lymphocyte differentiate into antibody secreting plasma cells and T lymphocytes play a role in specific immune responses. Cytotoxic T lymphocytes –CD8 cause lysis of infected cells and helper T lymphocytes –CD4 produce cytokines. Dendritic cells are seen in and around the odontoblastic layer. They are the major antigen presenting cells in pulp. Dendritic cells uptake, process and present foreign antigens as HLA-DR (human leukocyte antigen-antigen D related) antigens on the cell surface of CD4 lymphocytes. In addition to defence cells, odontoblasts also initiate inflammatory events and fibroblasts have the ability to recognize virus present in dental pulp.
4. **Fibres:** Collagen is the major organic component in the dental pulp. They range in length from 10 to 100 nm and exhibit cross striations at 64 nm. The pulp contains type I and type III collagens, traces of V and VI are also found. Type I and III are found in the ratio of 55:45. Collagen is synthesized and secreted by odontoblasts and fibroblasts. Odontoblasts secrete type I and fibroblasts secrete type III. The difference between the collagen produced by both the cells is that collagen secreted by odontoblasts has the ability to calcify, differences in terms of hydroxyl lysine content and cross-linkage have also been observed. The collagen fibres become thicker and more orderly arranged as age advances. They support the cells and help in the transport of the metabolites. The overall content of collagen increases with age. Apical pulp consists of more collagen than coronal region.

   Fine fibres called fibrillin measuring about 10–15 nm wide are also seen in dental pulp. Elastic fibres are absent in pulp and is the reason for dental pulp being termed as specialized connective tissue.

Pulp Core

Ground Substance

The ground substance of pulp is an amorphous gel-like substance with a complex mixture of macromolecules. It occupies the extracellular space. The major structural component of the ground substance is collagen which forms a framework and supports other components. Proteoglycans and glycoproteins also form an important part of the ground substance of the pulp. They are a combination of proteins, carbohydrates and water. They help in adhesion of cells and the fibres with the extracellular matrix.

The chief proteoglycans present in pulp are hyaluronic acid, dermatan sulphate, heparan sulphate and chondroitin sulphate. During formative stages of the dental pulp, chondroitin sulphate is predominant and decreases after tooth eruption.

The glysosaminoglycan molecules of the proteoglycans have an affinity to retain water contributing to increased water content in pulp.

Vascular Supply of the Pulp (Fig. 37.4)

Pulp is a highly vascular tissue with about 14% of its volume occupied with vessels. The velocity of blood flow and blood pressure is higher when compared to other tissues. Generally, two vessels of approximately 150 μm enter the radicular pulp through the apical foramen. These are accompanied by sensory and sympathetic nerve bundles. Smaller sized vessels enter through the accessory foramina. These are not accompanied by any nerve bundles. Once the vessels enter the pulp, their lumen size increases as they ascend coronally while their wall thickness reduces. Another feature which can be observed as the vessels move coronally is lateral branching. The vascular architecture is such that the venules are located in the periphery of the root canals. The main arterioles are located in an axial direction through the pulp and extended to form the capillary network. The small arterioles branch

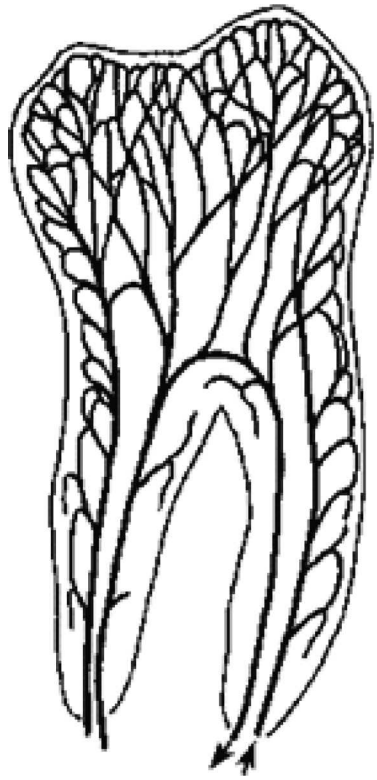


Figure 37.4 Vascular architecture of the pulp.

off at approximate 90° from the main arterioles, lose their smooth muscle coat as they reach the dentin and form capillaries. These capillaries form a network and is seen over the surface of the pulp extending towards the odontoblast layer. Majority of the capillaries near the odontoblast layer exhibit fenestrations. The 'fenestrations' are pores that will allow larger molecules to pass through and facilitate easy exchange of nutrients. Arteriovenous and venous–venous communication/anastomosis are evidenced in the pulp. Such anastomosis plays a role in regulation of blood flow. U-turn looping/hairpin looping of the vessels are seen at the periphery and function similar to the arteriovenous anastomosis.

Lymphatic vessels are seen throughout the pulp. The structure is similar to lymphatics in other tissues. The vessels are thin and irregular in shape with a diameter of 20–50 mm. The vessels have gaps between the endothelial cells. Abluminal projections and anchoring filaments give structural support and prevent the pulp from collapse during increase in pressure in the surrounding tissue fluid. The lymphatic vessels pass apically along with larger vessels through the apical foramen.

Innervation of Pulp

The dental pulp contains both sensory and autonomic nerves to fulfil its vasomotor and defensive functions. Hundreds of axons enter the tooth from the apical foramen to provide it with its sensory supply.

Sensory Nerves They are involved in perception of pain and transduction. They are derived from the branches of the maxillary and mandibular divisions of the trigeminal nerve. The small branches enter through the apical foramina and ascend in a coronal direction along with the blood vessels. They give out extensive branches near the cell-rich zone, forming the *parietal layer of nerves* or plexus of Raschkow.

The plexus contains both large myelinated A-delta and beta fibres (2–5 μm in diameter) and the smaller unmyelinated C fibres (0.3–1.2 μm). The myelinated fibres lose their myelin sheath near the cell-rich zone. They form a rich network of free nerve fibres near the cell-free zone and form specific receptors for pain. Further the free nerve terminals enter the odontoblastic layer, and penetrate into the predentine zone or to the inner dentine next to the odontoblastic cell process.

Autonomic Sympathetic Nerve Fibres The sympathetic nerve fibres originate from the cervical sympathetic ganglion and join the trigeminal nerve at its ganglion. They are unmyelinated and follow the course of the sensory nerves and the blood vessels. Sympathetic adrenergic vascular control exists in the dental pulp and are mediated through noradrenaline and neuropeptide Y. The sympathetic fibres regulate blood flow in the capillary network by innervation of the smooth muscle cells. Sympathetic vasoconstriction is activated by stress and pain stimuli and modulates the excitability of sensory nerves.

Interstitial Fluid

The extracellular fluid constitutes about 60% of the total pulp volume. The nature of the

interstitial fluid is similar to blood plasma except in the albumin and globulin levels. The concentration of albumin and globulin is lower in pulp. Interstitial fluid functions as a transport medium to deliver nutrients from capillaries to cells and removes waste products derived from cellular metabolism. The fluid acts as a means of communication between the cells and blood. Normal interstitial fluid pressure is 6 mmHg and it increases to 20 mmHg during inflammation.

Applied Histology

Interstitial Fluid and Inflammation

Hydrostatic pressure in the interstitial fluid which surrounds the pulpal cells is normally considerably lower than the blood pressure inside the vessels. The dental pulp has a relatively low interstitial pressure due to its enclosure between rigid dentin walls. Even a slight increase in pulpal fluid volume will raise the tissue pressure, which may compress blood vessels, leading to ischemia and necrosis (concept of self-strangulation). Inflammation may lead to an increase in both interstitial fluid volume and blood volume in the low-compliant pulp and thereby increase the tissue pressure.

However, as a protective measure the increased tissue pressure may, in turn, initiate increased lymph flow and absorption of fluid into capillaries in nearby non-inflamed tissue. Both of these later factors will transport fluid out of the affected area and subsequently out of the tooth and consequently lower the tissue pressure. Increased tissue pressure, whether caused by increased blood volume or increased capillary filtration, will promote outward flow of fluid through exposed dentin tubules and thereby help to protect the pulp against entry of harmful substances. It seems physiologically beneficial, therefore, for the pulp to have a high tissue pressure, which promptly increases when blood flow increases due to its low compliance.

Neurotransmitters

Substance P, 5-hydroxytryptamine, vasoactive intestinal peptide, somatostatin, prostaglandin, acetylcholine and norepinephrine are the neurotransmitters in the pulp. These neurotransmitters affect the vascular tone and modify the excitability of the nerve endings.

The response to all external stimuli such as heat, touch, pressure and chemicals is pain.

DEVELOPMENT OF THE PULP

At 8th week of embryonic life, the initiation of pulp development occurs in the region of deciduous incisors which is followed by subsequent posterior teeth from then on. The dental papilla attains more vascularity and once the first layer of calcified matrix is deposited during the bell stage of tooth development, the dental papilla is referred as the dental pulp. Undifferentiated mesenchymal cells in the dental papilla differentiate into fibroblasts. The vascularity of the pulp is elaborated by profuse branching from the developing jaw vessels. The neural innervations are also initiated. Plexus of Raschkow is not formed till root completion.

The lifespan of deciduous pulp in the oral cavity is 8 years and 3 months which is divided into three phases: (i) phase of growth, (ii) phase of maturation and (iii) phase of regression (**Table 37.1**).

Table 37.1 Lifespan of Deciduous Teeth

Phases	Duration	Explanation
Phase of growth	1 year	Beginning of root formation to root completion
Phase of maturation	3 years and 9 months	After root formation until root resorption
Phase of regression	9 years and 6 months	Beginning of tooth resorption till tooth exfoliation

The time period of the development of a permanent pulp organ is 12 years and 4 months.

FUNCTIONS OF THE PULP

The functions of the pulp are popularly described as inductive, formative, nutritive, protective and reparative.

1. **Inductive:** Pulp is derived through the ectomesenchymal differentiation of dental papilla. This is a result of epithelial–mesenchymal interaction which is an important event in the formation of the tooth. As part of the reciprocal induction, the dental papilla cells induce the formation of the enamel.
2. **Formative:** The pulp contains the cells which form the dentin, i.e. the odontoblasts. They secrete the organic matrix for dentin and also take part in its calcification.
3. **Nutritive:** The pulp is richly vascular. The odontoblasts get the nutrients through the pulp vascular system.
4. **Protective:** The pulp is supplied by sensory nerves and can be considered a sensory organ. Pulp responds to various thermal, chemical and physical stimuli in the form of pain and protect the tooth from injury. This pain registering ability forms an important part of defence mechanisms of pulp tissue. In certain situations, the pulp may become inflamed. Cells such as macrophages, monocytes, lymphocytes, neutrophils, plasma cells and mast cells try to act as the defence cells to protect the pulp.
5. **Reparative:** The pulp has the capacity to repair injury. Infection because of dental caries, exposure to heat, cold, pressure, chemicals, mechanical irritation, etc. causes injury to the odontoblastic layer. The walling off of the irritants is usually done by the formation of sclerotic dentin, where the dentinal tubules are filled with calcified materials.

Applied Histology

Pulp Capping Agents

Pulp capping is a type of treatment procedures which involves placement of medicaments onto the pulp (direct pulp capping) or close to the pulp (indirect pulp capping) so as to induce the reparative dentin formation. Usually calcium hydroxide ($Ca[OH]_2$) is used as a medicament.

When the injury is greater, death of the odontoblasts may occur. Differentiation of the totipotent cells from the sub-odontoblastic zone takes place; thus, new odontoblasts are formed. They secrete the reparative dentin.

PULP STONES

Pulp stones, also known as *denticles*, are calcified, nodular structures seen in the coronal or radicular pulp, more commonly in the coronal pulp. If these calcified structures show the dentinal tubules, they are called *true pulp stones*; others are false pulp stones. Some researchers feel that true pulp stones are formed because of the inclusion of remnants of Hertwig's epithelial root sheath into the pulp. These cells induce the differentiation of pulpal cells into odontoblasts and further lead to the deposition of dentin.

False pulp stones appear in concentric layers. They are formed around the blood vessels, within the collagen bundles and around the necrotic tissues.

Pulp stones begin to form around the nidus; they are initially small in size, gradually increase and sometimes may fill the entire pulp chamber.

Pulp stones may develop in apparently normal looking tooth. They may be single or multiple. Pulp stones are generally asymptomatic.

Depending on the relation with dentin, the pulp stones may be grouped as free, attached or embedded. The free pulp stones are present in the pulp, surrounded by the pulp tissue. Gradually, as the secondary dentin formation continues, these pulp stones get attached to the dentinal wall. Further dentin formation leads to the embedded pulp stone (**Fig. 37.5**).

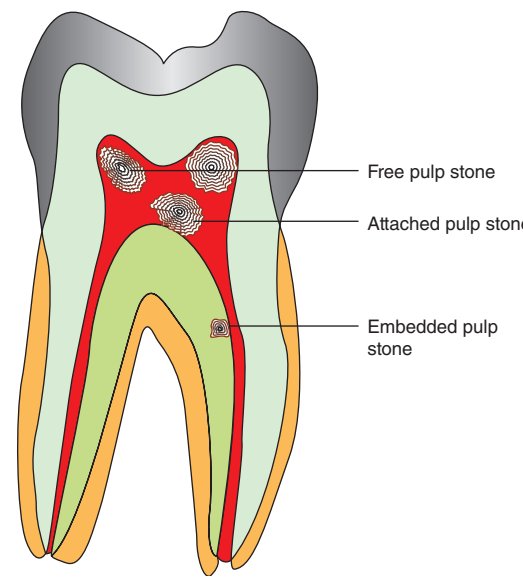


Figure 37.5 Pulp stones.

Applied Histology

Pulp Stones Can Complicate Endodontic Therapy

Pulp stones can interrupt and pose complications during endodontic treatment since these structures can obstruct the root canal.

AGE CHANGES (Fig. 37.6)

The changes demonstrated by pulp as age advances and the clinical implications of such changes are as follows:

1. Because of the continuous deposition of the secondary dentin, the size of the pulp chamber as well as the root canals decreases with age (**Fig. 37.6**).
2. Complete obliteration of the root canal may happen in old teeth as a result of which the vascular supply reduces. In turn, the fluid content of the tooth also decreases. Such teeth may become brittle and fracture easily.
3. As age advances, the cell population of the pulp and size of the cells decreases. The intracellular organelles also decrease in number.
4. The fibres of the pulp get arranged in bundles as age advances. This fibrosis may be longitudinal in the root and more diffuse in the coronal area. Fibrosis around the capillaries and the blood vessels also takes place as age advances.
5. Atherosclerotic plaque formation is seen in the vessel walls of the pulp tissue.
6. Degeneration of myelinated and non-myelinated axons takes place as age advances. This leads to decreased sensitivity.
7. Dystrophic calcifications may be seen in relation to the blood vessels or the collagen bundles. These are commonly seen in the root canals.

Applied Histology

Pulp as a Tool in Forensic Dentistry

Since pulp tissue is surrounded by hard tissue all around, it has become an important source of cells in forensic odontology. Even high temperatures as encountered in fire accidents or during a plane crash do not destroy the pulp tissue. DNA obtained from the pulp tissue has helped in personal identification. Further, blood group antigens can be identified from pulpal tissue aiding in the personal identification.

Pulpal Diseases

Pulpitis is the inflammation of the pulp which causes severe pain and loss of vitality of the pulp on progression. Pulpitis can be acute or chronic and reversible or irreversible in nature.

The pulp may undergo necrosis due to trauma, dental caries or other injuries. The tooth may become discoloured when the pulp is necrosed,

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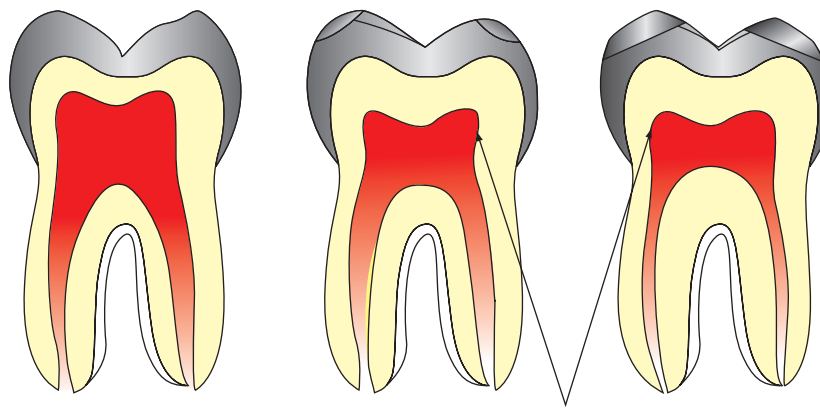


Figure 37.6 Age-related changes in the pulp.

(Continued)

leading to the non-vitality of the tooth. The non-vital tooth becomes brittle due to the lack of fluid inside. Such teeth may fracture easily.

Sometimes, the defence mechanism in the large cavities formed because of dental caries results in the exuberant formation of fibrous tissue which protrudes out from the pulp and resides inside the cavity. These are called pulp polyps. These are usually seen in the permanent first molars of young individuals.

Trauma to the tooth or dental caries or even root canal treatment can induce internal resorption of the tooth wherein the dentin of the tooth is resorbed by odontoclasts formed in the pulp. This results in thin tooth structure with a classical pink spot corresponding to the loss of tooth material with the display of pulpal tissue from within. The affected tooth is called as "Pink tooth of mummery" and the pathosis behind the appearance is called internal resorption.

ADDITIONAL READING

Pulpal Stem Cells and Stem Cell Niches

Dental stem cells are considered a new source of adult stem cells that could be used for regenerative medicine. Dental stem cells can be removed from an individual's primary or permanent teeth, expanded and put back into the same individual when repair becomes necessary. The question of immunosuppression does not arise as it is a type of autologous transplantation. Stem cells guarantee tissue repair and regeneration throughout life. The decision between cell self-renewal and differentiation is influenced by a specialized microenvironment called the 'stem cell niche'. In the tooth, stem cell niches are formed at specific anatomical locations of the dental pulp. The microenvironment of these niches regulates the participation of the dental pulp stem cell populations in tissue maintenance, repair and regeneration. Signalling molecules such as Notch proteins are important regulators of stem cell function, with the capacity to induce proliferation or differentiation. Dental injuries often lead to odontoblast apoptosis, which triggers activation of dental pulp stem cells. These cells proliferate, migrate, and differentiate into odontoblast-like cells, which elaborate reparative dentin. Enhancing the knowledge about the regulation of dental pulp stem cells within their niches in pathologic conditions will aid in the development of novel treatments for dental tissue repair and regeneration.

Pattern Recognition Receptors in Pulp

Pattern recognition receptors (PRRs) are proteins expressed by cells of the innate immune system to identify pathogen-associated molecular patterns associated with microbial pathogens or cellular stress. They may also be referred to as pathogen recognition receptors. Initial sensing of infection is mediated by PRRs, the activation of which leads to the expression of inflammatory mediators responsible for the elimination of pathogens and infected cells. PRRs act as immune sensors that provide immediate cell responses to pathogen invasion or tissue injury. PRRs in human dental pulp cells belong to the toll-like (TLR) and nod-like (NLR) receptor families by which cells recognize bacteria through bacteria-derived factors such as lipopolysaccharides. These receptors have been identified on dendritic cells and other cell types in dental pulp.

Odontogenic infections often lead to severe inflammatory pain, and certain bacteria found in necrotic root canal systems are associated with this clinical symptom. The mechanisms for bacterially induced odontogenic pain remain unknown. It is possible that bacteria or bacterial by-products might indirectly activate nociceptors by evoking the release of certain soluble factors like prostanoids and cytokines from cells in the infected tissue that activate nociceptors via a paracrine action. Bacteria or bacterial by-products might also directly activate nociceptors.

Endothelial Progenitor Cells in Pulp

Endothelial progenitor cells (EPCs) are a population of rare cells that circulate in the blood with the ability to differentiate into endothelial cells. These cells form the lining of blood vessels. The process by which blood vessels are born de novo from EPCs is known as vasculogenesis.

Cell therapy with EPCs to stimulate vasculogenesis as a potential treatment for ischaemic disease is an exciting area of research in regenerative

medicine. EPCs are present in bone marrow, peripheral blood and adipose tissue. Autologous EPCs are usually obtained by invasive biopsy which is a potentially painful procedure. An alternative approach is sourcing EPCs from the permanent and deciduous pulp tissue, which is easily available from extracted teeth, without ethical issues. The EPCs from dental pulp are a new progenitor cell source for cell-based therapy to stimulate angiogenesis/vasculogenesis during tissue regeneration.

Vasculogenic subfraction of cells based on CD31 and CD146 lineage are present in dental pulp. These cells demonstrate $CD34^+$ and vascular endothelial growth factor-2 (VEGF2)/$Flk1^+$ and are similar to the EPCs present elsewhere in the body. The pulpal EPCs show high proliferation, migration activities with multilineage differentiation and vasculogenic potential. Local transplantation of this subfraction of cells resulted in successful engraftment and an increase in the blood flow including high density of capillary formation in experimental animals. The transplanted cells were in proximity of the newly formed vasculature and expressed several proangiogenic factors, such as VEGF-A, G-CSF (granulocyte colony stimulating factor), GM-CSF (granulocyte macrophage colony stimulating factor) and MMP3 (matrix metalloproteinase).

Molecular Basis of Pulp Nociception

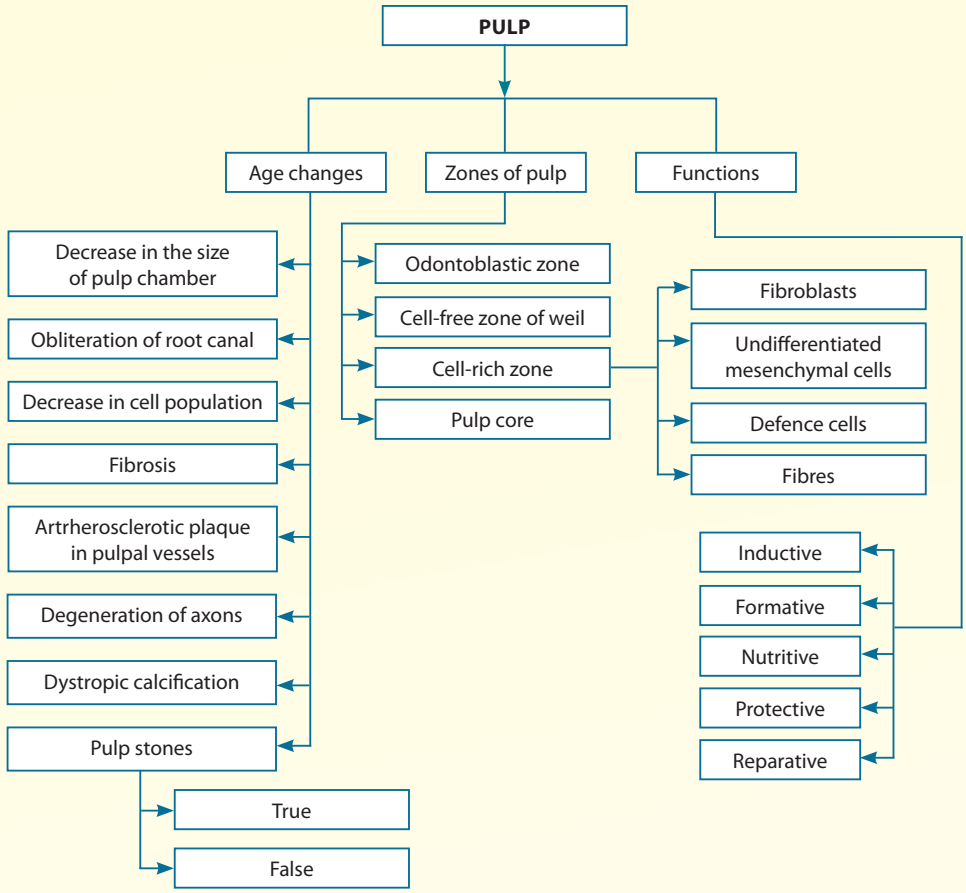
Stimulation of pulp nerve fibres causes dental pain. The pain-producing mechanism involves both neural and vascular structures. This defensive mechanism is a complex phenomenon which involves multiple systems that contribute to its occurrence and regulation. It involves a concerted effort between the central nervous system and the endocrine system, hypothalamus and hypophysis gland. The endocrine system mediates its effects on dental pulp through the corticotrophin-releasing factor (CRF) binding with its membrane receptor (CRF-Rs). Once activated, the release of endorphins from immune cells increases the peripheral anti-nociception. Physical and psychological stresses enhance the release of CRF from the hypothalamus. Synthetic CRF also potentiates the immunocompetent cells to secrete endorphins that interact with the opioid receptors on the peripheral afferent nerves, causing a significant anti-nociception. Endogenous opioids, which are present in large quantities in the brain, reduce pain transmission by preventing the release of the excitatory neurotransmitter substance P from the primary afferent nerve terminal. μ-type opioid receptors have been found in human tooth pulp along the ramification of the nerve root and in the coronal pulp. This peripheral localization aids in interaction of endogenous and exogenous opioids with the μ opioid receptors. The receptors for catecholamines, such as dopamine, adrenaline and noradrenaline, are mainly located in the membranes of blood vessels and some nerves. Catecholamines exert their physiological effects on adrenoreceptors in blood vessels. The smooth muscles of pulp vessels contain α_1, α_2 and β adrenoreceptors. The α receptors are responsible for the contraction of the vascular muscle, producing vasoconstriction (excerpts from Jain et al. 2013).

Key Points

1. The pulp is a soft connective tissue surrounded by dentin.
2. The shape of the pulp is similar to that of the tooth.
3. Extensions of the pulp into the cusps are pulp horns.
4. Each root has one or more root canals which contain the radicular pulp.
5. The apical end of the root canal is the apical foramen.
6. Accessory canals are the lateral branches of the root canal.

7. Histologic zones of the pulp are as follows:
   (a) Odontoblastic zone
   (b) Cell-free zone of Weil
   (c) Cell-rich zone
   (d) Pulp core
8. Odontoblasts are highly differentiated cells that may be in active, transitional or resting phase.
9. Each odontoblastic process extends into the dentinal tubule.
10. The space between the odontoblastic process and the dentinal tubule contains dentinal fluid.
11. The cell-free zone of Weil may show a few fibres. This zone permits the movement of odontoblasts towards the pulp.
12. Fibroblasts are the highest population of cells in the pulp.
13. Interstitial fluid pressure of normal pulp is 6 mmHg and of inflamed pulp is 20 mmHg.
14. Arteriovenous anastomosis and U looping of blood vessels help in regulation of blood flow.
15. The cell-rich zone shows the undifferentiated mesenchymal cells in the pulp.
16. The plexus of nerves formed by extensive branching of the nerve fibres at the cell-free zone is known as the *plexus of Raschkow*.
17. The functions of the pulp are as follows:
   (a) *Inductive:* Epithelial–mesenchymal interaction
   (b) *Formative:* Organic matrix of dentin
   (c) *Nutritive:* Through vascular supply
   (d) *Protective:* Through the sensory nerves
   (e) *Reparative:* Through the undifferentiated mesenchymal cells
18. Pulp stones are calcified structures seen more commonly in the coronal pulp. They may be true or false pulp stones depending on the presence of dentinal tubules. On the basis of the dentin relations, pulp stones may be free, attached or embedded.
19. Changes due to age are as follows:
   (a) Cellularity decreases
   (b) Fibrosis
   (c) Degeneration of nerves
   (d) Dystrophic calcification

Mind Map



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Multiple Choice Questions

1. Pulp is a
   (a) Connective tissue
   (b) Epithelial tissue
   (c) Glandular tissue
   (d) Muscle tissue
2. Which of the following is a soft tissue?
   (a) Cementum
   (b) Dentin
   (c) Enamel
   (d) Pulp
3. Which tissue-processing technique is used for obtaining sections of the pulp?
   (a) Decalcified sections
   (b) Frozen sections
   (c) Ground sections
   (d) Cytology
4. The total number of pulp organs in humans is
   (a) 20
   (b) 28
   (c) 32
   (d) 52
5. The correct order of histologic zones from the dentinal side towards the centre of the pulp is
   (a) Odontoblastic, cell rich, cell free, pulp core
   (b) Cell free, cell rich, odontoblastic, pulp core
   (c) Cell rich, cell free, odontoblastic, pulp core
   (d) Odontoblastic, cell free, cell rich, pulp core
6. The cell body of the odontoblast resides at the
   (a) Cementum
   (b) Dentin
   (c) Enamel
   (d) Pulp
7. The cell-free zone is the
   (a) Zone of Lucas
   (b) Zone of Raschkow
   (c) Zone of Weil
   (d) Zone of Wharton
8. The cell with the highest population in pulp is
   (a) Fibroblast
   (b) Odontoblast
   (c) Mast cell
   (d) Undifferentiated mesenchymal cell
9. The nerve plexus of pulp is
   (a) Batson's plexus
   (b) Branchial plexus
   (c) Plexus of Raschkow
   (d) Plexus of Whatson
10. The nerve fibre associated with dull, diffuse pain is
    (a) A-δ fibre
    (b) A-β fibre
    (c) C fibre
11. The nerve fibres associated with sharp pain are
    (a) A-δ fibres
    (b) A-β fibres
    (c) C fibres
12. The cell which forms the dentin is the
    (a) Ameloblast
    (b) Cementoblast
    (c) Fibroblast
    (d) Odontoblast
13. As age advances, the cell population of the pulp
    (a) Increases
    (b) Decreases
    (c) Does not change

CHAPTER 38



Periodontal Ligament

Overview

The periodontal ligament (PDL) is a soft, specialized connective tissue which connects the tooth to the alveolar bone. The space containing the PDL that is present around the tooth is called periodontal space which is 0.1–0.25 mm in width. The periodontal tissue is continuous with the gingival connective tissue coronally and extends to the level of the apical foramen apically. PDL develops from the dental follicle of the tooth germ. Histologically, PDL is composed of collagenous and oxytalan fibres, noncollagenous proteins, ground substance and cells. The fibroblasts form the major population of cells in the PDL. Other cells seen in PDL are cementoblasts, osteoblasts, osteoclasts, cementoclasts, undifferentiated mesenchymal cells, defence cells and epithelial cell rests. PDL plays a primary role in protecting the tooth from masticatory forces. As any other tissue in the body, PDL also undergoes changes as age advances.

INTRODUCTION

Periodontium refers to the tissues investing and supporting the teeth, including the cementum, periodontal ligament (PDL), alveolar bone and gingiva. The PDL is a soft, specialized connective tissue which connects the tooth to the alveolar bone. *Ligament* is a fitting term; it comes from the Latin *ligare* meaning *to bind* or *tie*. Although the PDL bears this term because it anchors the tooth to the bone, it differs in many respects from the other ligaments in the body.

This tissue has also been referred to as *gomphosis* in the literature. Gomphosis is not a connection between true bones but is considered a type of fibrous joint. (This term is not in usage, considering the lack of structural and functional resemblance.)

The embryologic origin of the PDL is from the dental follicle.

The average width of the periodontal space (the space containing the PDL that is present around the tooth) is 0.1–0.25 mm (**Fig. 38.1**). It is widest at the mouth of the socket and at the apex, and narrowest at the axis of rotation of the tooth, which is located at the junction of the apical and middle third of the root. This space can increase because of excessive occlusal forces and can reduce in non-functional teeth. It can narrow down as age advances. This space is said to be wider in deciduous dentition compared with permanent teeth.

The periodontal tissue is continuous with the gingival connective tissue coronally and extends to the level of the apical foramen apically. This is important when considering the progression of periodontitis from gingivitis and also the spread of inflammation from pulp to the PDL.

Applied Histology

Communication Between Pulp, PDL and Gingiva

Since PDL is continuous with gingiva and the apical foramen, periodontitis can occur as a progression from gingivitis. Pulpal pathosis can also spread to the PDL and vice versa.

When a sound tooth is extracted from its socket, the PDL is torn, and the periodontal fibres inserted into the cementum are retained on the root surface. If the tooth were dipped into a diluted dye solution such as methylene blue, the fibres would turn dark blue. In healthy tooth, the

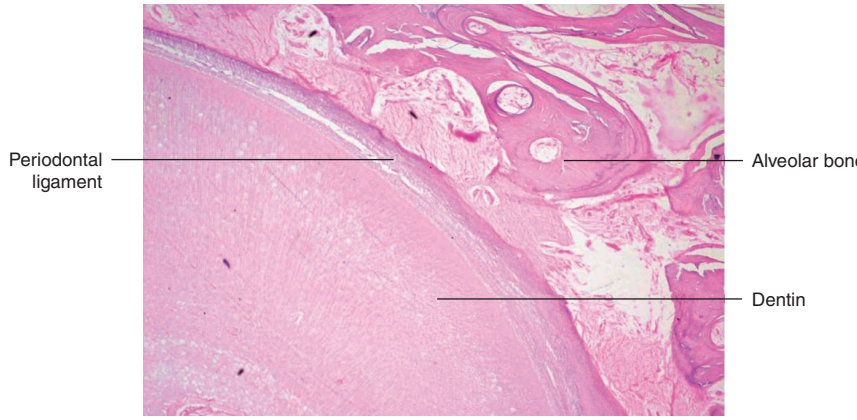


Figure 38.1 Histology of the periodontal ligament (haematoxylin and eosin, 10X).

whole length of the root would be stained. If the tooth is affected by advanced periodontal disease, where the fibres are destroyed partially or completely, the apical portion of the root would be stained and the rest of the root portion would not take up the stain.

This tissue is extensively investigated by various researchers as it is associated with various dental functions and is of clinical significance. This tissue is involved in inflammatory periodontal diseases (a common cause of tooth loss), and its possible reattachment consequent to disease is still a subject of interest to many researchers worldwide. Despite extensive research, this tissue remains enigmatic and has drawn much controversy.

DEVELOPMENT OF THE PERIODONTAL LIGAMENT

Dental follicle is composed of *mesenchymal cells of the dental follicle proper* in the centre and the *perifollicular mesenchymal cells* in the periphery (**Fig. 38.2**). As root formation continues, the perifollicular mesenchymal cells of the dental follicle gain polarity and exhibit enhanced synthetic activity. The cell elongates and demonstrates increased number of rough endoplasmic reticulum (RER), mitochondria and Golgi apparatus (GA) representing an actively secreting cell which progresses to synthesize and deposit collagen and glycoproteins and thus are called PDL fibroblasts.

Development of the Alveolar Crest Group of Principal Fibres

At the coronal third of the root, elaborated fibroblasts from the dental follicle cells elongate. These cells orient themselves in an oblique direction to the long axis of the tooth and secrete collagen

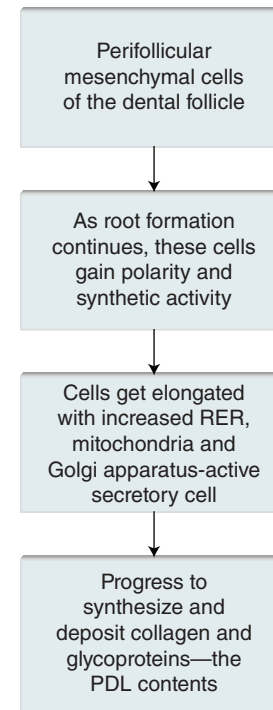


Figure 38.2 Formation of periodontal ligament fibroblasts. *PDL,* periodontal ligament; *RER,* rough endoplasmic reticulum.

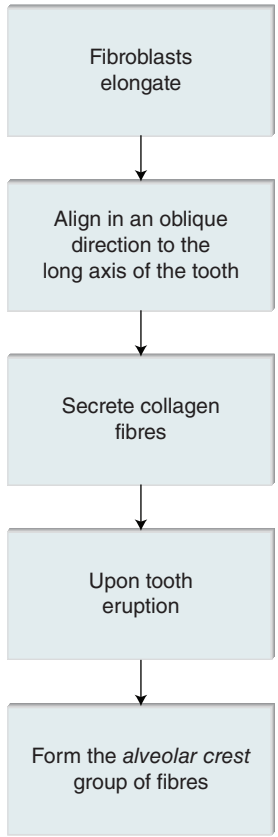


Figure 38.3 Process of the development of alveolar crest fibres.

fibres. With the eruption of the tooth, these fibres form the *alveolar crest group of fibres* (**Fig. 38.3**).

Development of Other Groups of Principal Fibres

First, small, fine, brush-like fibrils are found to arise from the cementum and extend into the periodontal space. Simultaneously, from the surface of bone, a small number of thin collagen fibrils are seen arising. The number and thickness of fibrils on the side of the bone increase. The fibres originating from the cementum are still short while those extending from the bone gradually increase in length. Soon after, the fibres originating from the cementum increase in length and thickness and blend with the fibres originating from the bone in the periodontal space forming the other group of fibres. The group of fibres in the coronal third of the root is established with the initial occlusal contact of the tooth and is called *horizontal group of fibres*. The *oblique group of fibres* is still in the progress of formation. With definitive occlusion, the oblique group of fibres matures. Subsequently, the *apical group of fibres* is also established completing the architecture of the PDL.

PDL Formation in Primary Tooth and Succedaneous Tooth

The development of these fibres differs in teeth with predecessors compared with those without predecessors. These differences are due to the stage at which the alveolar bone is formed. In the development of teeth without predecessors such as permanent molars and primary teeth, the tooth crown erupts through the alveolar bone. Secondary teeth erupt through the bony crypt, lingual to the primary teeth. In addition, alveolar bone must be deposited on the crypt lining before the formation of ligament fibres. Once the alveolar bone is deposited, the formation of the ligament is the same in teeth with predecessors and teeth without predecessors.

COMPONENTS OF THE PERIODONTAL LIGAMENT

The periodontal ligament is a highly cellular and complex vascular structure composed of fibres which are principally collagenous. The ground substance contains cells, vessels and neural elements.

Extracellular Matrix or Intercellular Substance

This is a complex interactive compilation of proteins in dynamic equilibrium that can regulate the gene expression of cells. Specific molecules in the extracellular matrix interact with genetically similar target cells to trigger a biological response that culminates in a distinct morphological and secretory result.

The extracellular matrix is the intercellular substance of tissues and is composed of a diverse number of macromolecules. It regulates the cellular function by the following methods:

1. Binding of soluble growth factors
2. Mediating the adhesion of cells via integrins and proteoglycans, which provides cells with anchorage and directed migration
3. Providing signals for governing cell function

The binding of growth factors to the matrix allows subsequent interaction with cells. The ability to localize and concentrate the growth factors with receptor-mediated cell binding to the matrix provides the organization of the tissue and also modulates the function of the tissue. In this way, the extracellular proteins are crucial for the dynamic progression of development and wound repair as well as the initiation and progression of pathologic alterations.

The rapid expansion and identification of collagenous and non-collagenous proteins and proteoglycans suggest that the number and type of macromolecules in the periodontal matrix will continue to grow.

Components of the Extracellular Matrix

1. Glycosaminoglycans and proteoglycans
2. Collagen
3. Oxytalan fibres
4. Non-collagenous proteins

Functions of the Cell Surface Proteoglycans

1. Cell adhesion
2. Cell–cell and cell–matrix interactions
3. Binding growth factors as co-receptors
4. Cell repair

Fibres of the Periodontal Ligament

As much as 90% of the fibres in the PDL are collagenous. The remaining are oxytalan and reticulin fibres.

Collagen Fibres

Collagen is a proteinaceous, triple-helical structure composed of different amino acids such as glycine, proline, hydroxyproline and hydroxylysine. These are synthesized by fibroblasts, the cells of PDL.

The formation of collagen can be understood as a two-step event:

1. **Intracellular event:** *Proprotein formation* (procollagen or tropocollagen) is similar to the formation of any other secretory protein of other cells. It is vitamin C dependent.
2. **Extracellular events**
   (a) Typical banded collagen microfibril formation
   (b) Fibril formation and fibre assembly

Family of Collagen Proteins The predominant extracellular matrix component of the periodontium is collagen. The collagen molecule consists of three distinct polypeptide chains called α-chains that form homotrimeric or heterotrimeric proteins.

There are at least 27 types of collagen that have been identified so far in the human body. Of these, *types I* and *III* are found in abundance in the PDL and are classified as fibrous collagens.

1. Type I collagen forms the bulk (80%) of fibres in the PDL.
2. Small amounts of types V and VI and traces of types IV and VII have also been found in the PDL.
3. The rate of turnover of the collagen is faster in PDL compared with all other connective tissues.

The presence of type III perhaps explains this rapid turnover. The rate of turnover differs in various parts of the same tooth, the highest being at the root apex.

The collagen fibres in PDL are about 5 μm in diameter. They are arranged in bundles running from the tooth to the bone. These fibres are known as the *principal fibre* bundles of the PDL. The terminal portion of the principal fibres of the PDL inserted in the cementum and alveolar bone is known as *Sharpey's fibres*. These fibres are smaller at the cementum end compared with those in the alveolar bone end. The Sharpey's fibres at the acellular cementum are fully mineralized, whereas those in the cellular cementum and alveolar bone are partially mineralized. The mineralization occurs at about 90° to the long axis of the fibre.

The principal fibres of the PDL can be grouped under five divisions according to the manner in which they are arranged. **Table 38.1** lists the groups of PDL fibres (**Fig. 38.4**).

Interstitial Spaces

Interstitial spaces are found in between each principal fibre bundle and are appreciated in both

Table 38.1 Groups of Periodontal Ligament Fibres

Fibre groups	Location	Origin	Insertion	Significance
Alveolar crest	Just beneath the junctional epithelium	Cementum, below the cementoenamel junction	Runs downwards and outwards and inserts into the alveolar crest	• Prevents extrusion of tooth from the socket and resists lateral, tilting and intrusive tooth displacement
Horizontal	Limited to the coronal one-fourth of the PDL	Cementum, apical to the alveolar crest group	Runs at right angles to the long axis of the tooth and inserts into the bone apical to the alveolar crest	• Resists horizontal and tipping forces
Oblique	Two-third of the length of the PDL	Cementum	Runs obliquely in coronal direction and inserts into the alveolar bone	• Is the largest group • Resists the vertical masticatory forces, thereby preventing intrusion of the tooth
Apical	Root tip	Cementum, around the apex of the root	Fans out in an irregular fashion and is inserted into the apex of the socket	• Not found in incompletely formed roots • Resists vertical, luxative and twisting forces • They are also said to protect delicate nerves and vessels at the root apex
Inter-radicular	Found in multirooted teeth, in between roots	Cementum	Inter-radicular septum	• Resists vertical and lateral movement • Tipping, torquing and luxation are also resisted • In chronic inflammatory periodontal disease, there is a total loss of this group of fibres

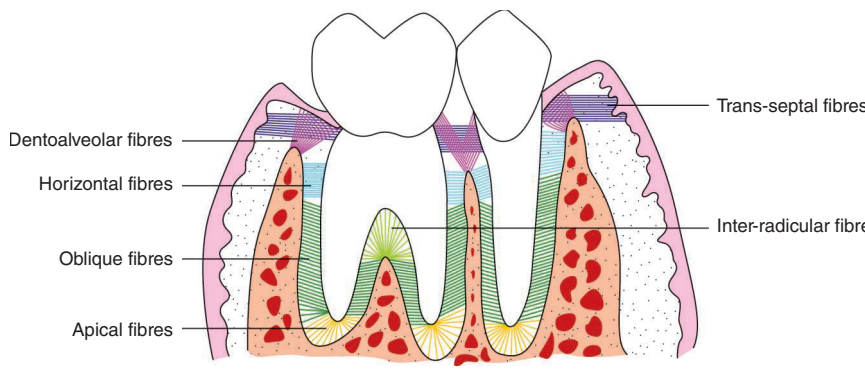


Figure 38.4 Principal fibres of the periodontal ligament—dentoalveolar, horizontal, oblique, apical and inter-radicular. The trans-septal fibres, which belong to the gingival group of fibres, are dealt with in Chapter 41.

cross-section and longitudinal planes of the PDL. These are positioned regularly along the length of the root, and the interval of these spaces depends on the need of these elements in the functioning of PDL. Interstitial spaces appear to carry vascular and neural elements. This space gets compressed during the masticatory load and thus withstands masticatory forces. The maintenance of the interstitial space is supported by collagen bundles surrounding these spaces.

Oxytalan Fibres

Oxytalan fibres are a form of immature elastin fibres, which are bundles of microfibrils of diameter ranging from 0.5 to 2.5 μm, comprising about 3% of the total extracellular fibre composition. They seem to have type IV collagen and elastin components. These fibres run longitudinally from the cementum into the PDL proper which is parallel to the root surface and almost perpendicular to the oblique group of fibres. They terminate in the apical complex of vascular and neural components. Although the functions of these fibres are not completely understood, they are thought to be involved in the regulation of the vascular flow in the PDL. Also, they are found to be thicker in areas of heavy masticatory loads and orthodontic forces.

Another form of immature elastin fibre, *eluanin*, is possibly seen within the PDL.

Apart from the immature elastin fibres, smaller collagen fibres that are allied with larger principal collagen fibres and run in different directions forming a plexus are known. These are called *indifferent fibre plexus.*

Reticulin Fibres

The reticulin fibre is composed of one or more types of very thin and delicately woven strands of type III collagen. These strands build a highly ordered cellular network and provide a supporting structure in the basement membrane within the PDL.

Cells of the Periodontal Ligament

The connective tissue consists of a heterogeneous cell population. The type and number of cells is dependent upon the functional state of the ligament.

1. **Fibroblasts**
2. **Formative cells:** Cementoblasts and osteoblasts of mesenchymal origin
3. **Resorbing cells:** Osteoclasts and cementoclasts derived from monocyte or macrophage lineage from the blood
4. **Undifferentiated mesenchymal cells:** Stem cells and precursors such as preosteoblasts and precementoblasts
5. **Defence cells**
6. **Epithelial cells** (rests of Malassez)

Fibroblasts

Fibroblasts are primary cells of the PDL. They are elongated and ovoid in shape and can be categorized as connective tissue cells, along with osteoblasts and cementoblasts. These synthesize collagen and degrade them intracellularly by phagocytosing them. These cells are responsible for the remodelling of collagen. Although the fibroblast is usually fusiform or cigar shaped, a variety of shapes have been described depending on the type of plane in which it is seen. The PDL fibroblast expresses rich intracytoplasmic organelles associated with protein synthesis. These cells exhibit a high rate of turnover of protein, especially collagen, in the extracellular matrix.

These cells display cell-to-cell contacts of the adherence and gap junction type. In addition, the fibroblast forms focal adhesions called *fibronexus* with the components of extracellular matrix. The fibronexus is a dense plaque present on the cytoplasmic side of the cell membrane. The intracellular actin filaments are linked with extracellular fibrils of the fibronectin by a transmembrane $\alpha\beta$-integrin complex.

Contraction and Motility The cytoskeleton of this cell demonstrates a rich network of actin, a fibrillar protein organized in the form of filaments. The presence of actin indicates the functional demands on the cell in terms of change in shape and migration. Furthermore, these cells have been thought to possess contractile properties responsible for generating a force for tooth eruption.

Fibroblasts and Biologically Active Molecules PDL fibroblasts synthesize and secrete various extracellular molecules such as components

of extracellular matrix, biologically active molecules such as proteinases, matrix metalloproteinases (MMPs), cytokines and growth factors. The biologically active molecules are as follows:

1. Bone morphogenetic proteins (BMPs)
2. Platelet-derived growth factor (PDGF)
3. Basic fibroblast growth factor
4. Interleukin 1
5. Osteoprotegerin
6. Prostaglandins
7. Receptor activator of nuclear factor–κB ligand (RANKL)
8. Tissue inhibitors of MMPs

Formative Cells

1. **Cementoblasts:** These are cementum-forming, square, cuboidal cells lining the surface of the cementum. Like fibroblasts, cementoblasts also display rich intracytoplasmic organelles indicating an association with protein formation and secretion. The appearance of these organelles depends on the degree of activity.
2. **Osteoblasts:** These are bone-forming, cuboidal cells lining the tooth socket. These are also referred to as specialized fibroblast-like cells of mesenchymal origin that have intracytoplasmic organelles very similar to fibroblasts. The layers of these cells are prominent on bone surfaces where there is active bone formation.

Resorptive Cells

Osteoclasts and Cementoclasts These cells are derived from blood cells of the macrophage type and are found in areas of bone and cementum resorption. Refer to Chapters 39 and 40 for further reading on these cells.

Undifferentiated Mesenchymal Cells

Precursor Cells Some researchers believe that these are formed from the stem cells of the bone marrow from where they migrate into the PDL. These cells have been found to be a source of new cells for the PDL. However, what remains to be elucidated is whether a single progenitor cell gives rise to daughter cells which differentiate into formative cells including fibroblasts or whether separate progenitor cells exist for each cell line. The cell population in PDL is always well balanced by the production of new cells to replace the cells which move out of the ligament or which undergo cell death by apoptosis.

Epithelial Rests of Malassez

These are remnants of Hertwig's epithelial root sheath scattered throughout the PDL. They are arranged as clumps of cells which are closely packed and have a prominent nucleus and a scanty cytoplasm. There are numerous epithelial rests in younger individuals but the number decreases as age increases.

Defence Cells

Monocytes/macrophages, mast cells and eosinophils are normal inhabitants of the PDL. Neutrophils and lymphocytes can be seen in response to inflammation.

1. **Monocytes:** They are located mainly around blood vessels and nerves and not in the dense connective tissue of the PDL. Monocytes can enzymatically degrade connective tissue matrix in response to inflammation.
2. **Macrophages:** These are fully matured monocytes in the tissue and are responsible for phagocytosing particulate matter and invading organisms. These synthesize several molecules and factors which have antiviral properties and help in the growth of fibroblasts and endothelial cells.
3. **Mast cells:** These are frequently associated with blood vessels. The function of these cells is production of histamine, heparin and factors associated with anaphylaxis.
4. **Eosinophils:** These cells are seldom seen in the PDL; they display the property of phagocytosis.

FUNCTIONS OF THE PERIODONTAL LIGAMENT

The periodontal ligament has the following functions:

1. Physical
2. Formative and remodelling

3. Nutritive
4. Sensory

Physical Function

1. The primary function of the PDL is to protect the tooth from masticatory forces by transmitting these forces to the supporting alveolar bone and also protect nerves and vessels in the PDL.

   The transmission of occlusal forces has been studied and various theories have been postulated among which the *viscoelastic theory* has been the most accepted till date. According to this theory, whenever an occlusal force falls on the tooth, the PDL deforms and allows the tooth to return to its original position. This occurs with the help of tissue fluid which plays a primary role, while fibres play only a secondary role. The tissue fluids move out of the PDL into the alveolar bone through the perforations in the cribriform plate. Consequently, the fibres tighten by absorbing the force which dissipates into the alveolar bone; later, the fluid returns to the tissue spaces.

Applied Histology

Viscoelasticity of PDL

The viscoelastic system of PDL acts as a shock absorber protecting the tooth from undue forces.

2. The PDL is responsible for maintaining the tooth in functional position during tooth eruption.
3. In addition, it serves as the tissue of attachment between the tooth and alveolar bone.

Formative and Remodelling Function

This is one of the most important functions of the PDL.

1. It enables the PDL to maintain a width of 0.2–0.3 mm despite being surrounded by hard tissues such as cementum and bone. Fibroblasts are considered to be the primary cells responsible for these functions.

Applied Histology

PDL Width and Occlusal Forces

The width of the PDL under normal circumstances is between 0.2 and 0.4 mm. When functional stresses are heavy, the ligament becomes thicker and when the tooth is functionless, the ligament becomes thin. The PDL widens to take the extra forces during traumatic occlusion, which can be readily appreciated on the radiograph as widening of radiolucent periodontal space between the radiopaque lamina dura of the alveolar bone proper and the radiopaque cementum.

2. The cells of the PDL take part in the formation, resorption, maintenance and repair of alveolar bone and cementum during physiologic tooth movement.
3. Furthermore, there is continual turnover of periodontal fibres. The fibroblasts synthesize and degrade collagen fibrils at a rate twice as high as gingival tissue and four times as high as skin. The half-life of collagen in the PDL is about one-fifth of that in the gingiva and about 1/15th of that in skin. Turnover slows down with age.
4. The PDL constantly undergoes remodelling, i.e. degenerated old cells and fibres are replaced by new ones, thus maintaining the homeostasis of the tissue.

Applied Histology

Response of the PDL on the Pressure Side During Horizontal Orthodontic Loads

The horizontal forces on the long axis of the tooth bring about wide areas of pressure on one side of the root and corresponding areas of tension on the other side of the root. During orthodontic tooth movement, the periodontal space becomes narrower on the side towards which a tooth is being moved and the crest of the alveolar bone is slightly deformed. If the forces are strong and long enough, certain cellular mechanisms occur within the PDL and on the surfaces of the alveolar bone. Resorption of the alveolar bone surface occurs on the side towards which the tooth is moved, by means of osteoclasts.

(*Continued*)

(*Continued*)

The changes on the pressure side can be grouped broadly into two categories:

1. **Direct resorption:** The pressure is relatively light.
2. **Hyalinization:** The pressure is large enough to produce compression of the fibres and subsequent injury to the fibroblast and other connective tissue cells, which can lead to necrosis of the areas of the ligament. This necrotic material is primarily removed by macrophages.

Nutritive Function

The periodontal ligament has a rich vascular supply which anastomoses with that in the gingiva and the adjacent marrow spaces of the alveolar bone. The anastomoses of the tissue fluid and vascular supply with bone marrow spaces are very essential in the maintenance of an adequate nutritional supply during functional demands.

Sensory Function

The PDL contains sensory receptors which perform the sensory functions of *pressure* and *pain*. At the light microscopic level, a plethora of nerve endings have been described within the PDL. These range from simple, free nerve endings to more elaborate, branched structures. Periodontal nerve fibres have both myelinated and unmyelinated structures. The myelinated fibres are 5–15 μm in diameter and mainly convey pressure sensation. Proprioceptors and unmyelinated fibres are about 0.5 μm in diameter and convey the sensation of pain to the higher neurological centres.

Applied Histology

Proprioceptors of PDL

The proprioceptors in the PDL provide 'positional awareness', which is not found in pulp. Pain due to a periodontal infection is easily pointed out by the patient. In contrast to this, pain of pulpal origin is difficult to localize. Further, the proprioceptors also protect the apical blood vessels from undue forces.

The sensory receptors performing this function are free nerve endings with tree-like ramifications, Ruffini's endings, coiled Meissner's endings and encapsulated spindle-like endings. The function of Meissner's endings and spindle-like endings are not yet completely determined.

1. **Ruffini's endings:** These are classified as Aβ fibres which act as slow adapting as well as rapidly adapting receptors depending on the position of the receptors in the PDL. These receptors possess the quality of proprioception, which is a salient feature of PDL that helps in localization of pain. The pulp tissue lacks these nerve endings and pulpal pain is poorly localized.
2. **Free nerve endings with tree-like ramifications:** These receptors are nociceptors, primarily responsible for carrying pain sensation and to some extent performing mechanoceptor functions.

Applied Histology

Dental Procedures and PDL Adaptation

In case of loss of a tooth, the adjacent sound teeth are utilized as support and the lost tooth is replaced. In the meantime, because of the loss of adjacent tooth, the sound teeth might be out of function for a while which can lead to poor adaptation of PDL to forces. Hence, in case of restoration of lost tooth or tooth structures, enough time should be provided for the PDL to adapt to the changes so as to efficiently transmit the forces. The patient should always be advised about the adjustment period. The restored tooth should be slowly introduced to mild forces initially followed by heavy forces. With any dental procedure it is highly vital to safeguard the function and the architecture of the PDL.

Blood Supply

The blood supply of the PDL is derived from appropriate superior and inferior alveolar arteries. The coronal end of the ligament receives its blood supply from the gingival vessels and the apical end from a series of perforating arteries from the alveolar bone. Primarily, it does not receive blood from the vessels entering the pulp at the apical foramen. This helps in the continued functioning of the ligament despite removal of root end in endodontic procedures.

PDL displays a rich, vascular network in the form of crevicular plexus of capillary loops and the presence of large numbers of capillary fenestrations, in contrast to regular continuous

capillary beds in other fibrous connective tissues. This fenestrated capillary end has increased capacity for diffusion and filtration. Furthermore, it is also suggested that it is a characteristic requirement of a tissue with a high turnover rate.

The veins within the PDL normally do not accompany the arteries; instead, they pass through the cribriform plates into intra-alveolar venous networks. Periodontal veins do anastomose with veins in the gingiva. A dense venous network is evident around the apex of the socket.

Nerve Supply

The nerve supply of the PDL is of the sensory and autonomic type. Autonomic supply of the PDL is not completely understood yet. Nevertheless, few descriptions are available of the sympathetic nerve supplies associated with the supply of the periodontal blood vessels. No evidence has been reported regarding parasympathetic supply.

Sensory nerve supply has been described under the functions of the PDL section. Nerves recording sensory functions have their higher centre situated in the semilunar ganglion and are brought to the periodontium through the trigeminal nerve and its end branches. Because of the presence of mechanoceptors in the PDL, small forces applied on the teeth may be identified. The movement which brings the mandibular teeth in contact with the occlusal surfaces of the maxillary teeth is arrested reflexively and altered into an opening movement if a hard object is chewed upon. This is the *jaw-jerk reflex*, which is a type of masticatory reflex very similar to the knee-jerk reflex.

Lymphatic Supply

Lymph channels draining the area beneath the junctional epithelium pass into the PDL and accompany the blood vessels into the periapical region. They continue through the alveolar bone to the inferior dental canal in the mandible and the infraorbital canal in the maxilla and then finally drain into submandibular nodes.

AGEING OF THE LIGAMENT

1. The width of the PDL normally varies between 0.2 and 0.4 mm and is maintained in response to masticatory stresses. The width is less in teeth without functional antagonists. The width of the PDL is thought to narrow down with age, as there is a reduction in biting force.
2. With regard to the extracellular matrix, changes due to ageing have been reported for both the collagen fibres and the ground substance. These consist of loss of cellularity and increasing fibrosis. The principal fibre bundles appear thicker and there may be loss of ground substance.
3. There are cellular changes in the PDL with ageing, such as reduction in the fibroblast and their collagen-degrading ability.
4. There is evidence of slower wound healing in old age.
5. In summary, ageing could make periodontal tissue more susceptible to disease because of its reduced tissue turnover and slower wound-healing ability. As a consequence, loss of tissue attachment is seen frequently in older individuals.

Applied Histology

Periodontal Pathosis

Periodontitis

Periodontitis is a chronic inflammatory disease of the periodontium. It occurs due to the effects of toxic products released by dental plaque and the bioactive molecules from the host defence mechanisms, resulting in destruction and loss of PDL tissue and adjacent alveolar bone. The outcome of this process can be pocket formation (pathologically deepened gingival sulcus) or gingival recession, tooth mobility and eventually tooth loss. The goal of periodontal therapy is to regenerate the lost tissues and restore them to their original form, architecture and function. Nevertheless, perfect repair may not take place. A major reason why periodontal regeneration is a challenge to clinicians is the need for restoration of four different tissues of the periodontium.

Scleroderma

Scleroderma or systemic sclerosis is a connective tissue disease associated with a variety of autoantibodies and is characterized by widespread subcutaneous and submucous fibrosis. In about 7% of the cases, there is evidence of uniformly widened periodontal space at the expense of the surrounding alveolar bone.

ADDITIONAL READING

Tooth Attachment Mechanism

A tooth is thought to contain two fibrous joints to accommodate masticatory cyclic loads. A gomphosis is a specialized fibrous joint which attaches teeth (cementum) to the alveolar bone. The cementodentinal junction is also termed *gomphosis* though it is narrower in width than the PDL space. It is a fibrous joint between cementum and root dentin capable of accommodating functional loads similar to that between cementum and alveolar bone. These joints are defined by the attachment of dissimilar materials through interfaces of graded stiffness, such as (i) alveolar bone attached to cementum with the PDL forming a fibrous enthesis and (ii) cementum attached to root dentin with the cementodentinal junction. (The site of soft-tissue insertions within mineralized tissues is termed *enthesis*.) The physical properties (structure, chemical composition and mechanical properties) of the enthesis within the periodontium facilitate distribution and transmission of functional loads, similar to the osteoligamentous and osteotendinous junctions in skeletal system.

Biomechanics of Periodontium

The biomechanical function of a load-bearing system is defined by the physical properties of the tissues and their interfaces. The tooth is subjected to a variety of loads of which compressive loads dominate the occlusal surface. These functional loads are accommodated by the PDL and the soft tissue–hard tissue binding interfaces, facilitating micromotion between the tooth and the alveolar bone. The PDL exhibits the property of hysteresis (the lagging of an effect behind its cause) and is viscoelastic in nature.

The structural orientation and integration of the PDL, including variations in chemical composition, results in an increase in the mechanical properties and graded stiffness. PDL consists of two distinct orientations of ligaments, namely the circumferential type and the radial type. Within the PDL space, the primary orientation of the ligament is radial. The circumferential orientation is continuous with radial type, adjacent to the alveolar bone and cementum. It contains higher carbon, lower calcium and leucine-rich proteins, which are responsible for maintaining the following:

1. Soft tissue–hard tissue cohesion
2. Stiffness of PDL
3. Hygroscopic nature of PDL–bone interface
4. PDL–cementum attachment sites

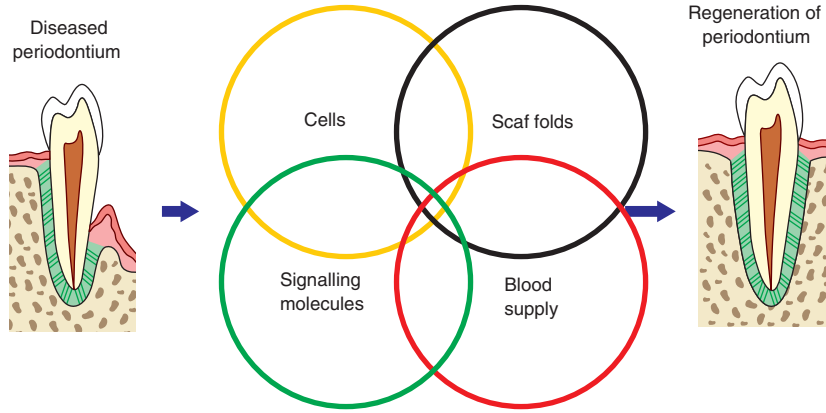
The combined structural and chemical properties provide graded stiffness to PDL–bone and PDL–cementum interfaces. The presence of circumferential ligaments leads to lower bending stress concentrations at these attachment sites. The circumferential ligament also allows stresses at the attachment sites to distribute along the direction of their fibres first, before dissipating into the adjacent bone and cementum. The transition from a softer tissue to a mineralized tissue is via graded interfaces, where the reduced elastic modulus increases gradually from PDL to bone and PDL to cementum within the bone-PDL-cementum complex. The structural integration along with the graded properties results in the biomechanical efficiency of the bone-PDL-cementum complex.

Regeneration of Periodontium

Periodontitis is an inflammatory disease affecting the periodontium, the tissues that surround and support the teeth. Periodontitis involves progressive loss of the alveolar bone around the teeth, and if left untreated, it can lead to the loosening and subsequent loss of teeth. Regeneration of periodontium is bringing back the diseased tissues to their original dimensions. It includes restoration of periodontal tissues in both height and function, formation of alveolar bone and a newly formed cementum. At the cellular level, regeneration is a complex process that requires coordination between the proliferation, differentiation and development of various cell types.

Bioactive molecules such as growth factors, cytokines, non-collagenous proteins like osteopontin, cementum attachment protein and bone sialoprotein help in induction of formative cells of the periodontium. Bone morphogenic protein and enamel matrix derivatives have also been proven to improve cementogenesis.

Stem cells remaining in the PDL after the tooth has fully developed are also used for periodontal



regeneration. During the healing of a periodontal wound, these stem cells, together with the stem cells located in the perivascular region of the alveolar bone, are stimulated to proliferate, migrate into the defect and differentiate to form new cementoblasts, PDL fibroblasts and osteoblasts. However, perfect synchronization is required to achieve a new periodontal support.

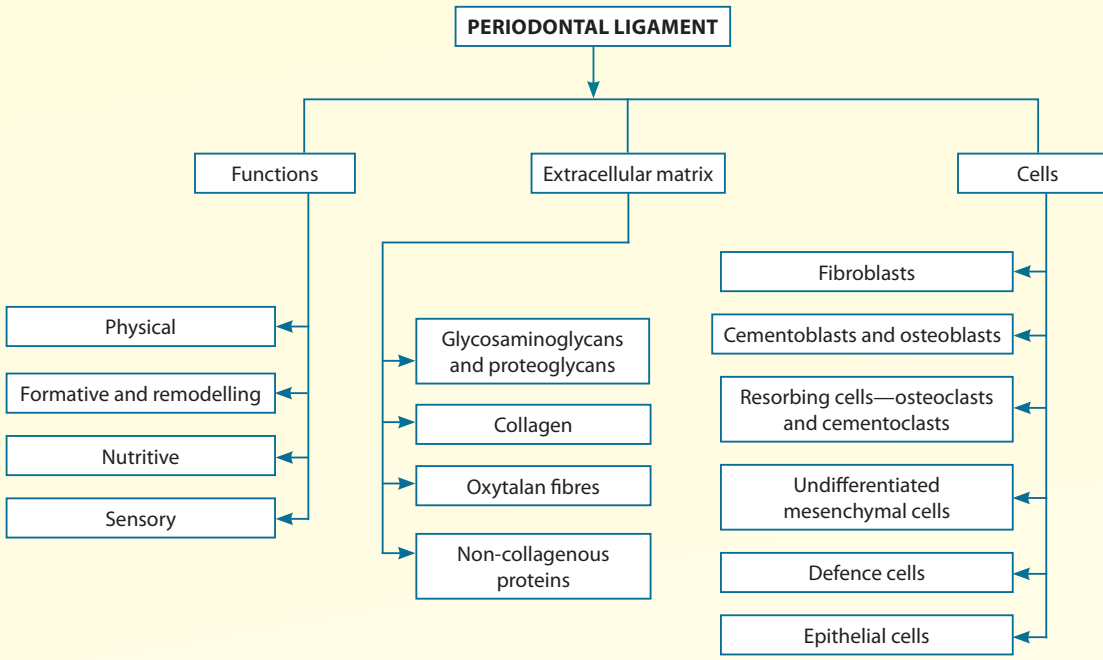
Novel Periodontal Ligament Specific Periostin

Periostin is a mesenchymal cell marker predominantly expressed in collagen-rich fibrous connective tissues, including heart valves, tendons, perichondrium, periosteum and PDL. Knockdown of periostin expression in mice results in early onset periodontitis and failure of cardiac healing after acute myocardial infarction, suggesting that periostin is essential for connective tissue homeostasis and regeneration. Periostin plays a wide variety of roles in tissue development along with disease, its function in tissue remodelling as a response to injury is a common underlying role in these different mechanisms. Periostin is transiently upregulated during cell fate changes. It influences extracellular matrix restructuring, tissue remodelling and the epithelial-mesenchymal transition, all of which can be related to tissue healing, development and disease. Thus, it functions as a mediator, balancing appropriate and inappropriate responses to tissue damage.

Key Points

1. Periodontium refers to the tissues investing and supporting the teeth, including the cementum, periodontal ligament (PDL), alveolar bone and gingiva.
2. The PDL is a highly cellular and complex vascular structure composed of fibres, cells and vascular and neural elements.
3. The average width of the periodontal space is 0.1–0.25 mm. It is widest at the mouth of the socket and at the apex, and narrowest at the axis of rotation, which is located at the junction of apical and middle third of the root.
4. The proprioceptors in PDL provide 'positional awareness'.
5. The rate of turnover of the collagen in PDL is faster when compared with all other connective tissues.

Mind Map



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Multiple Choice Questions

1. The tissues that support and invest the teeth in maxilla and mandible are collectively referred to as the
   (a) Periodontal ligament
   (b) Periodontium
   (c) Both a and b
   (d) None of the above
2. Masticatory mucosa comprises the
   (a) Gingiva
   (b) Alveolar mucosa
   (c) Dorsum of the tongue
   (d) Both a and b
3. The width of the PDL space is wider at the
   (a) Middle third
   (b) Apex
   (c) Cervical third
   (d) None of the above
4. Procollagen formation is dependent on which vitamin?
   (a) Vitamin A
   (b) Vitamin C
   (c) Vitamin E
   (d) All of the above

5. The types of collagen present in PDL are
   (a) II and III
   (b) III and IV
   (c) I and III
   (d) Both a and c
6. The inter-radicular group of periodontal fibres is present
   (a) Between two roots of multirooted teeth
   (b) In the apex
   (c) In between two teeth
   (d) All of the above
7. The fibres of the PDL which prevent intrusion of teeth are
   (a) Apical fibres
   (b) Inter-radicular fibres
   (c) Oblique fibres
   (d) None of the above
8. The cells of PDL include all except
   (a) Fibroblasts
   (b) Epithelial cell rests of Malassez
   (c) Defence cells
   (d) Langerhans cells
9. The most important property of PDL is
   (a) Mastication
   (b) Healing
   (c) Proprioception
   (d) Anti-inflammation
10. Ageing of PDL leads to the
    (a) Widening of the ligament
    (b) Narrowing of the ligament
    (c) Loss of the ligament
    (d) All of the above



CHAPTER 39

Cementum

Overview

Cementum is a part of periodontium. It is a thin layer of avascular mineralized connective tissue that covers the root portion of the teeth. Some of the physical, chemical and structural properties of cementum are similar to bone. Cementum serves in anchorage of the tooth. With disintegeration of Hertwig's epithelial root sheath (HERS), dental follicle cells come in contact with radicular dentin and differentiate into cementoblasts. Cementoblasts secrete cementum matrix which undergoes mineralization to form cementum. The incremental lines representing the rhythmic deposition of cementum are called Salter lines. Based on cellularity, cemental fibre origin, and presence or absence of fibres, cementum can be classified into many types. Each type is seen in specific locations in the tooth. Cementum possesses the capability of regeneration and hence can repair itself if lost.

INTRODUCTION

Cementum is a thin layer of mineralized connective tissue that covers the root portion of the teeth. It is considered a part of periodontium (supporting and attachment apparatus of tooth) because it gives attachment to the periodontal ligament (PDL) fibres. Some of the physical, chemical and structural properties of cementum are similar to those bone, but it is avascular, unlike bone.

PHYSICAL PROPERTIES OF CEMENTUM

Cementum is yellowish in colour and lighter when compared with dentin. It lacks a shiny surface, by which it can be distinguished from enamel. The hardness of cementum is less than that of enamel, dentin and bone.

Cementum is permeable to water and inorganic ions in normal conditions. The permeability decreases with age. Cementum varies in thickness. It is thinnest near the cervical region (20–50 μm) and gradually becomes thicker towards the apex, where it measures about 150–200 μm.

Applied Histology

Association Between PDL and Cementum Permeability

Periodontal infections can alter the normal characteristics of cementum. The permeability of cementum is affected by plaque and calculus deposits.

CHEMICAL COMPOSITION OF CEMENTUM

Cementum consists of around 45–50% inorganic components and 50–55% organic components and water.

The inorganic portion of cementum is similar to other mineralized structures such as bone and dentin. It consists of calcium and phosphate in the form of hydroxyapatite crystals. Other trace elements such as copper, iron, fluoride, magnesium, sodium, zinc, silica and potassium are present in varying amounts. Fluoride ions are present in higher concentrations in cementum than in any other hard tissue of the body. The magnesium content of cementum is half of that present in dentin.

The organic portion of cementum mainly consists of type I collagen which constitutes about 90% of the organic matrix. Smaller amounts of

collagen types III, V, VI, XII and XIV are also seen in cementum.

The non-collagenous proteins present in cementum are alkaline phosphates, osteonectin, osteocalcin, sialoprotein, osteopontin, proteoglycans and growth factors (bone morphogenic protein [BMP], fibroblast growth factor [FGF] and platelet-derived growth factor [PDGF]). These non-collagenous proteins help in the regeneration and remineralization of cementum.

Polypeptides such as cementum-derived attachment protein, referred to as CAP, and cementum-derived growth factor are expressed in the matrix cementum. They promote attachment of mesenchymal cells and may play a role in the formation of cementum. Cementum attachment protein helps to create a pool of cementoblastic population which help in the regeneration of the supporting structures of the tooth. CAP is also used as a marker to differentiate cementum and bone.

FORMATION OF CEMENTUM (CEMENTOGENESIS)

The process of formation of cementum is known as *cementogenesis*. Cementoblasts are derived from the dental sac (dental follicle) of the tooth germ and are responsible for the secretion of cementum. Cementum is formed during root formation and throughout the life of the tooth.

Under the influence of the cells of the inner enamel epithelial layer, which is one of the two layers of Hertwig's epithelial root sheath (HERS), the outermost layer of the dental papilla gets converted into odontoblasts which deposit radicular dentin along the inner aspect of the HERS. But unlike in the coronal portion, where the inner enamel epithelial cells become functional ameloblasts to form enamel, in the radicular portion the HERS gets invaded by the cells of the dental follicle. Some of the cells of the dental follicle which come in contact with the newly formed radicular dentin differentiate into cementoblasts which in turn deposit cementum over the dentin. It has also been recently proposed with evidences that the HERS epithelial cells can undergo epithelial mesenchymal transition into cementoblasts which in turn can secrete cementum matrix.

Cementoblasts

Cementoblasts are polygonal cells that secrete collagen and protein polysaccharides. They contribute to the formation of the organic matrix of cementum. The cementoblasts have numerous rough endoplasmic reticulum, mitochondria and Golgi complex. The nucleus is vesicular with two to three nucleoli.

Cementoid

The newly deposited cementum is an organic matrix consisting of collagen and ground substance and is called cementoid tissue. This later undergoes mineralization to form cementum.

The cementoblasts usually move in an outward direction during cementum formation, and as a result of this, they are seen lining the surface of the cementum. Sometimes, the cementoblasts are entrapped in the matrix during deposition. These are called *cementocytes*. Cementocytes are seen in a space called lacunae in the mineralized cementum. The cementocytes possess processes lodging in the canaliculi seen directed towards the periodontal ligament (PDL) surface. This is in contrast to osteocytes wherein the canaliculi of the cells are seen all around the osteocyte. This appearance in the cementocyte notifies that the PDL surface is the source of nutrition supply to these cells.

After sufficient increment of matrix has been deposited, mineralization of matrix occurs. Mineralization in the newly formed cementum matrix appears as fine filamentous crystals near the calcifying fronts. The crystals are parallel to the root surface in the apical region and perpendicular to the root surface in the lateral and coronal regions. Matrix vesicles are also seen. They initiate mineralization in the newly laid matrix.

As the cementum formation continues, the fibres of the developing periodontal ligament—Sharpey's fibres—are inserted into the cementum matrix and provide attachment between the tooth and the alveolar bone.

CLASSIFICATION OF CEMENTUM

1. **Based on cellularity**
   (a) *Acellular cementum*: Cementum without cells
   (b) *Cellular cementum*: Cementum with cells

2. **Based on the time of origin**
   (a) *Primary cementum*: It is the first-formed cementum and is acellular. It develops slowly as the tooth erupts, extending from the cervical portion to the coronal two-third of the root. It consists of intrinsic and extrinsic fibres (PDL).
   (b) *Secondary cementum*: It forms after the tooth reaches the occlusal plane. It consists of extrinsic and intrinsic fibres and is present in the apical third and the inter-radicular portions of the teeth.
3. **Based on the presence of collagen fibrils**
   (a) *Afibrillar cementum*: Cementum without collagen fibrils
   (b) *Fibrillar cementum*: Cementum with collagen fibrils
4. **Based on the origin of the matrix fibres**
   (a) *Extrinsic cementum*: Cementum with matrix fibres derived from the periodontal ligament
   (b) *Intrinsic cementum:* Cementum with matrix fibres derived from cementoblasts
   (c) *Mixed fibre cementum:* Cementum containing both extrinsic and intrinsic matrix fibres

Acellular Cementum

Acellular cementum appears structureless. It extends from the cementoenamel junction and covers the cervical and middle third of the root. Since it is deposited first, it is also called the primary cementum. As this type of cementum is secreted slowly, there is sufficient time for the cementoblasts to move away from the secreted matrix. Hence, the cementoblasts are not entrapped in the matrix and the primary cementum is acellular in nature.

The innermost part of the acellular cementum, near the dentin, will have collagen fibres secreted by the cementoblasts and this part is called the *primary acellular intrinsic fibre cementum*. The rest of the primary cementum consists of fibres secreted by periodontal ligament fibroblasts and this portion is called *primary acellular extrinsic fibre cementum*. The bulk of the primary acellular cementum is formed by extrinsic fibres because it is secreted after the formation of the periodontal ligament.

Ground Section of Acellular Cementum (Fig. 39.1)

Under a light microscope, primary cementum appears acellular and structureless. Incremental lines, known as *Salter lines*, are seen oriented close to each other and parallel to the root surface. These lines represent periods of deposition of new layers of cementum. They are more mineralized than the adjacent cementum. The principal fibres of the periodontal ligament (Sharpey's fibres) may be seen as light-coloured striations perpendicular to the root surface.

Cellular Cementum (Fig. 39.2)

Cellular cementum is seen at the apical third of the root. Since it is deposited after the acellular

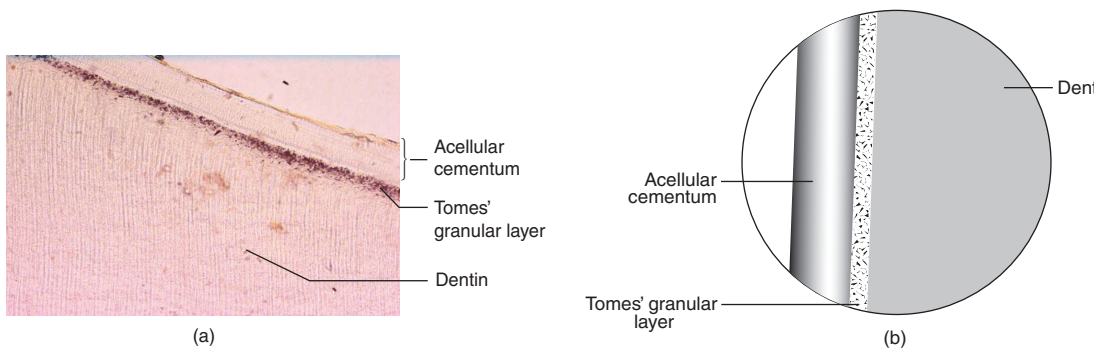


Figure 39.1 Acellular cementum and Tomes' granular layer: (a) photomicrograph (ground section, 10X) and (b) schematic diagram.

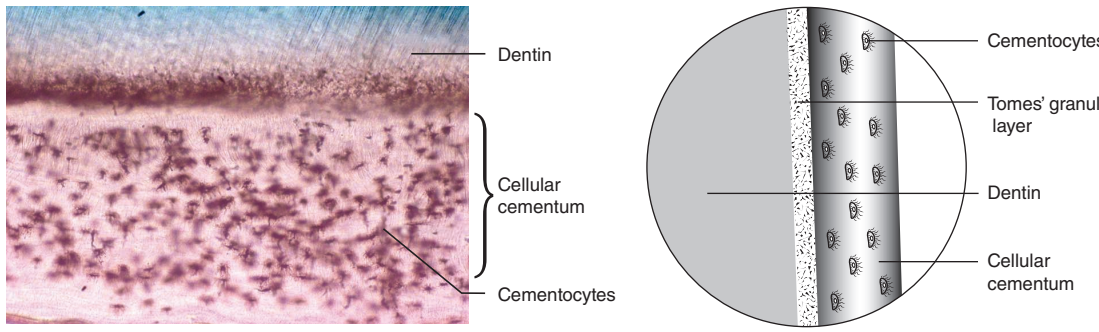


Figure 39.2 Cellular cementum: (a) photomicrograph (ground section, 40X) and (b) schematic diagram.

cementum, it is known as the *secondary cementum*. The formation of the cellular cementum is faster, leading to the entrapment of cementoblasts in the matrix.

The cellular cementum is of two types: cellular mixed fibre cementum (consisting of bone, intrinsic fibres and extrinsic fibres) and cellular intrinsic fibre cementum. A peripheral layer of cementoid with cementoblast lining is always seen in cellular cementum.

Cementocytes

Cementocytes are resting cells seen entrapped in the matrix of cellular cementum. They are similar to osteocytes and lie in a space called lacunae. Numerous cell processes or canaliculi radiate from the cell body. The cell processes extend to communicate with the adjacent cell and are seen directed towards the periodontal ligament. This arrangement ensures that they get nourishment from the periodontal ligament. Few organelles are present in the cytoplasm of cementocytes.

Ground Section of Cellular Cementum (Fig. 39.2)

The cementocytes are lost during the process of sectioning and staining, and the lacunae are filled with air and appear as dark spaces under transmitted light. Incremental lines of Salter are seen parallel to the root surface, but they are placed far apart when compared with acellular cementum. Sharpey's fibres are minimal in number and are placed at an angle to the root surface.

Acellular Afibrillar Cementum

Acellular afibrillar cementum is seen over the enamel near the cementoenamel junction. It does not have any entrapped cementocytes. Though this cementum is referred to as afibrillar, it contains fibres in the matrix, but they lack the characteristic collagen periodicity (banding).

Acellular Extrinsic Fibre Cementum

This type of cementum is present in the cervical third and covers two-third of the root of the tooth and is formed in both the pre-eruptive and the post-eruptive phases. It lacks cells and is composed of densely packed collagen fibre bundles. The extrinsic fibres are Sharpey's fibres (**Fig. 39.3**) derived from the periodontal ligament.

Cellular Intrinsic Fibre Cementum

Cellular intrinsic fibre cementum is usually seen in relation to cementum formed as a result of repair and regeneration processes. It consists of cementocytes with intrinsic fibres. The intrinsic fibres are secreted by cementoblasts. It does not possess the ability to serve as anchorage. This type of cementum is seen in the apical region of the tooth.

Mixed Fibre Cementum

This type of cementum consists of both extrinsic and intrinsic fibres. It is seen in the apical and furcation regions. It helps to reshape the root surfaces

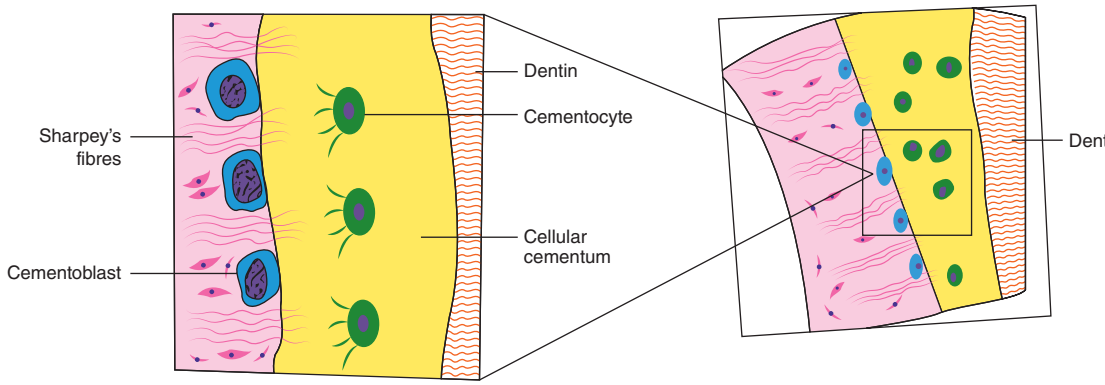


Figure 39.3 View of cemental structure and attachment of Sharpey's fibres.

in physiologic and pathologic drifting of teeth inside the tooth socket.

CEMENTOENAMEL JUNCTION (Fig. 39.4)

Cementoenamel junction (CEJ) is the junction between the cementum and the enamel at the cervical portion of the teeth, and it is variable. Three types of junctions exist:

1. **Sharp junction (butt joint):** The cementum meets the enamel in a sharp line. This type is seen in 30% of teeth.
2. **Gap junction:** The cementum does not meet the enamel in the cervical region, and there is no CEJ. A portion of the root in the cervical region will be devoid of cementum. This may be due to delay in the degeneration of Hertwig's epithelial root sheath, thereby preventing the contact between dental sac cells and dentin, leading to lack of differentiation of cementoblasts. This type of junction is seen in 10% of teeth.
3. **Overlap junction:** The cementum overlaps the enamel. This occurs when the reduced enamel epithelium covering the crown degenerates near the cervical region, permitting the dental sac cells to come into contact with the enamel. The cells differentiate into cementoblast and thereby deposit cementum over the enamel. This is the most common type of CEJ, seen in 60% of the teeth.

Very rarely, the enamel overlaps the cementum at the junctional region.

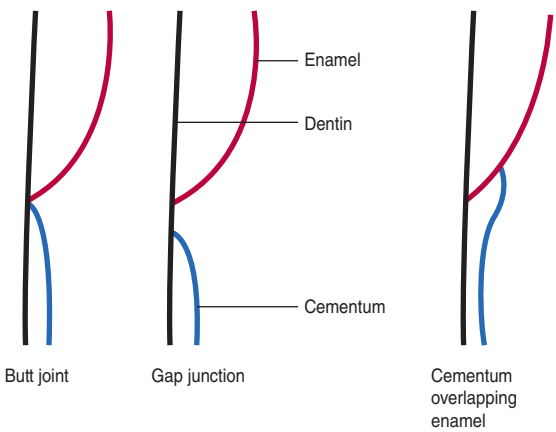


Figure 39.4 Cementoenamel junction.

CEMENTODENTINAL JUNCTION

Cementodentinal junction (CDJ) between cementum and dentin is usually smooth but can be scalloped in deciduous teeth. The CDJ is more prominent in cellular cementum than acellular cementum. At the CDJ, the dentinal fibres intermingle with the cemental fibres. Rarely, cementum is separated from dentin by a layer called intermediate cementum. It appears structureless and does not show features of either cementum or dentin. Intermediate cementum is also known as the *hyaline layer of Hopewell Smith*, and it is mostly seen in the apical portion of the root.

RESORPTION AND REPAIR OF CEMENTUM

Applied Histology

Cementum is comparatively more resistant to resorption than bone. This feature is utilized in orthodontic tooth movement. Controlled application of pressure during orthodontic tooth movement causes resorption in bone rather than in cementum, making movement of teeth possible.

In cases of excessive trauma, localized areas of resorption occur in cementum. In such conditions, repair takes place by deposition of cementum by cementoblasts. The repair tissue that forms is cellular type. Repair in cementum occurs in two ways (**Fig. 39.5**):

1. **Anatomical repair:** The resorbed area is completely filled up with cementum. The continuity of the root surface and the periodontal attachment is re-established.
2. **Functional repair:** The resorbed area is filled up partially, resulting in a bay-like defect on the root surface. The alveolar bone forms a bony projection to establish the normal physiologic width of the periodontal attachment.

Applied Histology

Orthodontic Treatment

When compared with bone, cementum is more resistant to resorption because of its avascularity. Bone undergoes degenerative changes faster due to its rich vascularity. This feature is made use of in orthodontic tooth movement. The pressure which is applied during orthodontic treatment causes bone resorption while the cementum shows minimal or no resorption. This helps in the alignment of teeth.

Tooth Sensitivity

Apical migration of gingiva leads to exposure of cementum. As cementum is softer than enamel, it wears away faster than enamel. Loss of cementum leads to exposure of dentin, causing sensitivity and increased susceptibility to root caries.

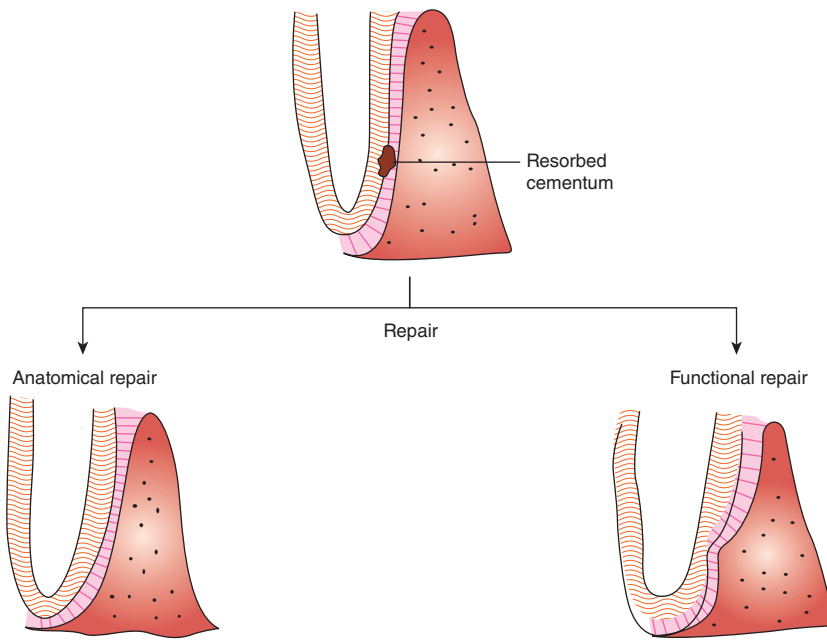


Figure 39.5 Cementum repair.

FUNCTIONS OF CEMENTUM

1. **Anchorage (attachment):** Cementum provides a medium for the attachment of periodontal ligament fibres, thereby helping in binding of tooth with alveolar bone. Acellular cementum is mainly involved in the attachment process.
2. **Adaptation:** Masticatory forces cause occlusal wearing, thereby reducing the tooth length. By the continuous deposition of cellular cementum at the apical region of root, the decrease in tooth length is compensated and an occlusal relationship is maintained.
3. **Repair:** Fracture or resorption occurring in the roots is repaired by the deposition of cellular cementum, because it forms at a faster rate.

Applied Histology

Cementum Pathosis

Hypercementosis

Excessive deposition of cementum is called hypercementosis. It may be diffused or localized and may affect single or multiple teeth. Hypercementosis involving multiple teeth is a feature in Paget's disease. It causes difficulty during extraction. When excessive deposition of cementum improves the function of a tooth, it is known as *cementum hypertrophy* whereas excessive deposition of cementum in a non-functional tooth is known as *cementum hyperplasia*.

Hypophosphatasia

It is a hereditary condition characterized by loosening and premature loss of anterior deciduous teeth. Loss occurs due to the absence of cementum in the teeth. There is no proper attachment between the teeth and alveolar bone by periodontal ligament fibres.

Cementicles

They are small masses of cementum attached to the root surface or located freely in the periodontal ligament. Cementicles occur due to microtrauma causing a tear in the cementum. They are more common in the apical and middle third regions of root and in furcation areas.

Cemental Spurs

Excessive deposition of cementum on the root surface can appear as attached spheres called cemental spurs much similar to enamel pearls. They can be misinterpreted as calculus clinically or radiologically.

ADDITIONAL READING

Bone and Cementum

Phenotypic similarities between the osteoblast forming the bone and the cementoblast forming the cellular intrinsic fibre cementum have been proven. There are few more similarities and differences between the bone and cementum, listed in **Table 39.1**.

Resistance to Resorption

Cementum is more resistant to resorption when compared to bone. This fact is attributed to the avascular nature of cementum and the rich vascularity of bone. Bone undergoes physiologic resorption; the cells covering bone surfaces play a regulatory role on the osteoclasts. Exposure of the bone surface to hormones and inflammatory mediators causes resorption, allowing osteoclasts to colonize the surface. Unlike the bone surface, the root surface is not affected by parathyroid hormone which is an important hormone mediating the serum calcium level. This is because the layer of cells covering the root surface forms a protective barrier against resorption. Parathyroid hormone receptors are present in cellular intrinsic fibre cementum and absent in acellular extrinsic fibre cementum. Hence, cellular cementum responds to regulatory molecules similar to bone whereas acellular cementum shows a very mild response.

Incremental Lines

The rhythmic deposition of cementum is represented by incremental lines of Salter. They do not have a regular rhythmic distribution as seen in other mineralized tissues of tooth structure. They are unevenly spaced. Incremental lines in acellular cementum are arranged more regularly and evenly than in the cellular cementum. Counting

Table 39.1 Similarities and Differences Between Bone and Cementum

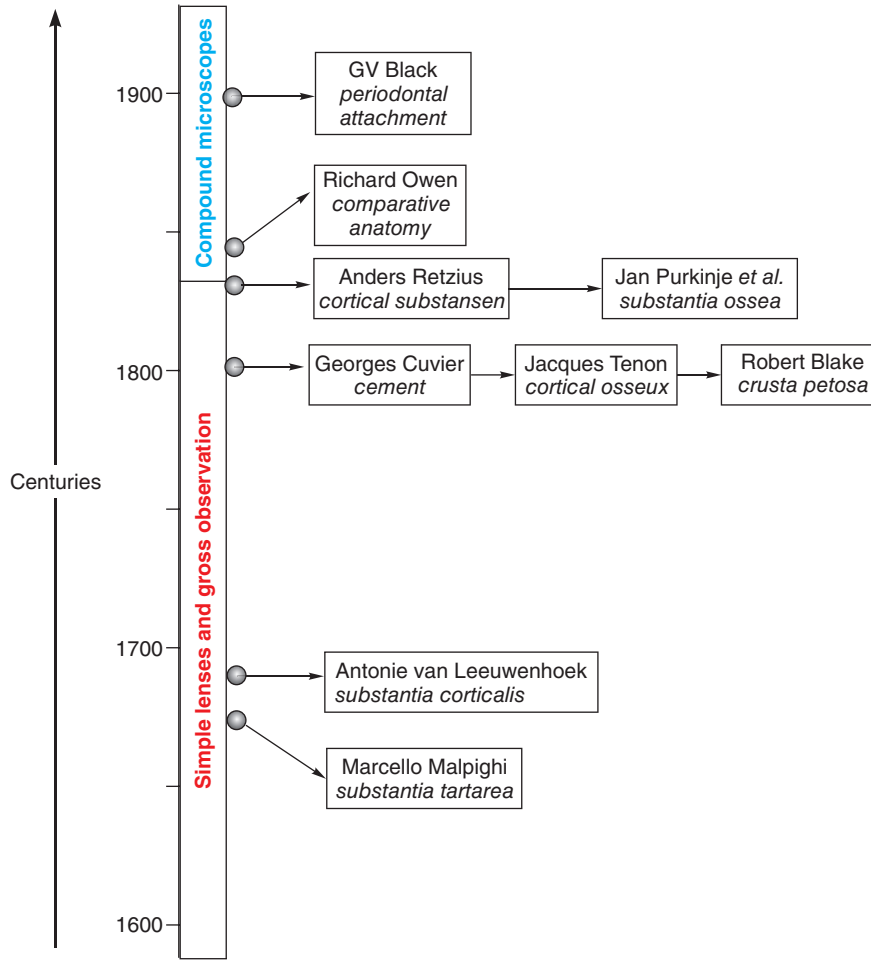
Features	Bone	Cementum
	Similarities	
Cells	Osteoblasts, osteocytes and osteoclasts	Cementoblasts, cementocytes and odontoclasts
Extracellular matrix	Predominantly type I collagen	Predominantly type I and type III collagen
Non-collagenous proteins	Bone sialoprotein and osteopontin	Both bone sialoprotein and osteopontin are present in smaller quantities
Inorganic component	Predominantly calcium and phosphate in the form of hydroxyapatite	Predominantly calcium and phosphate in the form of hydroxyapatite
	Differences	
Composition	67% inorganic material, 33% organic material	45% inorganic material, 33% organic material and 22% water, approximately
Non-collagenous proteins	Cementum attachment protein absent; fibromodulin and lamican are absent	Cementum attachment protein present; fibromodulin and lamican are present
Rate of apposition	1–2 μm/day (lamellar bone)	0.005–0.01 μm/day (acellular cementum)
Vascularity	Vascular	Avascular
Nerve supply	Richly innervated	Lacks nerve supply
Ability to remodel	Effective remodelling capacity	Limited ability to remodel
Resistance to resorption	Resorbs quickly under hormonal influences	Resistant to resorption when compared to bone

of incremental lines of acellular cementum has been proven to be a reliable indicator of age and of events in life which evoked a disturbance in the metabolism.

Cementum During Orthodontic Tooth Movement

Osteoclast activation and differentiation occurs during resorption of cementum due to excessive orthodontic forces. Numerous biological mediators, including hormones, cytokines, macrophage colony-stimulating factor (M-CSF), and RANK, RANKL and OPG signalling pathways, regulate differentiation and function of cementoclasts/odontoclasts. Upregulation of RANKL occurs in fibroblasts, osteoblasts, and other resident and transient cells in the compressed periodontal ligament in response to orthodontic loading. Cementum repair is initiated with fibroblast-like cells from the periodontal ligament which invade the sites of resorption. The architecture of the collagen structure determines the pattern of deposition of the non-collagenous proteins. The fibroblast-like cementoblastic cells secrete non-collagenous matrix proteins, particularly osteopontin and bone sialoprotein, and fill up the spaces in the residual collagen fibril structure. Collagen fibrils secreted by the cementoblasts intermingle with the residual fibrils of the existing collagenous structure forming a thin cementoid repair matrix. This type results in formation of intrinsic fibre of cementum. Further mineralization with hydroxyapatite crystals occurs forming reparative cementum. Mechanical loading forces during orthodontic treatment induce Cox-2 mRNA expression and the synthesis of prostaglandin (PGE2) in cementoblastic precursors. PGE2 further mediates differentiation of cementoblasts and upregulates expression of genes involved in mineral metabolism, including osteocalcin and alkaline phosphatase (excerpts from Feller et al. 2016).

TIMELINE IN THE DISCOVERY OF CEMENTUM



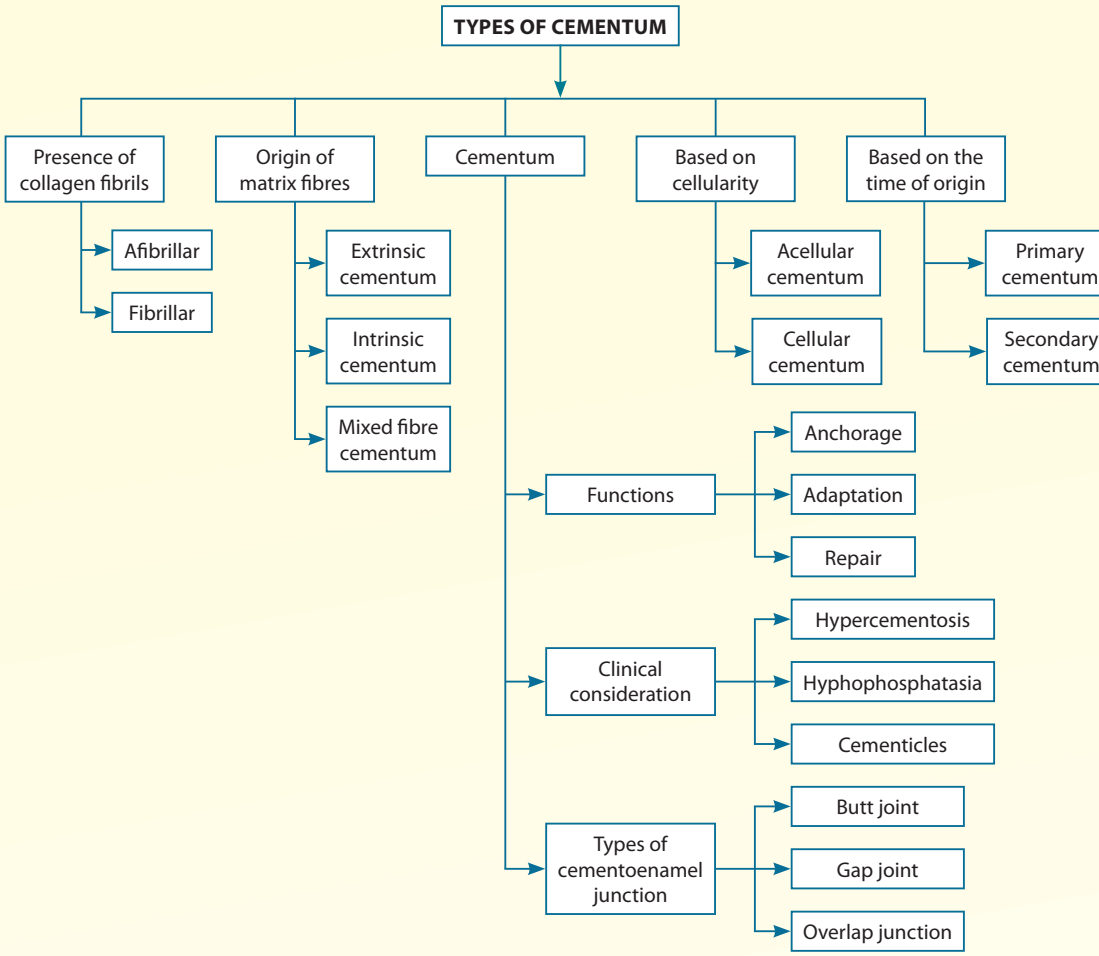
Adapted from Foster et al., 2017.

SECTION IV

Key Points

1. Cementum consists of around 45–50% inorganic components and 50–55% organic components and water.
2. Higher content of fluoride is present in cementum when compared with any other hard tissues of the body.
3. The newly deposited cementum is an organic matrix consisting of collagen and ground substance and is known as *cementoid tissue*.
4. Cementocytes are similar to osteocytes and they lie in a space called lacunae.
5. Different types of cementum can be described by combining the types of fibres (intrinsic and extrinsic) and the presence or absence of cementocytes.
6. Acellular afibrillar cementum is seen over the enamel near the cementoenamel junction (CEJ).
7. Cementum overlapping the enamel is the most common type of CEJ, seen in 60% of teeth.
8. Excessive deposition of cementum is called *hypercementosis*.

Mind Map



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Multiple Choice Questions

1. Fluoride content is more in the
   (a) Cementum
   (b) Bone
   (c) Enamel
   (d) Dentin
2. The type of collagen seen predominantly in the cementum is
   (a) Type III
   (b) Type II
   (c) Type I
   (d) All of the above
3. Extrinsic fibres in cementum are secreted by
   (a) Periodontal ligament fibroblasts
   (b) Cementoblasts
   (c) Osteoblasts
   (d) Cementocytes
4. Incremental lines of cementum are
   (a) Retzius
   (b) von Ebner
   (c) Salter lines
   (d) Both a and b
5. Acellular extrinsic fibre cementum consists of
   (a) Intrinsic fibres
   (b) Cells
   (c) Extrinsic fibres
   (d) All of the above
6. Secondary cementum is known as cellular cementum because of the presence of
   (a) Osteocytes
   (b) Cementocytes
   (c) Chondrocytes
   (d) Cementoclasts
7. The commonest type of cementoenamel is the
   (a) Butt joint
   (b) Gap junction
   (c) Enamel overlapping cementum
   (d) Cementum overlapping enamel
8. Intermediate cementum is also known as the
   (a) Hyaline layer
   (b) Mixed fibre cementum
   (c) Hyaline layer of Hopewell Smith
   (d) None of the above
9. The type of cementum predominantly involved in the process of attachment with the periodontal ligament is
   (a) Cellular
   (b) Acellular
   (c) Both a and b
   (d) None of the above
10. Functional repair of cementum is
    (a) Repair without a defect, restoring the normal anatomy
    (b) Repair with a bay-like defect
    (c) Formation of a bony projection by the alveolar bone to establish the normal physiologic width of the periodontal attachment
    (d) Non-formation of a bony projection by the alveolar bone and the extension of the periodontal ligament to fill the defect
    (e) Both b and c

CHAPTER 40



Bone

Overview

Endoskeleton of vertebrates is constituted by a rigid form of specialized connective tissue—bone. The inorganic (33%) and organic (67%) components of bone consist of hydroxyapatite and collagen and non-collagenous proteins such as proteoglycans, osteocalcin, osteonectin and osteopontin, respectively. Grossly, bone is composed of compact bone and cancellous bone with a lamellar arrangement. The basic unit of bone is Osteon which is composed of a Haversian canal in the centre. The adjacent Haversian canals are connected by Volkmann canals. Bone is surrounded by periosteum. Osteoblasts, osteoclasts and osteocytes are the cells of the bone. The part of the maxilla and mandible that forms and supports the sockets of the teeth is called alveolar bone. Alveolar bone is further composed of alveolar bone proper, which is the bone seen just around the tooth, and supporting bone, which supports the alveolar bone proper. The architecture of bone in terms of compact or cancellous nature varies between maxilla and mandible as well as in the regions of the same jaw.

INTRODUCTION

Bone is a rigid form of a specialized connective tissue that constitutes the endoskeleton of vertebrates. It helps in functions such as movement, support and protection of the various organs of the body. Bone is a dynamic tissue, which is continually being formed and resorbed in response to mechanical, nutritional and hormonal influences throughout life. It also serves as a source of calcium and helps meet the demands of the body when the serum calcium levels decrease.

Bone is composed of 67% organic and 33% inorganic substances. The inorganic component consists of hydroxyapatite. The organic component consists of collagen and non-collagenous proteins such as proteoglycans, osteocalcin, osteonectin and osteopontin.

CLASSIFICATION OF BONE

Classification of bone based on its gross appearance has been discussed in detail in Chapter 2.

On the basis of its histologic appearance, the bone can be classified into the following:

1. Mature bone/lamellar bone
2. Immature bone/woven bone

Mature Bone

Mature bone is further classified into compact and cancellous bone:

1. **Compact bone:** It is dense in nature. The hard outer layer of the bone is composed of cortical bone tissue with minimal gaps and spaces. Its porosity is 5–30%. This tissue gives bone the smooth, white and solid appearance and accounts for 80% of the total bone weight of an adult skeleton.
2. **Cancellous bone:** Porous or sponge-like bone is called cancellous bone. It is highly vascular and consists of numerous spaces mostly filled with red bone marrow that gives it a honeycomb-like or spongy appearance. The red marrow is present at a younger age and is replaced by yellow marrow as the age increases. Cancellous or *spongy bone* is found at the ends of long bones and forms the major component of bones because it presents a large surface area that responds readily to the physical and metabolic demands of the body. Cancellous bone is more metabolically active than compact bone and has a higher remodelling rate.

Immature Bone

The immature bone is also called *woven bone*. The collagen fibres are randomly interwoven in various directions, lending the term *woven* to this type of bone. The woven bone appears haematoxyphilic or blue because of increased proteoglycan content compared with mature bone. Woven bone is formed when osteoblasts produce osteoid rapidly, which occurs initially in all foetus bones, and is later replaced by stronger lamellar bone. Woven bone develops in adults during bone repair.

GROSS STRUCTURE OF BONE

The gross appearance of bone consists of a dense outer compact bone with a central marrow component that is interrupted by a network of bony trabeculae called the cancellous bone. Both the compact and the cancellous bone consist of microscopic layers or *lamellae*.

The lamellae are arranged regularly around the blood vessels. *Osteon* is the basic unit of bone and it is shaped in the form of a cylinder (**Fig. 40.1**). The centre of this cylindrical structure has the *Haversian canal*, which contains blood vessels. The adjacent Haversian canals are connected by *Volkmann canals*, which also carry small blood vessels. These canals run within the osteons, perpendicular to the Haversian canals, interconnecting each other and the periosteum. This forms a continuous and complex system of canals. Each lamella contains collagenous fibres that are parallel to each other. Each Haversian canal is surrounded by concentric lamellae.

The compact bone is surrounded by a connective tissue layer called the *periosteum*. It consists of two layers: outer fibrous layer and inner endosteal layer. Bone contains a large population of cells that are embedded in the intercellular matrix they produce. Cells present in the bone are the osteoblast, osteocyte and osteoclast.

Cells

Osteoblasts

Osteoblasts (**Fig. 40.2**) are progenitor cells that help in the synthesis of bone matrix. They are round to polygonal cells seen lining the forming surfaces of bone. They have a single nucleus, which is eccentrically placed away from the adjacent bone surface. As osteoblasts have a secretory function, they have abundant cellular organelles required for an active protein synthesis. The cytoplasm has numerous rough endoplasmic reticulum which give the cell a deep basophilic appearance. These synthesize procollagen molecules which are stored in the Golgi complexes as secretory vesicles. Exocytosis of these secretory products takes place and the molecules are assembled extracellularly as fibrils to form the osteoid layer. Osteoblasts also secrete cytokines that regulate cell metabolism. They also contain the alkaline phosphatase enzyme which helps in creating an alkaline environment for bone formation.

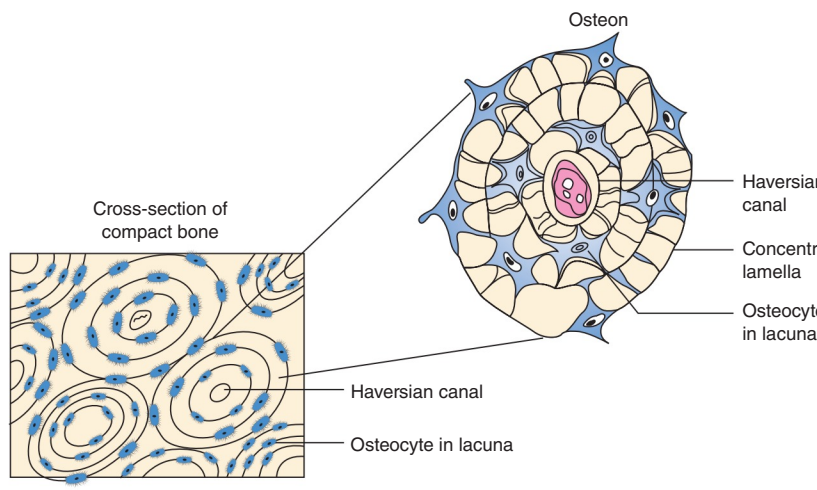


Figure 40.1 Histology of bone.

SECTION IV

Osteocytes

Resting osteoblasts are called osteocytes (**Fig. 40.2**). Once the osteoblasts secrete the extracellular matrix and are entrapped, they reduce in size and form the osteocytes. These cells are smaller and less basophilic than osteoblasts. The space in which the osteocytes are present is called the *osteocytic lacuna*. The osteocytes have fewer cellular organelles when compared with an osteoblast but possess the necessary organelles required for continuous production of matrix components throughout life. They also have cytoplasmic processes. These participate in calcium homeostasis by mobilizing calcium in and out of the bone matrix.

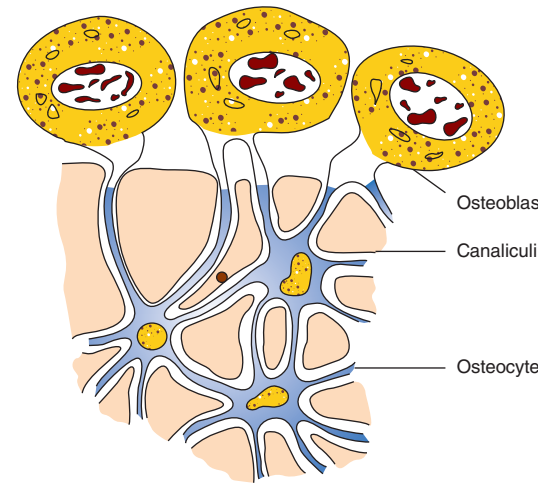


Figure 40.2 Osteoblasts and osteocytes.

Osteoclasts

Osteoclasts are bone-removing cells (**Fig. 40.3**). They are seen on the resorbing surfaces of the bone. Some osteoclasts are seen lying in resorption bays or recesses called *Howship's lacunae* formed by erosion of bone. Osteoclasts are large cells (about 100 microns) and are multinucleated (10–20 nuclei).

Osteoclasts have the following four zones:

1. **Ruffled border:** The part of the osteoclast involved in carrying out resorption is called the ruffled border, and it is made up of finger-like processes extending into the bone surface which is to be resorbed.
2. **Sealing zone:** This zone is present at the outer region of the ruffled border. It helps the cell to make a close contact with the bone and prevents the resorptive ions such as protons and proteases from damaging the adjacent tissues.
3. **Basolateral zone:** The basolateral surface acts as an area receiving regulatory signals from the adjacent cells.
4. **Secretory zone:** This zone is the area from which the resorbed products or degraded

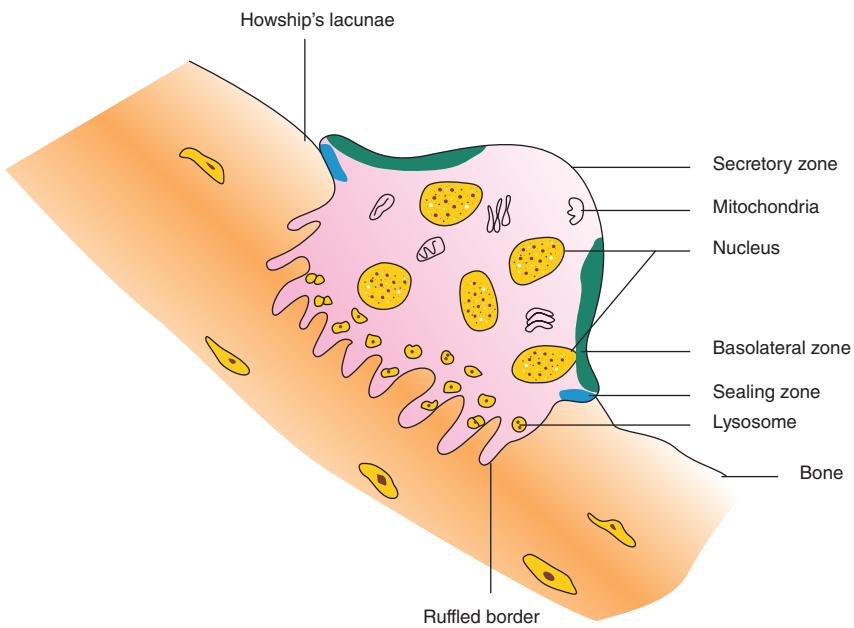


Figure 40.3 Osteoclast.

bone matrix are moved out of the cell (exocytosis). It contains numerous mitochondria, abundant Golgi complexes, rough endoplasmic reticulum and lysosomes. The lysosomes contain acid phosphatase and other lysosomal enzymes. Lysosomal enzymes along with matrix metalloproteinases help in the degradation of bone.

Bone Matrix

The major portion of the bone consists of the matrix. It has inorganic and organic components. The inorganic component of bone consists of *carbonated hydroxyapatite* ($Ca_{10}[PO_4]_6[OH]_2$). They are in the form of needle-like crystals or plates. The matrix is initially laid down as unmineralized *osteoid* and is later mineralized.

The organic part of matrix is mainly composed of collagens. The types of collagen seen in bone are types I, III and V, of which type I is more predominant. Collagen provides resilience to bone tissue and helps prevent fractures. Non-collagenous proteins also contribute to the organic component. Examples of non-collagenous protein include proteoglycans and glycoproteins such as osteonectin, osteopontin and osteocalcin. Other exogenous proteins which form part of the bone matrix include cytokines such as interleukins and growth factors.

TURNOVER OR REMODELLING OF BONE

Bone remodelling is a continuous process of bone resorption and bone formation for maintaining normal bone mass. It involves the removal of mineralized bone by osteoclasts followed by the formation of bone matrix through the osteoblasts. Bone remodelling serves to adjust bone architecture to meet changing mechanical needs, and it helps to repair microdamages in bone matrix, preventing the accumulation of old bone. It also plays an important role in maintaining plasma calcium homeostasis. The regulation of bone remodelling is both systemic and local.

The part of bone that shows the beginning of resorption is called the *cutting cone*. This zone is lined by osteoclasts. After a layer of bone is resorbed, mononucleated cells colonize that region and differentiate into osteoblasts. Osteoblasts produce a layer of bone called the *reversal line* over which new bone is laid down to form an osteon and is mineralized. This zone where laying of new bone takes place is called the *filling cone*.

The systemic factors that regulate remodelling are the parathyroid hormone (PTH), calcitriol and other hormones such as the growth hormone, glucocorticoids, thyroid hormones and sex hormones. Factors such as insulin-like growth factors (IGFs), prostaglandins, tumour growth factor-β (TGF-β), bone morphogenetic proteins (BMP) and cytokines are also involved. The receptor activator of NF-κB (RANK) ligand (RANKL) and osteoprotegerin (OPG) system regulates the osteoclast. RANKL induces formation of osteoclast while OPG inhibits formation.

ALVEOLAR BONE

The alveolar bone is a part of the maxilla and mandible that forms and supports the sockets of the teeth. It consists of an outer cortical bone and a central trabecular bone. Along with the cementum, the alveolar bone forms the attachment apparatus of the teeth. The alveolar bone is similar to the bone in other parts of the body. It is also referred to as *pars alveolaris* or the alveolar process. The alveolar bone in between the roots of teeth is called the *interdental septum*. The bone which supports the alveolar bone is called the *basal bone* (**Fig. 40.4**).

Development of the Alveolar Bone

The alveolar bone is a tissue of mesenchymal origin. It forms in the early foetal life, during the initial stages of tooth development. It develops from the cells of the dental follicle. After the first layer of radicular dentin is laid down, the Hertwig's epithelial root sheath gets invaded by the cells of the dental follicle and loses its continuity. The cells of the dental follicle then come in contact with the radicular dentin, following which there is differentiation of cementoblasts, osteoblasts and fibroblasts. The osteoblasts are responsible for the formation of the alveolar bone.

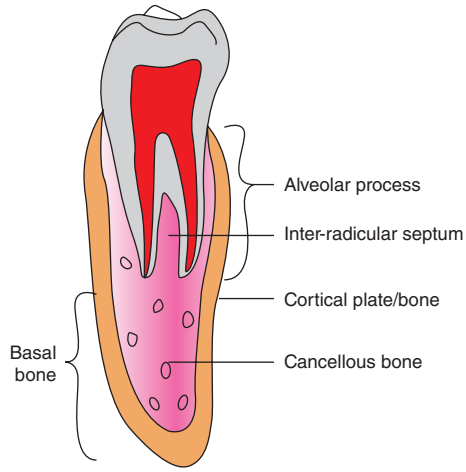


Figure 40.4 Longitudinal section through the jawbone.

This process leads to the contact of radicular dentin with the dental follicle cells.

Development begins with mineral deposition at the small foci in the mesenchymal matrix surrounding the tooth buds. These small, mineralized areas increase in size, fuse and become resorbed and remodelled until a continuous mass of bone is formed. The bone develops in an irregular arrangement and then takes up a definite structure. The development of the alveolar process depends on the root formation and occurs only during the eruption of teeth. The alveolar bone is present as long as the tooth is present in the alveolus; after tooth extraction, the alveolar bone is lost, and only the basal jawbone is left behind in an edentulous jaw.

Applied Histology

Tooth Germ and Alveolar Bone

Developmental disturbances leading to absence of tooth germ in turn leads to non-development of the alveolar bone. This can pose difficulties in rehabilitation procedures.

Functions

1. Supports the teeth
2. Provides a framework for bone marrow
3. Acts as a reservoir for ions, especially calcium
4. Helps distribute and absorb forces during mastication

Parts of the Alveolar Process

The alveolar bone and the basal bone of the mandible do not have any clear-cut boundaries. The alveolar bone can be divided into two parts on the basis of how it has adapted itself to provide its function.

The alveolar process has two parts:

1. Alveolar bone proper
2. Supporting alveolar bone

Alveolar Bone Proper

The alveolar bone proper is just adjacent to the tooth socket around the root, and it gives attachment to the principal periodontal ligament fibres. The alveolar bone proper is also called *cribriform plate* as it has a sieve-like arrangement because of the presence of perforations and canals for the entry of vessels and nerves. The alveolar bone proper is made up of bundle bone and lamellated bone.

Bundle Bone The bone which is the site of attachment for the periodontal fibres is called the *bundle bone*. These fibres which enter the bone are referred to as *Sharpey's fibres*. Sharpey's fibres are oriented oblique or at right angles to the surface of the tooth. These fibres are arranged in a regular manner in the form of bundles giving rise to the term *bundle bone*. The fibres attached to the alveolar bone are larger than the fibres getting attached to the cementum. Sharpey's fibres consist of a central core region which is uncalcified and is surrounded by a calcified outer layer; some of the fibres are completely calcified.

Occlusal forces have an effect on the bundle bone. The normal physiologic tooth movement can cause remodelling of this region. In some areas of the alveolar bone proper, the bundle bone is absent.

Lamina Dura A thin layer of compact bone of the alveolar bone proper appears as a radiopaque area lining the tooth socket; this is called the *lamina dura*. The increased radiopacity of lamina dura when compared with the supporting alveolar bone is due to the difference in orientation of the mineral crystals. The total mineral content is the same in both the regions.

Applied Histology

Significance of Lamina Dura in Diagnostics

Interruptions in the continuity of the lamina dura in the apical region of an alveolus are of diagnostic significance in the radiographic identification of periapical lesions. This discontinuity indicates inflammation and disease process.

Lamellated Bone The bone immediately adjacent to the bundle bone is the *lamellated bone*. It contains lamellae, which are thin plate-like structures arranged parallel to each other. It also consists of Haversian systems, osteon and canaliculi. Each osteon consists of concentric layers or lamella of osseous tissue that surround the central Haversian canal. The Haversian canal contains the bone's nerve and blood vessels. Between the adjoining osteons, there are angular intervals that are occupied by interstitial lamellae.

Interdental Septum The alveolar bone between the adjacent teeth is called the *interdental septum*. It is composed of the compact bone of the alveolar bone proper and trabecular/cancellous bone. It is the bone that divides one socket from another. The alveolar bone between the roots of the same tooth is called the *inter-radicular septum* and is seen in molars with two or three roots.

Supporting Alveolar Bone

The supporting alveolar bone has two regions:

1. **Cortical bone:** It contains cortical plates. The cortical plates are narrower in the maxillary region and thickest in the molar region of the mandibular bone. They are seen on the facial and lingual surface of the alveolar bone.
2. **Spongy bone:** It is also called *spongiosa* or *cancellous bone*. It contains trabeculae that enclose irregularly shaped marrow spaces. The pattern of the trabecular arrangement varies widely as it depends on the occlusal forces. The spongy bone is seen more in the maxilla than in the mandible and is predominant in the inter-radicular spaces.

   The spongy bone is further divided into two types in a dentulous jaw:

   (a) *Type I:* This contains trabeculae that are present regularly in a ladder-like arrangement.

   (b) *Type II:* This contains trabeculae in an irregular arrangement.

   Type I is seen more in the mandibular alveolar bone and Type II in the maxillary alveolar bone.

Density of the Alveolar Bone

The density of the alveolar bone is more in the anterior regions of the maxilla and the mandible than in the posterior regions.

According to the *Carl E. Misch Classification* system (**Fig. 40.5**), the density of bone is classified into four types in an edentulous jawbone:

1. **D1:** Primarily made of cortical bone
2. **D2:** Consists of coarse trabecular bone covered by dense cortical bone
3. **D3:** Consists of fine trabecular bone covered by thin cortical bone
4. **D4:** Contains only trabecular bone without crestal cortical bone

Structure of the Alveolar Bone

The morphology of the alveolar bone varies between different individuals. The alignment, angulation of the teeth and amount of occlusal forces in a particular region greatly influence the morphology of the alveolar bone. The height and thickness of the alveolar bone differ according to the inclination of the teeth. The distance between the cementoenamel junction and the crestal margin of the alveolar bone is 1.5–2 mm in healthy individuals.

Proportion of the Alveolar Bone in the Maxilla

The architecture of the alveolar bone in the maxilla varies due to the presence of maxillary

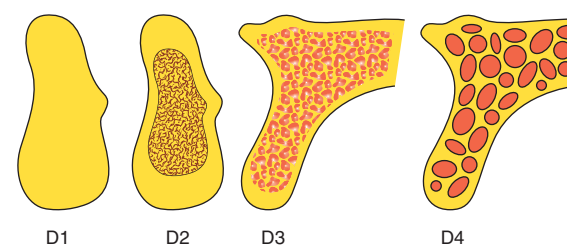


Figure 40.5 Density of bone in an edentulous jaw—Carl E. Misch classification.

sinus and proximity to the floor of the nasal cavity. A cross-section of the alveolar bone at the middle third of the root reveals that the thickness is more in the palatal aspect than in the buccal aspect. Bone thickness in the anterior region is lesser than that in the posterior regions. The outer cortical plates of the jawbones lie closer to the anterior teeth than the posterior teeth. Cancellous bones occupy the area between the two cortical plates more often in the posterior teeth region than in the anterior teeth region (**Figs 40.6–40.8**).

Proportion of the Alveolar Bone in the Mandible

The cortical plates of the mandible are thicker than in the maxilla. The arrangement of the compact and cancellous bone is similar in both, with the anterior teeth regions directly apposed by compact bone and a lesser amount of cancellous bone in between. The posterior teeth region has more of cancellous bone in between the cortical bone (**Figs 40.6–40.8**).

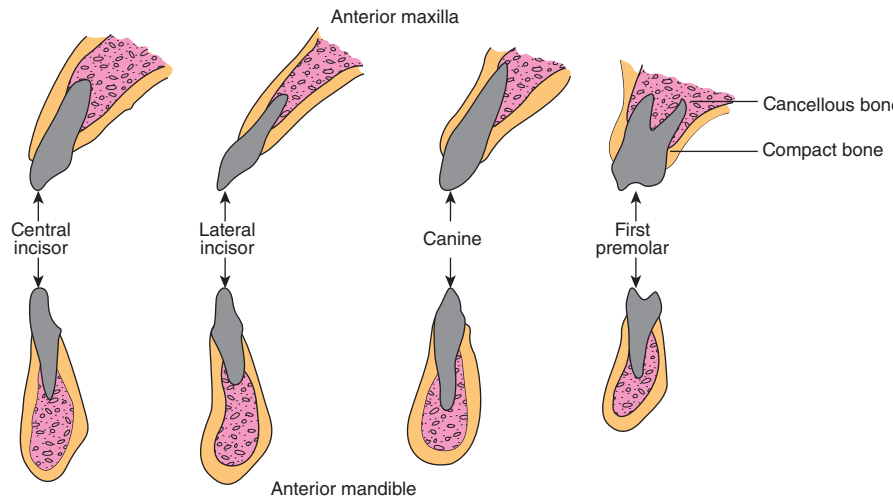


Figure 40.6 Proportion of cancellous bone and compact bone in the anterior region.

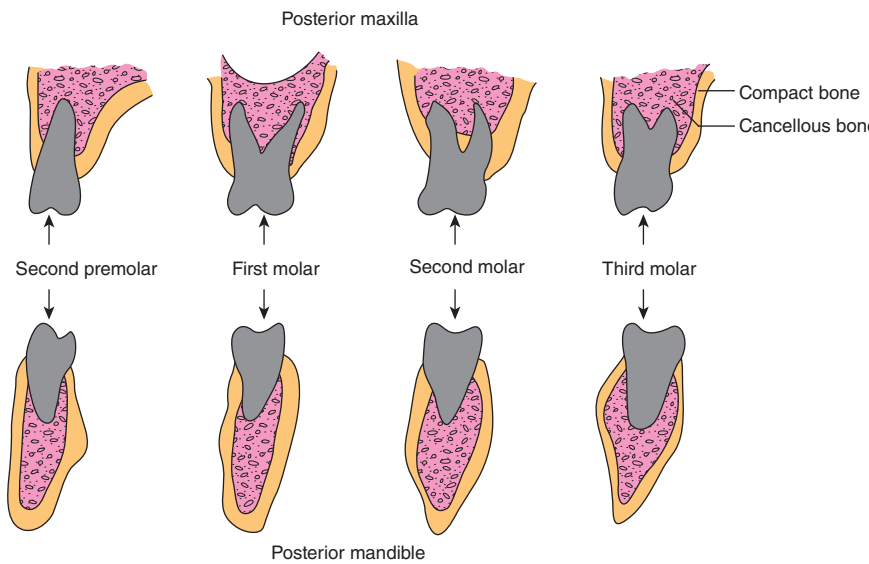


Figure 40.7 Proportion of cancellous bone and compact bone in the posterior region.

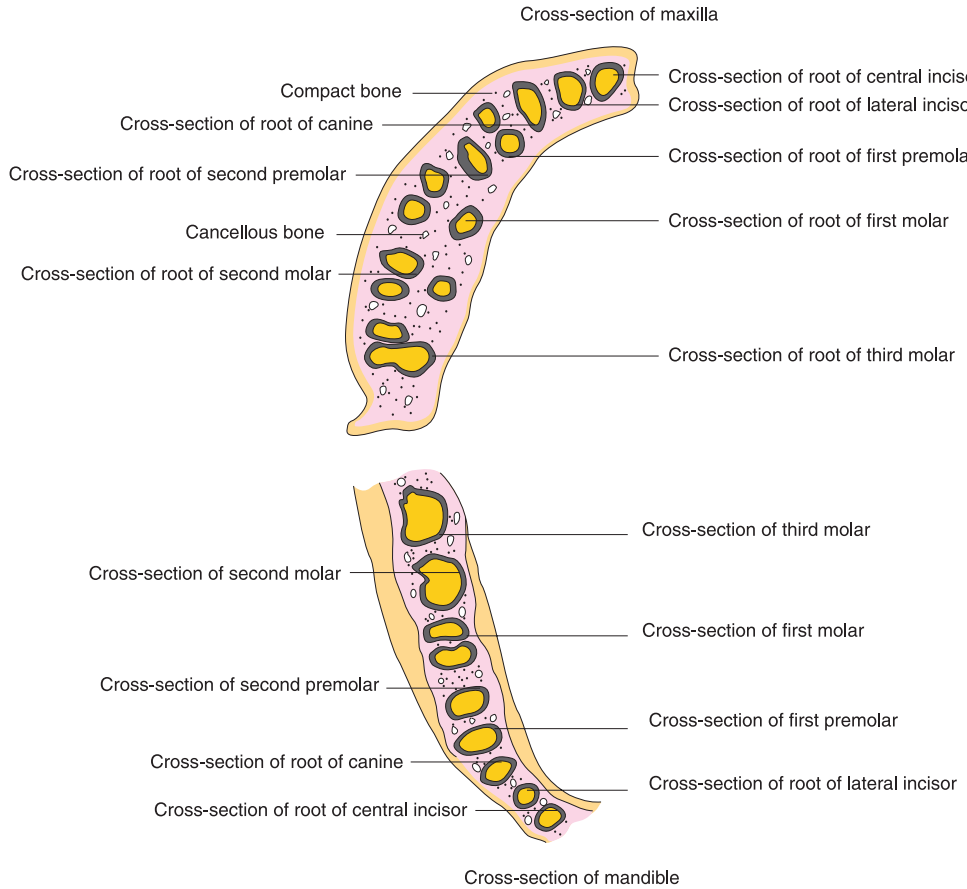


Figure 40.8 Cross-section of maxilla and mandible at the level of alveolus.

Physiologic Changes in the Alveolar Bone

The turnover rate of alveolar bone is higher as compared to other parts of the skeleton. The alveolar bone is always under a constant state of fluctuation. Formation and removal are continuous in the alveolar bone. This internal remodelling is regulated by local and systemic factors. The highest level of remodelling happens in the bundle bone adjacent to the periodontal ligament. The increased rate of remodelling is the result of constant mesial and occlusal movement of the teeth. Mesial drift/mesial movement occurs throughout life to compensate for the loss of teeth substance on the proximal aspect (due to the mesial component of occlusal forces to which the teeth is constantly subjected to). Refer to Chapter 43 for further explanation.

Applied Histology

Alveolar Bone Remodelling and Orthodontic Treatment

The alveolar bone remodels itself more quickly than cementum. This helps the field of orthodontics, which involves correction of malaligned teeth.

Pattern of Bone Resorption in Maxilla and Mandible After Tooth Loss

In maxilla, the direction of resorption is upwards and inwards while in mandible the resorption occurs downwards and outwards.

Fenestration and Dehiscence

In certain anterior teeth, the bone on the facial aspect is very closely apposed, leaving isolated areas on the root surface devoid of bone. If such a defect is circumscribed, it is called fenestration; if it extends to the marginal bone, it is called dehiscence.

ADDITIONAL READING

Post-Extraction Changes in the Alveolar Bone

Tooth extraction leads to reduction in the buccolingual and apicocoronal dimensions of the alveolar ridge. Immediate implant placement and bone grafting are done to avoid such a change in dimension. The fundamental principle of bone physiology is the adaptation of bone mass and bone structure to the levels and frequencies of strain. Wolff's law mechanical loads influence the adaptive response of bone tissue. Post-healing of the extraction socket takes place when adequate strain stimulus does not exist, which leads to loss of bone mass. Maintenance and formation of bone mass depends on strain levels. Bone resorption is evident more at the buccal aspect than at the lingual aspect leading to greater vertical bone loss buccally than lingually. This phenomenon results in a ridge that is sloped in the lingual-buccal direction (excerpts from Hansson and Halldin 2012).

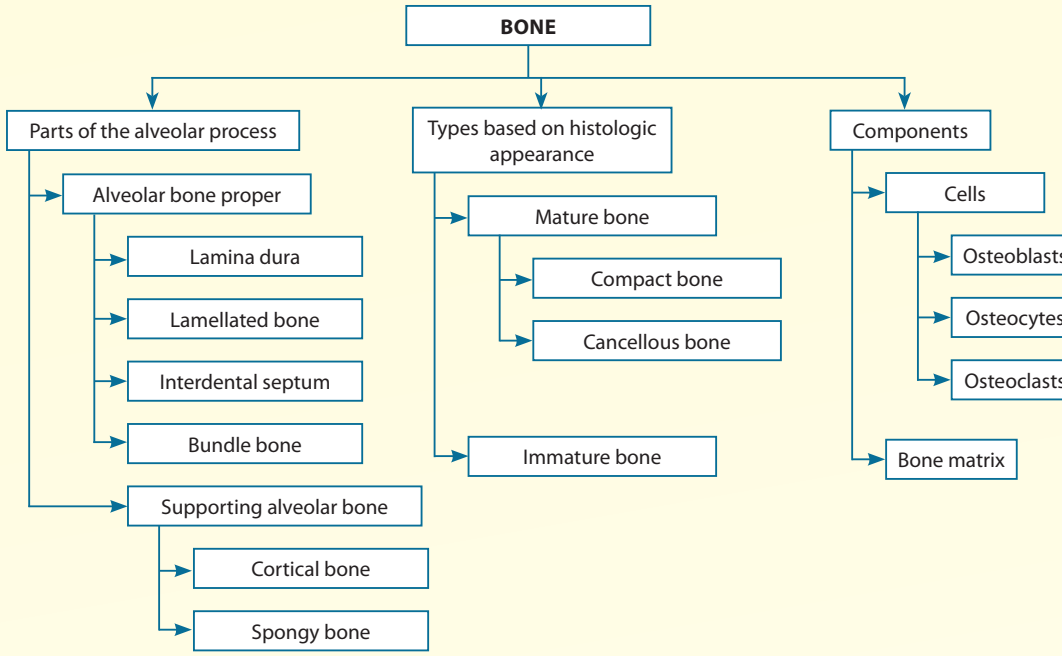
Osteoimmunology of the Alveolar Bone

Constant remodelling happens in bone due to the balanced actions of bone-producing osteoblasts and bone-resorbing osteoclasts (OCLs). Physiologic bone remodelling occurs whenever there is a change in electrolyte levels, predominantly calcium. It also occurs due to the effects of mechanical forces on bone. Pathologic bone production and resorption due to excessive OCL action can also result in net bone loss. The field of osteoimmunology involves research in understanding the mechanisms regulating this bone loss. Chronic or acute inflammation is often associated with net bone loss. Skeletal and immune systems have cells and signalling molecules which are functionally linked in bone loss occurring in periodontal disease (PD) (chronic inflammation) and orthodontic tooth movement (OTM) (acute inflammation). Receptor activator of nuclear factor-kappa B (NF-κB) lig and (RANKL)-receptor activator of NF-κB (RANK)-osteoprotegerin (OPG) system and notch signalling influence the development of cells in osteoimmunology of pathological alveolar bone loss in PD and controlled alveolar bone loss in OTM (excerpts from Tompkins 2016).

Key Points

1. Bones consist of 67% organic and 33% inorganic substances.
2. Osteon is the basic unit of bone.
3. The Volkmann canals run within the osteons perpendicular to the Haversian canals and carry small blood vessels.
4. Osteoblasts are progenitor cells that help in the synthesis of bone matrix.
5. The spaces in which the osteocytes are present are called the osteocytic lacunae.
6. The part of the osteoclast involved in carrying out resorption is called the ruffled border.
7. Bone remodelling is a continuous process of bone resorption and bone formation, which helps maintain the normal bone mass.
8. The part of bone which shows the beginning of resorption is called the *cutting cone* and that in which laying of new bone takes place is called the *filling cone*.
9. Bundle bone is the site of attachment of the periodontal fibres.
10. The alveolar bone proper is also called *cribriform plate* as it has a sieve-like arrangement because of the presence of perforations and canals for the entry of vessels and nerves.

Mind Map



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Multiple Choice Questions

1. Which of the following statements about bone is true?
   (a) Bone does not regenerate
   (b) Bone remodels throughout life
   (c) Bone remodels only in the younger age group
   (d) None of the above
2. The composition of bone is
   (a) 80% organic and 20% inorganic
   (b) 4% organic and 96% inorganic
   (c) 67% organic and 33% inorganic
   (d) 50% organic and 50% inorganic
3. Which type of bone appears like a sponge?
   (a) Cancellous
   (b) Compact
   (c) Woven bone
   (d) Both a and b
4. Acid phosphatase is seen in the
   (a) Osteoclast
   (b) Osteoblast
   (c) Osteocyte
   (d) Bone matrix
5. The receptor activator of NF-κB (RANK) ligand (RANKL)/osteoprotegerin (OPG) system regulates the
   (a) Osteocyte
   (b) Osteoclast
   (c) Osteoblast
   (d) Fibroblast
6. The alveolar bone proper is made of
   (a) Woven bone
   (b) Bundle bone and lamellated bone
   (c) Sharpey's fibres
   (d) Cancellous bone
7. Lamina dura is
   (a) A part of the supporting alveolar bone
   (b) The other name of the basal bone
   (c) The radiographic appearance of the alveolar bone proper
   (d) Both a and c
8. The alveolar bone seen between the first molar teeth is called the
   (a) Interdental septum
   (b) Interalveolar septum
   (c) Inter-radicular septum
   (d) Both a and b
9. The density of the alveolar bone is more in the
   (a) Anterior regions of the maxilla
   (b) Anterior regions of the mandible
   (c) Posterior regions of the maxilla and mandible
   (d) Both a and b
10. The distance between the cementoenamel junction and the crestal margin of the alveolar bone is
    (a) 2–5 mm
    (b) 5–7 mm
    (c) 1.5–2 mm
    (d) 2.5–3 mm



CHAPTER 41

Oral Mucous Membrane

Overview

The oral mucous membrane or oral mucosa is often called the lining of oral cavity. Due to functional adaptation, the structure of the oral mucosa varies in different regions. Anteriorly, the oral mucosa is continuous with the skin of the lip through a transitional zone—the vermilion border—and posteriorly with the mucosa of the pharynx. The basic components of oral mucosa are the epithelium, lamina propria and submucosa. The epithelium is of the stratified squamous type with or without keratinization in different regions of oral mucosa. Masticatory mucosa, lining mucosa and specialized mucosa are the types of mucosa based on the functions. Gingiva and hard palate comprise masticatory mucosa while the dorsal surface of tongue comprises specialized mucosa with the presence of taste buds. Labial mucosa, buccal mucosa, ventral surface of the tongue, floor of the mouth, soft palate and vermilion surface comprise lining mucosa. Thorough knowledge of the structure and function of the oral mucosa are prudent for successful clinical practice since many local and systemic diseases cause changes in oral mucosa as well as maintenance of the integrity of oral mucosa is essential during any dental treatment procedure.

INTRODUCTION

The term *mucous membrane* describes the moist lining of the following:

1. Body cavities that communicate with the exterior
2. Gastrointestinal tract
3. Nasal passage

The lining of oral cavity is called oral mucous membrane or oral mucosa. Anteriorly this oral mucosa is continuous with the skin of the lip through a transitional zone, the vermilion border, and posteriorly with the mucosa of the pharynx. In the oral cavity, the structure of the oral mucosa varies in different regions because of functional adaptation.

FUNCTIONS OF THE ORAL MUCOSA

1. **Defensive:** A large number of microorganisms reside in the oral cavity and behave as commensals. These microorganisms can become pathogenic and can cause infection if they are able to gain access to the underlying tissues. The oral mucosa acts as an efficient barrier against the entry of these microorganisms and the toxins produced by them. It also secretes antibodies and has an efficient humoral and cell-mediated immunity.
2. **Protection:** It separates and protects the deeper tissues from compressive and shearing forces that might result because of mastication and surface abrasion that might occur due to hard particles in diet.
3. **Secretion:** The oral mucosa is kept moist due to saliva secreted by the glands. Minor salivary glands are situated within the oral mucosa whereas the major salivary glands are situated at a distance from the mucosa. The moist surface prevents the mucosa from drying. It helps in speech, mastication, swallowing and perception of taste. It also helps to retain water and electrolytes.
4. **Sensory:** The oral mucosa has receptors which respond to touch, pressure, pain and temperature. The sensation of taste is perceived by the

taste buds present in the dorsum of tongue which is not found elsewhere in the body.

CLASSIFICATION OF THE ORAL MUCOSA

On the basis of their primary function, the oral mucosa is classified into three main types:

1. **Masticatory mucosa**, which contributes to about 25% of the total area comprising the gingiva and hard palate.
2. **Lining mucosa**, which contributes to about 60% of the total area. This includes lip, cheek, vestibular fornix, alveolar mucosa, floor of the mouth and soft palate.
3. **Specialized mucosa**, which contributes to about 15% of the total area. This includes dorsum of the tongue.

COMPONENTS OF THE ORAL MUCOSA

The two main components of the oral mucosa are stratified squamous oral epithelium and the underlying connective tissue layer known as *lamina propria*. The irregular junction between the epithelium and connective tissue has upward projections of connective tissue (connective tissue papilla) interdigitating the epithelial ridges or pegs (rete pegs). A structureless layer, the *basal lamina*, is seen at the interface between the epithelium and connective tissue. In some regions such as the lip and cheek, a layer of loose fatty or glandular connective tissue separates the oral mucosa from the underlying muscle. This layer is known as *submucosa* (**Fig. 41.1**). In some regions such as the gingiva and hard palate, the oral mucosa is directly attached to the periosteum

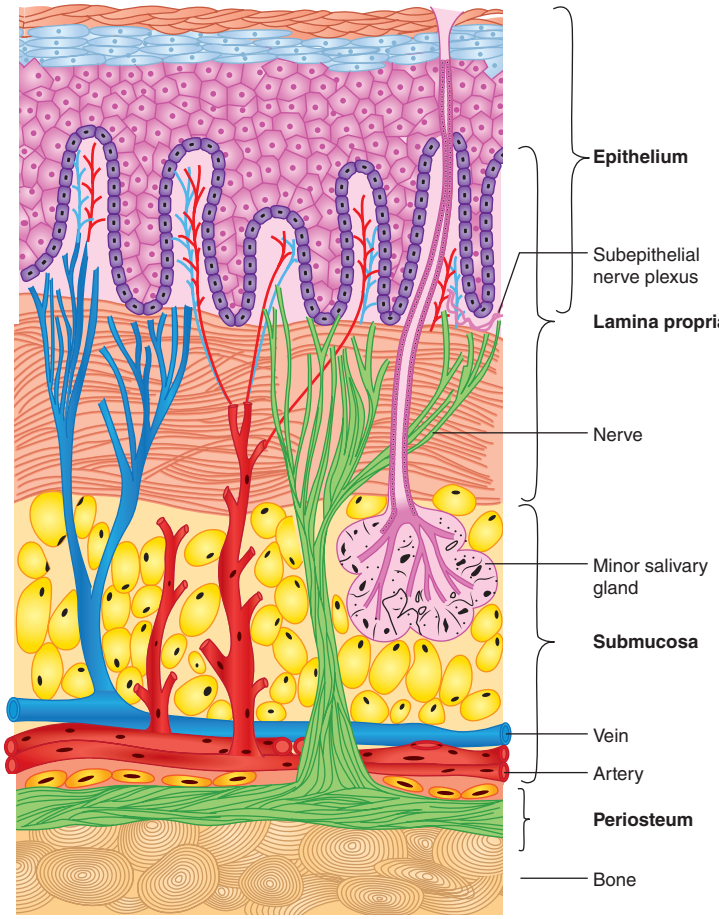


Figure 41.1 Components of the oral mucosa.

of the underlying bone without any intervening submucosa. This type of firm attachment is known as *mucoperiosteum*.

Epithelium

The epithelium of the oral cavity is derived from embryonic ectoderm and is of the stratified squamous type. It may be keratinized or non-keratinized. In most of the areas of the oral cavity, the epithelium is not keratinized, except in the gingiva, hard palate and dorsal surface of the tongue where it is keratinized.

The two populations of epithelial cells are as follows:

1. **Progenitor population:** These groups of cells remain in the basal layer and divide to give rise to new cells. There are two distinct subpopulations of progenitor cells. There is a smaller population of cells representing the stem cell which go through the cell cycle slowly and produce basal cells. The larger population is made up of amplifying cells which increase the number of cells available for maturation.
2. **Maturity population:** These groups of cells, after their origin, become determined and migrate from the basal layer to the surface to replace the cells that are shed. Because of this migration, they become part of each layer at every stage. The migration of cell from the basal layer to the surface is known as *maturation*, and the cells increase in size and shape during this process.

The time taken for the cells to divide and pass through all the layers is known as the *turnover rate*. The turnover rate is faster in oral mucosa when compared with skin (27 days). Maturation of the epithelial layer in the oral cavity follows two patterns: keratinization and non-keratinization.

Applied Histology

Healing occurs faster in the oral cavity because of increased blood supply and increased epithelial turnover.

Keratinized Epithelium

Keratinized epithelium has four cell layers which are named on the basis of their morphological appearance as follows (**Fig. 41.2**):

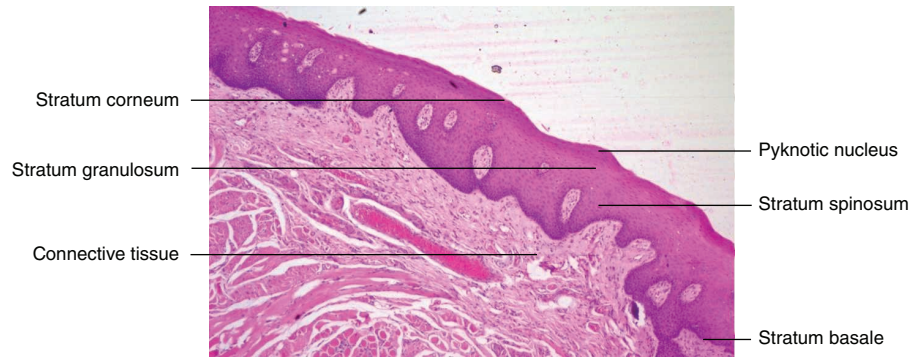
1. Basal layer (stratum basale)
2. Spinous layer (stratum spinosum)
3. Granular layer (stratum granulosum)
4. Cornified layer (stratum corneum)

Stratum Basale The basal layer is a single layer of cuboidal or columnar cells adjacent to the lamina propria, separated from it by basal lamina. The cells of the basal layer are the least differentiated among the oral epithelial cells. Mitotic activity is prominent in this layer as new cells are formed here. The term *parabasal* is used to refer to the innermost layer of stratum spinosum adjacent to the basal layer. It resembles the basal layer in that it shows some mitotic figures. Hence, the basal cell layer and parabasal spinous cells are often described as *stratum germinativum*.

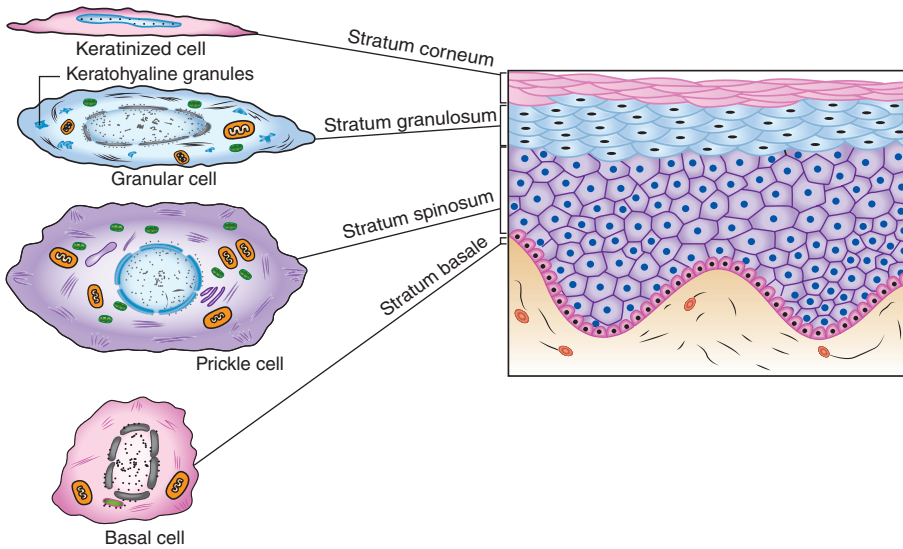
Applied Histology

Anticancer medications result in oral ulcerations as these drugs affect the mitotic rate of the mucosal cells.

The cells of the basal layer show intracellular organelles associated with synthesis and secretion of proteins such as ribosomes, rough endoplasmic reticulum, mitochondria, Golgi apparatus and also tonofilament of keratin, reflecting their epithelial nature. *Hemidesmosomes* are specialized structures seen in relation to the cells of the basal layer and their surface facing the basal lamina. These structures provide adhesion between the epithelium and the connective tissue. *Desmosome* is another structure seen on the lateral side of the adjacent basal cells. This provides close contact or cohesion between the cells of the basal layer. Both the desmosomes and hemidesmosomes have attachment plaques (hemidesmosome has one whereas desmosome has a pair) to which the tonofilaments (intermediate filaments arising from the cytoskeleton) arising from basal cells are attached.



(a)



(b)

Figure 41.2 Keratinized stratified squamous epithelium: (a) photomicrograph (para-keratinized epithelium—haematoxylin and eosin, 10X) and (b) schematic diagram.

Stratum Spinosum The spinous layer is above the basal layer and is made up of several rows of polyhedral cells. The cells are larger and more rounded than those of the basal layer. The cells of this layer exhibit prominent intercellular bridges—the desmosomes—which give the cells a prickly appearance. Tonofibrils are cytoplasmic protein structures in *epithelial* tissues that converge at desmosomes and hemidesmosomes. The tonofibril network and desmosomes make up the tensile supporting system for the epithelium. During tissue preparation, the cells shrink away from each other and remain in contact only at points (due to the desmosomes anchoring the cells together). This gives the cells a spiny appearance.

Involucrin, a precursor protein of the cornified envelope, is present in this layer. However, there is a progressive decrease in protein synthetic activity through the layer. In the upper part of the spinous layer, the cells show spherical, membrane-coating granules closely associated with the cell membrane, called *keratinosome, lamellar granule* or *Odland body*.

Stratum Granulosum The cells of the granular layer show more maturation than those of the basal and prickle cell layers. The cells are flatter, wider and larger than spinous cells with less organelles and more tonofilaments. The most prominent finding is the presence of a large number of small, basophilic granules, called *keratohyaline granules* (which stain blue with haematoxylin and eosin). The nuclei show signs of degeneration and pyknosis. Proteins are still synthesized but at a reduced rate. The keratohyaline granules contain profilaggrin (precursor of the protein filaggrin) which plays an important role in binding keratin filaments together. The membrane-coating granules, also seen in the upper spinous layers, discharge their lipid-rich contents into the intercellular space. They act as a cementing substance and contribute to the permeability barrier of this layer. Synthesis of proteins such as involucrin and loricrin helps increase the thickness of the cell membrane, thus forming a resistant cornified cell envelope.

Stratum Corneum The cornified layer represents the final stage in the maturation of the epithelial cells. The cells of this layer, termed *squames*, are larger and flatter than the granular cells. They are devoid of nuclei, organelles and Odland keratohyaline granules because of the release of proteases within the cell (autolysis). The cells consist of closely packed tonofilaments coated by protein filaggrin (protein of keratohyaline granules). This is collectively called *keratin*. It is strongly cross-linked by disulphide bonds which give mechanical and chemical resistance. This layer is histologically amorphous and acidophilic (stains red with haematoxylin and eosin).

As the desmosomes become weaker and disappear, the cells of this layer desquamate or shed, necessitating the constant turnover of epithelial cells.

While the cells described earlier are termed *orthokeratinized cells*, a variation in keratinization, known as *para-keratinization,* is seen in some parts of the oral cavity, such as the gingiva and parts of the hard palate. Here, the cells retain the pyknotic or shrunken nuclei or partially lysed organelles till they desquamate.

Non-Keratinized Epithelium (Fig. 41.3)

This epithelium is composed of the following three layers:

1. Stratum basale
2. Stratum intermedium
3. Stratum superficiale

As in keratinized epithelium, the non-keratinized epithelial cells enlarge and become flatter as they move towards the surface. The basal cell layer resembles that of the keratinized epithelium.

The cells of the stratum intermedium are larger than those of the stratum spinosum, and their cell surfaces are more closely applied with a less-prominent intercellular bridge and hence lack the prickly appearance. The granular layer is not present, and the cells above stratum intermedium lack keratohyaline granules and filaggrin and have less-developed tonofilaments. The membrane-coating granules are smaller than those of the keratinized epithelium and account for the greater permeability of the non-keratinized epithelium. The cells of the superficial layer contain nuclei and have more organelles when compared with the cells of the stratum corneum. The superficial layer lacks keratin filaments and does not stain intensely with eosin, unlike keratinized epithelium.

Non-Keratinocytes

About 10% of the cells of the oral epithelium are *non-keratinocytes* as they do not have the ability to keratinize. These cells include melanocytes, Langerhans cells, Merkel cells and inflammatory cells. These cells lack desmosomal attachments with the adjacent cells (except the Merkel cell). The cytoplasm shrinks around the nucleus to produce a clear halo during the histologic preparation; thus, they are also called *clear cells.*

Melanocytes They are pigment (melanin)-producing cells derived from the neural crest. They migrate into the basal layer of the epithelium. They are thought to be long, living cells that are self-replicating. They lack tonofilaments and desmosomes but have long branching dendritic processes that extend in several directions and across several layers of epithelium. Each melanocyte establishes contact with 30–40 keratinocytes

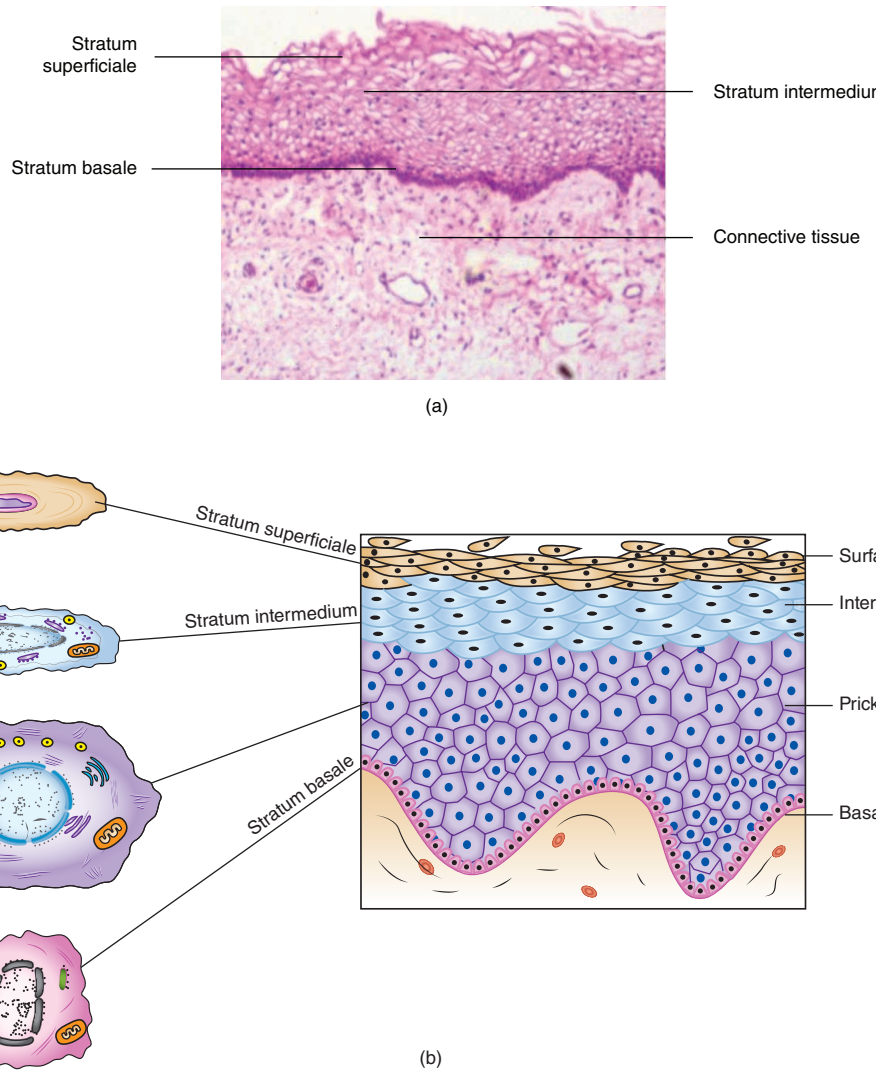


Figure 41.3 Non-keratinized epithelium: (a) photomicrograph (haematoxylin and eosin, 10X) and (b) schematic diagram.

through its dendritic process. Melanin is synthesized by melanocytes using the enzyme tyrosinase. It is packed in small granules called *melanosomes* that are transferred into the cytoplasm of the adjacent keratinocytes through the dendritic process. Sometimes, the melanin pigment can be dispersed in the connective tissue where it is taken up by the macrophages, termed *melanophages*. Melanocytes appear as clear cells in the haematoxylin section and have a spider-like appearance with silver stain (dendritic cell).

Variation is seen in the location of the melanin pigment in the oral cavity. The gingiva, buccal mucosa, hard palate and tongue are the regions where melanin pigmentation is commonly seen. The degree of pigmentation does not depend on the number of melanocytes but relies on various factors such as size of the

melanosomes, the degree of dispersion and melanization of melanosomes and the rate of degradation of the pigment.

Langerhans Cells Langerhans cell is a clear or dendritic cell derived from the bone marrow. It leaves the bloodstream, enters the lamina propria and penetrates the basal lamina to reach the epithelium. This migration is related to the release of chemokines by the keratinocytes to the surface receptors on the Langerhans cells. These cells are seen in the upper layer of oral epithelium. Under a light microscope, these cells appear as clear cells due to the lack of desmosomes.

Ultrastructurally, these cells have vacuolated nucleus and characteristic rod- or flask-shaped granules called *Birbeck's granules*. Langerhans cells have an immunologic function as antigen-presenting cells. They recognize antigens entering the epithelium from the external environment and engulf them. Intracellular lysosomes present in the Langerhans cells split the antigens into peptide components. These fragments are then transferred and presented to the T-lymphocytes either locally or at the lymph nodes. It is suggested that as the Langerhans cells migrate from the epithelium to the regional lymph nodes to present the fragments of the antigen to the lymphocytes, they help the epithelium of the oral mucosa interact with the entire lymphoid system to mount an immune response.

Merkel Cells These are seen in the basal layer close to nerve fibres. These are thought to be pressure receptor cells that are derived from the neural crest. Merkel cells respond to touch sensation. In contrast to melanocytes and Langerhans cells, these cells are not dendritic. They occasionally possess keratin filaments and desmosomes and hence do not appear as clear cells histologically. Ultrastructurally, these cells have a nucleus which shows deep invagination and a characteristic rodlet appearance. The other characteristic finding is the presence of small, membrane-bound granules in the cytoplasm which are seen in close proximity to the nerve fibre associated with the cell. It is thought that these granules liberate a transmitter-like substance across the synapse-like junction between the cell and the closely associated nerve fibre generating an impulse. These cells are more commonly seen in masticatory mucosa such as the gingiva.

Inflammatory Cells A number of inflammatory cells can be seen in various layers of epithelium. The most common among them are the lymphocytes which are closely associated with the Langerhans cells. These inflammatory cells are transient and do not reproduce themselves in the epithelium like other non-keratinocytes.

Junction of Epithelium and Connective Tissue

The interface between the epithelium and the connective tissue is an undulating surface where the papillae of the connective tissue interdigitate with the epithelial ridges. This undulating arrangement makes the interface larger than a simple flat junction and does the following:

1. Provides better attachment
2. Enables external forces applied to the epithelium to be dispersed over a wider area of connective tissue; the masticatory mucosa has more number of papillae per unit area when compared with the lining mucosa
3. Provides a wider area for metabolic exchange between the epithelium and the connective tissue

Under a light microscope, this interface appears 1–2 μm thick and stains positively with periodic acid–Schiff stain and is termed *basement membrane*. Ultrastructurally, it is called the *basal lamina* and is made of three layers:

(a) *Lamina lucida* is a clear zone just below the epithelial cells.

(b) *Lamina densa* is the middle of the three layers.

(c) *Lamina fibroreticularis* (sublamina densa) is located adjacent to lamina propria and contains fine reticular fibres.

All the layers of basal lamina except the components of lamina fibroreticularis are thought to be derived from the epithelium.

The basal cells of the epithelium are not directly attached to the connective tissue but form

mechanical adhesions with basal lamina through attachments called hemidesmosomes.

The basal lamina is composed of a network of type IV collagen in which proteoglycan and glycoprotein molecules such as laminin and fibronectin are found. Other proteins such as integrins and bullous pemphigoid antigens strengthen the bond between the basal cell and the basal lamina. Fine anchoring fibrils of type VII collagen bind to the type IV collagen of the basal lamina.

Lamina Propria

Lamina propria is the connective tissue of variable thickness present immediately below the epithelium, supporting it. It is divided into superficial papillary and deep reticular layers for descriptive purposes:

1. The **papillary layer** is made up of finger-like projections of the connective tissue (papilla) which extend deep into the epithelium and interdigitate with the epithelial ridges. The number, length and width of these papillae vary in different parts of the oral cavity. In areas of masticatory mucosa, there is an increase in the length and number of papillae, whereas in the areas of lining mucosa, the papillae may be short or absent. The papillary layer is made up of loosely arranged, thin collagen fibres.
2. The **reticular layer** is below the papillary layer and is always present. It is made up of thick collagen fibres which are arranged in bundles.

The lamina propria consists of cells, fibres and blood vessels embedded in ground substance. In addition to fibroblasts, macrophages, mast cells and inflammatory cells are seen. The extracellular matrix is composed of collagen fibres mainly of type I (90%) and type III (8%). A small amount of elastic fibres is present which do not form bundles like collagen fibres. The ground substance is composed of proteoglycans and glycoproteins. The blood supply comes from the plexus of large vessels in the submucosa or from the deeper part of the reticular layer. These give rise to small branches which form a capillary plexus between the papillary and the reticular layer. From these, capillary loops pass into the connective tissue papilla to lie close to the basal layer of epithelium.

Submucosa

Submucosa is the connective tissue of varying thickness which serves to attach the lamina propria to the underlying bone or muscle. The structure of the submucosa decides the nature of attachment, whether loose or firm. While the submucosa is prominent in some parts of the oral cavity such as cheeks, lip and parts of the palate, it is less prominent or absent in some other parts. The lamina propria is directly attached to the bone tightly in the areas devoid of submucosa. In such cases, the epithelium and the lamina propria are collectively referred to as mucoperiosteum. The submucosa contains large blood vessels, nerves and lymphatics. Adipose tissue and minor salivary glands are also seen in the submucosa.

Applied Histology

Loose Connective Tissue and Spread of Infection

Infections can spread rapidly and extensively in the oral mucosa causing swelling. This is especially seen in areas of the submucosa with loose connective tissue.

Cytokeratins

The cytoskeleton of all epithelial cells is made up of microfilaments, microtubules and cytokeratins.

Microfilaments are about 4–6 nm in diameter whereas microtubules have a diameter of 25 nm. Cytokeratins are called intermediate filaments as their diameter is about 7–11 nm which ranges between that of microfilaments and microtubules. Cytokeratins are important in maintaining the shape of the cell and also function as stress-bearing structures. Apart from being a component of epithelial cells, cytokeratins are also seen in contact areas such as desmosomes and hemidesmosomes. There are about 20 types of cytokeratin which are classified as type I (neutral or basic, 1–8) and type II (acidic, 9–20). Each epithelial cell expresses at least one pair comprising one type I and one type II. The CK phenotype which the cells possess reflects the differentiation pathway which the cell has followed. Cytokeratins have a high degree of tissue and layer specificity. The suprabasal cells of keratinized mucosa express *CK1* and *CK10* while

the suprabasal cells of non-keratinized mucosa express *CK4* and *CK13*. Similarly, there is regional variation in the expression of cytokeratin. While the ventral surface of tongue expresses *CK5*, *CK6* and *CK14*, the soft palate expresses *CK7*, *CK8* and *CK18*.

TYPES OF THE ORAL MUCOSA

As already mentioned, the oral mucosa is of three types:

1. **Masticatory mucosa:** Gingiva, hard palate
2. **Lining mucosa:** Labial mucosa, buccal mucosa, mucosa lining the floor of the mouth, ventral surface of the tongue, soft palate
3. **Specialized mucosa:** Dorsal surface of the tongue

Masticatory Mucosa

In dentate individuals, the gingiva and hard palate are covered by masticatory mucosa, the epithelium of which is orthokeratinized or parakeratinized. In edentulous individuals, the chewing surfaces of dental arches are covered by masticatory mucosa. The connective tissue contains collagenous fibres which are thicker and more organized than those fibres in the lining mucosa. The connective tissue adheres firmly to the underlying periosteum of the bone, making the mucosa immobile.

Gingiva

The gingiva is a part of the masticatory mucosa which covers the alveolar process of the jaws and surrounds the necks of the teeth. The gingiva protects the underlying tissues of the tooth attachment from the oral environment. Since the gingiva is tooth dependent, it disappears when teeth are extracted.

The gingiva can be anatomically divided into *marginal, attached* and *interdental gingiva.*

Marginal Gingiva or Free Gingiva This is the terminal visible edge of the gingiva, about 1–2 mm wide, surrounding the tooth in a collar-like fashion. It is also known as *unattached gingiva*. The surface facing the teeth forms the soft tissue wall of the sulcus. The surface of the gingival margin is smooth, in contrast to that of the attached gingiva, from which it is demarcated by an indentation called *free gingival groove*. On the buccal and lingual sides, the free gingiva extends from the gingival margin in an apical direction to the free gingival groove which is located at a level corresponding to the cementoenamel junction.

Applied Histology

Gingival Attachment

The level of attachment of gingiva is an important factor to be considered while placing restorations. The clinical crown is smaller than the anatomical crown in the case of young individuals; as a result, tooth preparation and crown placement are difficult. The restoration has to be replaced later when recession takes place.

Gingival Recession

It causes exposure of cementum. As cementum is softer than enamel, it wears off easily resulting in abrasion and root caries.

Attached Gingiva The attached gingiva or *functional mucosa* is a band of keratinized mucosa measuring 3–12 mm in width. It is bound to the underlying periosteum of the alveolar bone. The mean turnover time for the attached gingival tissue is 10 days.

Extensions

1. **Coronally:** Free gingival groove, if it is conspicuous (during a clinically healthy state)
2. **Apically:** Mucogingival junction, a junction between the attached gingiva and the alveolar lining mucosa (**Fig. 41.4**)

Width of the Attached Gingiva The attached gingiva varies in width between individuals and between different areas in the oral cavity. The width of the attached gingiva ranges from 1 to 6 mm. It is greatest in the mandibular posterior lingual aspect and narrowest in the buccal aspect of the third molar region of the mandible.

Mucogingival Junction or Line This is a stationary junction between the attached gingiva and the alveolar mucosa. This junction is not visible in the palate as the entire palatal mucosa is attached.

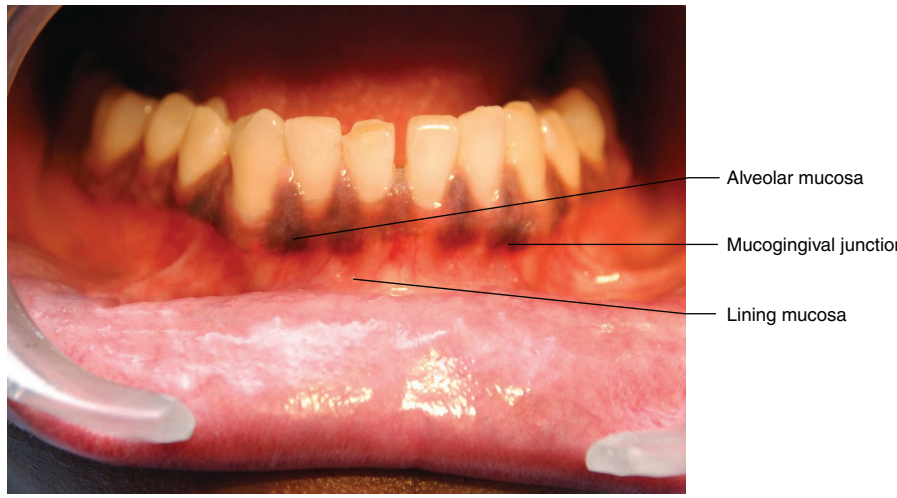


Figure 41.4 Mucogingival junction.

The junction between the tooth and the oral mucosa (gingiva) is called *dentogingival junction*. This junction is very unique and dynamic. This is the only attachment in the body between a soft tissue and a hard tissue which is exposed to the external environment, and it possesses its own battery of protective mechanisms.

Interdental Gingiva The interdental gingiva or papilla assumes its shape on the basis of the contact relationships between the teeth, the width of the approximating tooth surfaces and the course of the cementoenamel junction. In the anterior dentition, the interdental papillae are of a pyramidal form, while in the posteriors, especially in molars, they are more flattened in the buccolingual direction. Because of the presence of the interdental papillae, the marginal gingiva follows a more noticeable scalloped outline throughout the dentition.

Col (Fig. 41.5) The posterior teeth have approximating contact surfaces rather than contact points. The interdental gingiva has a shape in conformity with the outline of the interdental contact surfaces; a concavity, col, is established in the premolar and molar regions. The interdental papillae have a facial portion and a lingual or a palatal portion separated by a col region. Col is non-keratinized and shares many features with those of junctional epithelium.

Gingival Sulcus or Crevice The gingival sulcus is an area of potential space between a tooth and the surrounding gingival tissue and is lined by sulcular epithelium. In healthy gingival conditions, the gingival sulcus ranges from 0.5 to 3 mm in depth. The clinical depth of this sulcus beyond 3 mm is considered a pathologic deepening which is termed *periodontal pocket*. The inner surface of the sulcus facing the tooth is lined by the sulcular epithelium, which is normally non-keratinized. A detailed discussion of sulcular epithelium follows.

Applied Histology

Periodontal Pocket

The clinical depth of this sulcus beyond 3 mm is considered a pathologic deepening which is termed periodontal pocket.

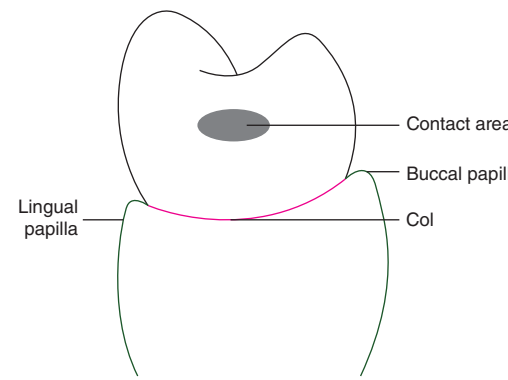


Figure 41.5 Interdental col.

Junctional Epithelium It is a highly specialized epithelial tissue which divides faster than any other normal epithelium. The mean turnover time of junctional epithelium is 2–6 days.

The junctional epithelium is basically a stratified, squamous, non-keratinizing epithelium comprising two layers: basal and suprabasal layers.

The junctional epithelium differs from the gingival oral epithelium and sulcular epithelium in origin and structure. This specialized epithelium ranges in thickness from few cells at its most apical portion to between 15 and 30 cells at its most coronal portion adjacent to the sulcular epithelium, and the cells align themselves in a plane parallel to the tooth surface. The length of this epithelium is approximately 0.25–1.35 mm. The unique feature of this epithelium is that it exhibits two basal laminas—external and internal—the cells of which are derived from the basal cells situated away from the tooth surface:

1. **External basal lamina:** The basal cells rest on the external basal lamina that interfaces with the connective tissue, as in any other epithelium.
2. **Internal basal lamina:** Suprabasal cells have a similar appearance and maintain actual attachment of gingiva to the tooth surface (enamel or cementum) by means of the structural complex, internal basal lamina. The internal basal lamina is distinctive because it binds to calcified surfaces rather than connective tissues.

The cells of the basal layer proliferate rapidly while those of the suprabasal layer have no mitotic activity. The epithelium and connective tissue interface is not characterized by rete ridges and tends to be straight with only mild undulations present in more coronal portions.

One more characteristic feature of this epithelium is wide intercellular gaps, larger than those in either sulcular or oral epithelium. Hence, even in healthy gingiva, numerous polymorphonuclear leukocytes are evident. During inflammatory conditions, the numbers of these cells increases dramatically. Lymphocytes are also found inside the epithelial lining in the junctional epithelium.

The junctional epithelium exhibits several characteristic features such as acting as a barrier against plaque bacteria and allowing access of gingival fluid, inflammatory cells and components of the immunologic host defence to the gingival margin. Furthermore, it possesses a rapid turnover contributing to the host–parasite equilibrium and repair of injured tissue. In addition to these, some investigators have speculated that these cells might have some endocytic capacity equal to that of macrophage and neutrophils and this activity might be protective in nature.

Development of the Junctional Epithelium The enamel of the unerupted, fully formed crown is covered by a few layers of flattened cuboidal cells (derived from ameloblasts and the cells of stratum intermedium of the enamel organ) called *reduced enamel epithelium*. Normally, it terminates at the cementoenamel junction. At this early stage, the epithelial attachment to the crown surface is by means of hemidesmosomes. When the tooth breaks through the oral mucosa, the reduced enamel epithelium fuses with the oral epithelium and is converted into the junctional epithelium, forming a collar around the fully erupted tooth. Concurrently, gingival sulcus is also formed (**Fig. 41.6**). This process takes 1–2 years to get completed. The junctional epithelium, like all squamous epithelia, is a continually renewing structure with epithelial cells moving coronally to be shed off at the free surface into the base of the sulcus.

Migration of the Junctional Epithelium The position of the junctional epithelium varies with different stages of eruption. During the initial stages of eruption, the junctional epithelium covers most of the crown portion of the tooth. Once the tooth reaches the occlusal plane, the junctional epithelium covers about one-fourth of the crown. At this stage, the clinical crown is smaller than the anatomical crown. (The part of the tooth that is covered by enamel is the anatomical crown. The clinical crown is that part of the tooth which is exposed to the oral cavity.) As age increases, the junctional epithelium migrates to the cementoenamel junction, placing the clinical and the anatomical crown at the same level. In older age, it migrates to the cementum exposing the roots leading to a larger clinical crown.

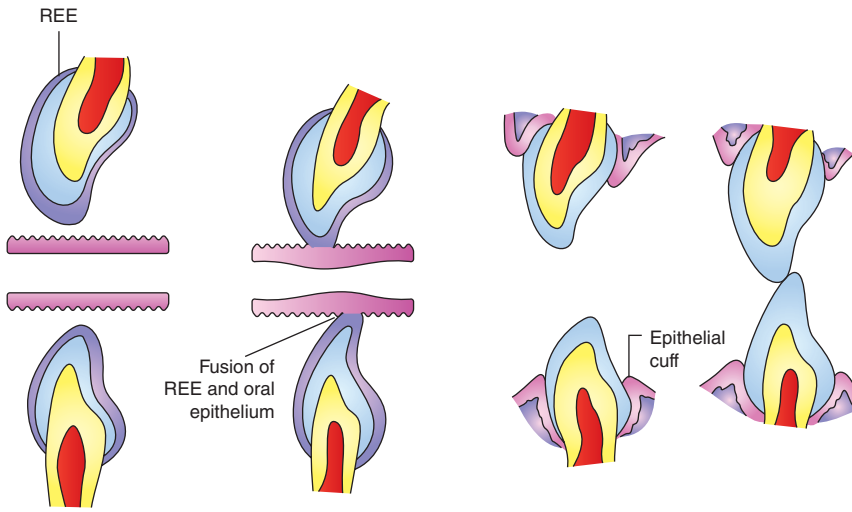


Figure 41.6 Development of the junctional epithelium. *REE*, reduced enamel epithelium.

This process occurs due to the detachment of the basal layer of cells. This basal layer of cells further get reattached at a more lower/apical level. The process of migration of junctional epithelium happens physiologically without any degeneration. During the presence of inflammation, the apical migration occurs faster, which results in a periodontal pocket (**Fig. 41.7**).

Applied Histology

Pathological Migration of the Junctional Epithelium

During the presence of inflammation, the apical migration occurs faster, which results in a periodontal pocket.

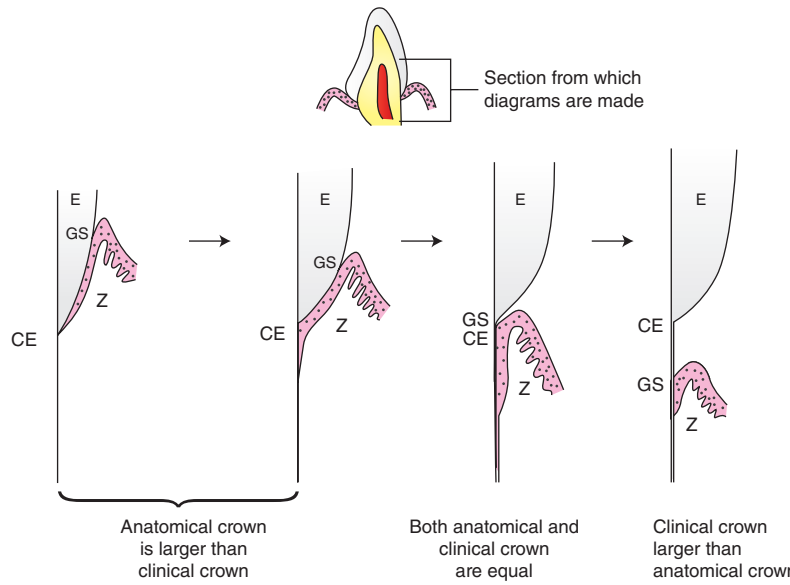


Figure 41.7 Migration of the junctional epithelium. *CE*, cementoenamel junction; *E*, enamel; *GS*, bottom of gingival sulcus; *Z*, attachment epithelium.

Sulcular Epithelium It extends between the oral epithelium and the junctional epithelium, from the coronal limit of the junctional epithelium to the crest of the gingival margin, and lines the gingival sulcus. It is a thin, non-keratinized, stratified, squamous epithelium with more folded rete pegs as compared with the junctional epithelium. This epithelium is less permeable compared with the junctional epithelium. Unlike the junctional epithelium, this contains fewer inflammatory cells, primarily neutrophils.

The purpose of gingival fibres is to maintain a tight gingival cuff and close adaptation of gingiva to tooth, restricting subgingival colonisation (**Fig. 41.8**; **Table 41.1**).

Stippling

The surface of the gingiva is characterized by an 'orangepeel' appearance known as *stippling* which reflects the contour of the epithelial connective tissue boundary in healthy gingiva. Stippling can be described as fine or coarse as it varies with age and gender. It is obliterated as part of the early signs of inflammation. The evidence of stippling starts at the age of 2–3 years, and its absence has been described as normal in older ages.

Applied Histology

Stippling

It is obliterated as part of the early signs of inflammation.

Hard Palate

The hard palate is vaulted (concave); this space is mostly filled by tongue at rest. The anterior two-third of the palate has a bony skeleton formed by the palatine processes of the maxilla and the horizontal plates of the palatine bone. The incisive fossa is a depression in the midline of the bony palate posterior to the central incisor teeth into which the incisive canals open. The mucosa of the hard palate is a masticatory mucosa with ortho- or para-keratinized epithelium. The mean turnover time of hard palate cells is 24 days.

The submucosa in the lateral regions of the anterior palate is composed of fatty tissue and that in the posterior palate is composed of palatine glands. In the centre of the palate, there is no submucosa and the connective tissue is directly adherent to the underlying periosteum of the bone termed *median raphae* (**Fig. 41.9**).

Rugae are a series of elevated ridges that appear in the anterior region of the hard palate

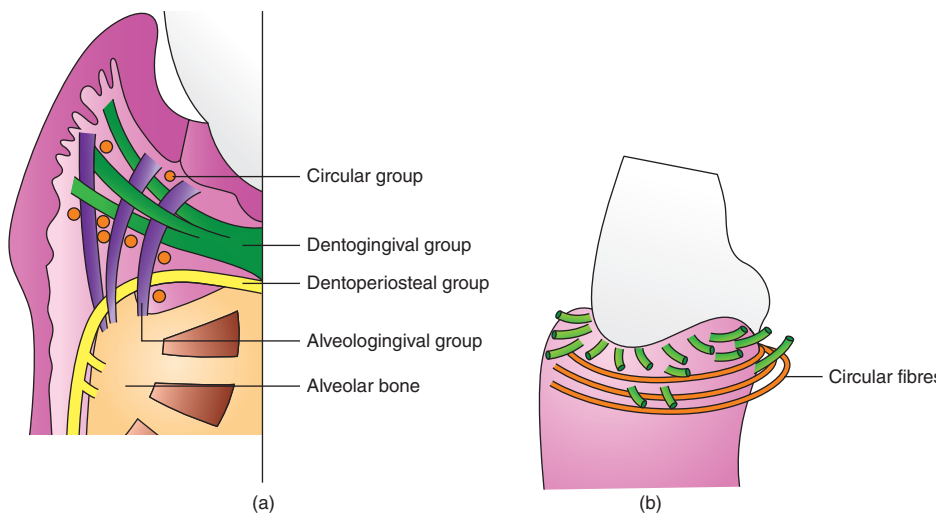


Figure 41.8 (a) Different fibre groups within gingiva. (b) Circular fibres.

Table 41.1 Gingival Fibres

Fibres	Origin	Insertion	Distribution
Dentogingival	Cementum, coronal to the alveolar crest	Inserts into lamina propria of the gingiva	Is grouped as superficial, middle and deep; groups lie between the crevicular epithelium and the alveolar crest
Longitudinal	Within free gingiva	Inserts within free gingiva	Extends long distances, sometimes all over the arch
Circular	Within marginal and interdental gingiva, encircling the tooth	Inserts into cementum and/or alveolar bone, coronal to the alveolar crest	Some cross interdentally to join the fibre group of the adjacent teeth
Alveolo-gingival	Crest of the alveolar bone	Fans out into overlying lamina propria of free and attached gingiva	Radiates coronally
Dentoperiosteal	Cementum	Passes over the alveolar crest and inserts into the buccal and lingual periosteum	Is distributed in labial and lingual gingiva
Transseptal	Cementum of one tooth	Inserts into cementum of the adjacent tooth	Is distributed interdentally over the interdental septum, over the base of the junctional epithelium and coronal to the alveolar crest
Semicircular	Cementum near the cementoenamel junction	Crosses the free gingiva margin, in cementum on the opposite side of the same tooth	Is distributed over free gingival margin
Transgingival	Cervical cementum	Inserts into marginal gingiva of adjacent tooth	Reinforces circular and semicircular fibres and merges with circular fibres
Interdental/inter-papillary	Coronal portion of inter-dental gingiva	Inserts into buccal and lingual papillae	Runs in the buccolingual direction, connecting buccal and lingual papillae
Vertical	Alveolar mucosa/attached gingiva	Inserts into marginal and interdental papillae	Runs vertically in coronal direction

on each side of the median raphae and behind the incisive papilla (**Fig. 41.10**). Rugae patterns are formed by the 12th–14th week of prenatal life, and they become more apparent and remain stable throughout the person's life. With the increase in the size of the anterior part of the palate in the early years of life, the length of the rugae and the distance between each elevation increase. The number of rugae on each side of the palate varies between three and five. The palatine rugae do not extend posteriorly beyond the anterior half of the hard palate and they never cross the midline. The anterior rugae are more apparent than the posterior ones. Two-third of the rugae are curved and the rest are angular. The last ruga is often undivided; the medial and lateral parts are not connected and do not continue in their axial orientation. The rugae pattern is not bilaterally symmetrical. They are easily palpated and can be felt by the tongue.

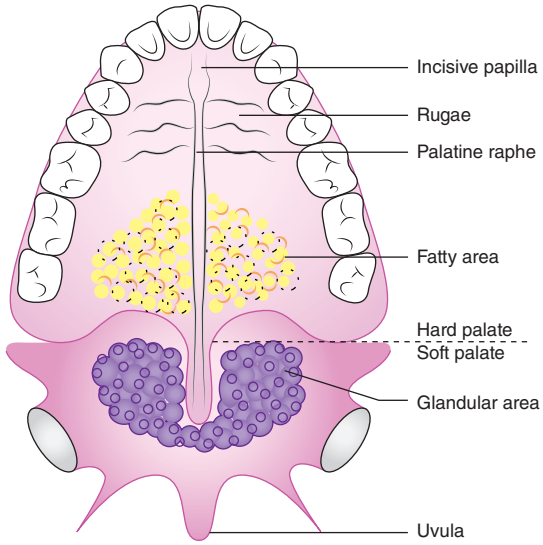


Figure 41.9 Anterior fatty zone and posterior glandular zone of the palate.

Applied Histology

Rugoscopy

Rugae are unique in each individual like fingerprints and can be used to identify individuals for forensic purposes. The analysis of rugae pattern is called rugoscopy.

Histologic Feature of Rugae

Rugae are folds of epithelium with dense connective tissue. Since the papillary layer of the connective tissue is directly adherent to the underlying bone, rugae are termed *traction bands*.

The features of the masticatory mucosa in gingiva and hard palate are compared in **Table 41.2**.

Applied Histology

Local Anaesthesia Infiltration into Masticatory Mucosa

Infiltration of local anaesthesia into masticatory mucosa is very difficult because of the firm attachment of mucosa to the underlying bone, whereas in lining mucosa, infiltration is easy as the fluid gets dispersed fast without causing much pain.

Lining Mucosa

The lining mucosa reflects from the lip and cheek onto the alveolar mucosa in the labial aspect and it reflects onto the lingual mucosa in the lingual aspect. The lining mucosa covers almost the entire oral cavity except the gingiva, hard palate and dorsal surface of the tongue. It includes the labial mucosa, buccal mucosa, alveolar mucosa, mucosa lining the floor of the mouth, ventral surface of the tongue and soft palate. Unlike the masticatory mucosa, the lining mucosa is not subjected to high-level friction. It is soft and has the ability to stretch and be compressed. It has non-keratinized epithelium and a loose lamina propria. The interface between the epithelium and the lamina

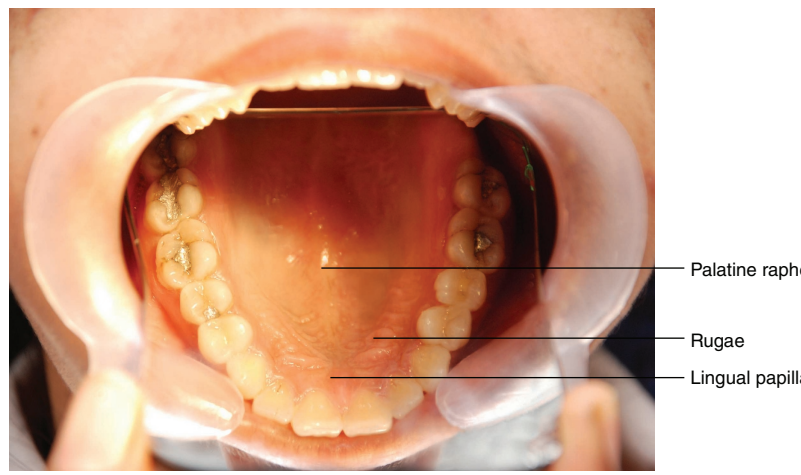


Figure 41.10 Rugae.

Table 41.2 Comparison of the Features of the Masticatory Mucosa

Features	Gingiva	Hard Palate
Covering epithelium	Stratified squamous epithelium	Stratified squamous epithelium
Epithelial thickness	Thick	Thick
Type of keratinization	Orthokeratinization or parakeratinization	Orthokeratinized, often parakeratinized in parts
Lamina propria		
Types of fibres present	Collagen fibres	Presence of thick collagen fibres forming a dense tissue especially in the rugae region
Structure of the papilla	Narrow papillae	Long papillae
Vascularity	Highly vascular but presence of long capillary loops showing anastomoses	Moderate vascular supply with short capillary loops
Attachment to the underlying structure	Absence of submucosa Mucosa firmly attached by collagen fibres to the periosteum of alveolar process by collagen fibres—mucoperiosteum	Dense collagenous connective tissue attaches the mucosa to periosteum—mucoperiosteum

propria is smooth with less-pronounced epithelial ridges and connective tissue papilla. The lamina propria contains collagenous, elastic and reticular fibres. The collagen fibres follow an irregular course and are arranged in a network. This allows the mucosa to be stretched to a certain extent. The elastic fibres control the extensibility of the mucosa by allowing them to recoil. This retracting effect on the mucosa by the elastic fibres prevents the mucosa from being caught between the teeth during chewing. A submucosa is present deep to the lamina propria and its structure varies in different types of lining mucosa.

Labial and Buccal Mucosa

The epithelium covering the inner surface of the lip and the cheeks is thick and non-keratinized. The lamina propria is made of dense connective tissue papillae, primarily made of collagen and some elastic fibres. The interface between the epithelium and the lamina propria shows short and irregular papillae. Strands of dense connective tissue make up the submucosa which binds the lamina propria to the fascia covering the muscles. Fat and minor salivary glands are seen between the strands of connective tissue. The mean turnover time of labial and buccal mucosal cells is 14 days.

Applied Histology

Changes in Labial and Buccal Mucosa

Trauma or any frictional force can lead to keratinization of non-keratinized epithelium. Such a transformation in the buccal mucosa at the level of the occlusal line because of the friction caused by the cusps of the occluding teeth is called linea alba. Linea alba occurs as a white line which is readily visible on clinical examination.

In case of patients with habits such as night grinding (bruxism), a larger area of the buccal mucosa can demonstrate keratinization. The clinical identification of such a modification can be a clue in terms of diagnosis of parafunctional habits of the patient.

Occasionally, sebaceous glands may be present in the connective tissue of cheeks presenting as yellow spots called Fordyce spots in the mucosa on clinical examination. This presentation is a developmental anomaly rather than a disease state.

Alveolar Mucosa

The mucous membrane covering the outer surface of the alveolar process shows thin, non-keratinized epithelium. The lamina propria shows short papillae and the underlying blood vessels are seen close

to the surface. This gives the mucosa a red colour, which is in contrast to the pale pink colour of the keratinized gingiva.

The submucosa is loosely attached to the periosteum and consists of loose connective tissue and minor salivary glands. The alveolar mucosa is continuous with the gingiva and is separated from it by the mucogingival junction.

Ventral Surface of the Tongue

The mucous membrane covering the ventral surface of the tongue is thin and is made of non-keratinized stratified squamous epithelium. The connective tissue papillae are short and numerous. Few elastic fibres are present in lamina propria. The submucosa is not distinct and merges with the connective tissue surrounding the muscle fibres.

Floor of the Mouth

A very thin, non-keratinized stratified squamous epithelium covers the lamina propria in the floor of the mouth. It has few elastic fibres and the papillae are short. The submucosa is loosely attached to the underlying structures and has fat and sublingual salivary glands. The mean turnover time of the cells of the floor of the mouth is 20 days.

Applied Histology

Sublingual Drug Delivery

The thin non-keratinized epithelium and larger veins underneath the ventral surface of the tongue and floor of the mouth favour easy drug delivery. The drug when placed underneath the tongue is absorbed swiftly by the body. An example of such a placement of drug is nitroglycerine tablets that relieve angina.

Soft Palate

The epithelium is thin, non-keratinized and has few taste buds. The lamina propria is vascular, giving the soft palate a darker pink colour in contrast to the pale colour of the keratinized hard palate. It has many elastic fibres and the submucosa is loosely attached to the underlying structure and has numerous mucous salivary glands.

Vermilion Zone

The vermilion zone, situated between the labial mucosa and the skin of the lip, has a structure different from the skin or the mucosa. While the skin is covered by a thick keratinized epithelium, the vermilion zone has a thin keratinized epithelium, which is translucent due to the increased presence of *eleidin*. The lamina propria has long papillae and carries capillaries close to the surface. The close proximity of the blood vessels to the surface along with thin transparent epithelium gives this zone a red colour that is characteristic of the humans. As this zone is exposed to atmosphere and the submucosa is devoid of mucous glands, it dries up easily and requires moistening with saliva by the tongue. The junction between the vermilion zone and the labial mucosa is called the *intermediate zone*. This shows parakeratinized epithelium.

The features of the lining mucosa in various parts of the oral cavity including the vermilion zone are compared in **Table 41.3**.

Applied Histology

Suturing Lining Mucosa

The lining mucosa is loosely attached to the underlying structures. Any incision creates gaping of wounds and hence suturing is compulsory in these areas.

Specialized Mucosa

Dorsal Surface of the Tongue

The mucosa covering the dorsal surface of the tongue is different from that seen anywhere else in the oral cavity. It is mostly keratinized. It has different types of papillae, some of which bear taste buds. In addition to its mechanical function, the tongue has an important sensory function (taste) and the mucosa covering the dorsal surface of the tongue is regarded as specialized mucosa (**Fig. 41.11**).

Applied Histology

White Coating on the Tongue

Desquamated cells of the oral mucosa are present in saliva and they settle on the dorsum of the tongue forming a white coating. Patients should be advised to brush the dorsal surface of the tongue to avoid white coating and subsequent microbial colonization which might lead to bad breath.

Table 41.3 Comparison of the Features of the Lining Mucosa

Features	Labial and Buccal Mucosa	Alveolar Mucosa	Floor of Mouth	Soft Palate	Ventral Surface of Tongue	Lips—Vermilion Zone
Covering epithelium	Stratified squamous epithelium	Stratified squamous epithelium	Stratified squamous epithelium	Stratified squamous epithelium	Stratified squamous epithelium	Stratified squamous epithelium
Epithelial thickness	Very thick	Thin	Very thin	Thin	Thin	Thin
Type of keratinization	Non-keratinized	Non-keratinized	Non-keratinized	Non-keratinized	Non-keratinized	Orthokeratinized
Lamina propria						
Types of fibres present	Collagen and elastic fibres	Elastic fibres	Collagen and few elastic fibres	Many elastic fibres forming an elastic lamina	Collagen and some elastic fibres	Collagen and some elastic fibres
Structure of papilla	Long slender papillae	Short papillae	Short papillae	Short papillae	Short papillae	Many narrow papillae
Vascularity	Rich anastomosing capillary loops into papillae	Capillary loops close to the surface supplied by superficial periosteal vessels	Highly vascular with short anastomosing capillary loops	Rich in vascularity with well-developed capillary network	Capillary network in subpapillary layer, reticular layer comparatively avascular	Capillary loops close to surface in papillary layer
Attachment to underlying structure	Firm attachment to underlying muscle	Loose attachment to periosteum	Loose attachment to underlying muscle	Loose attachment to underlying tissues	Not distinct; attached to underlying muscle	Firm attachment to underlying muscle

The dorsal surface of the tongue is divided into anterior two-third (derived from the first pharyngeal arch) and posterior one-third (derived from the third pharyngeal arch) by a V-shaped groove, the *sulcus terminalis*. While the mucosa covering the anterior two-third or the body of the tongue has numerous papillae, the mucosa covering the posterior one-third or the base of the tongue contains nodules of lymphoid tissue.

The papillae on the anterior two-third of the tongue are of four types:

1. **Filiform papillae:** They cover almost the entire anterior surface and give the tongue a velvety appearance (**Fig. 41.12**). These are cone-shaped structures consisting of a core of lamina propria covered by keratinized stratified squamous epithelium forming hair-like tufts. This gives the tongue an abrasive surface and helps it to be involved in mastication by compressing the bolus of food against palate. There are no taste buds in filiform papillae.

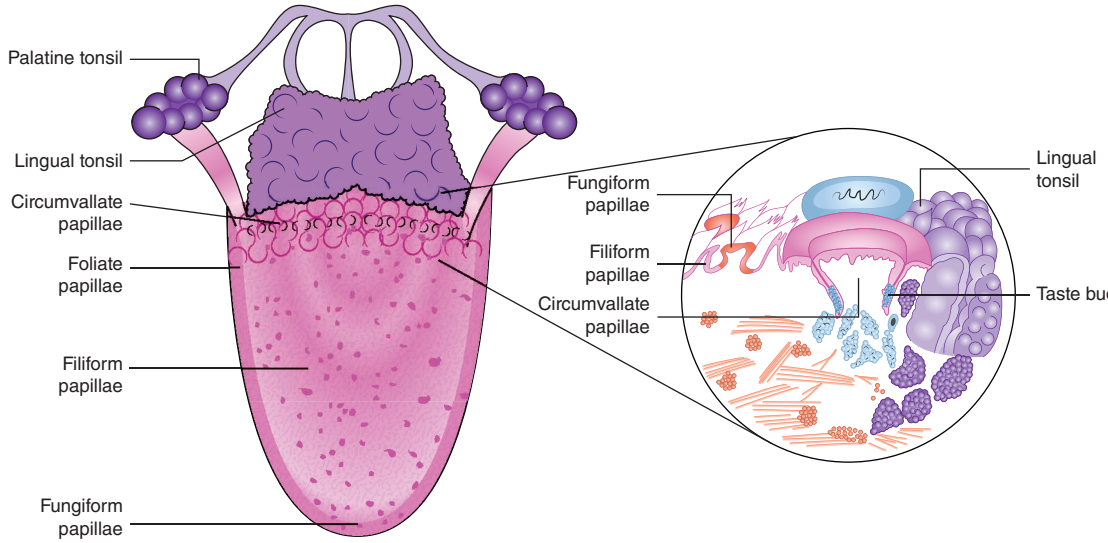


Figure 41.11 Dorsum of the tongue showing papillae.

Applied Histology

Geographic Tongue

It is also called benign migratory glossitis and appears as red and white areas in the tongue. The redness corresponds to loss of filiform papillae and the white areas correspond to orthokeratinization of the filiform papillae. This lesion might be associated with the burning sensation of the tongue.

Black Hairy Tongue

Epithelial turnover of filiform papillae is affected leading to accumulation of a thick layer of keratin, debris and dead cells in the tongue causing black hairy appearance. Brushing the tongue is advised to remove the debris and dead cells. Brushing also activates shedding of epithelial cells.

2. **Fungiform papillae:** They are isolated, elevated, mushroom-shaped papillae scattered between numerous filiform papillae (**Fig. 41.13**). They are reddish, round, smooth structures. The redness is due to the rich vascularity of lamina propria which is visible through the thin overlying epithelium. Few taste buds are found on their superior surface.
3. **Foliate papillae:** They are leaf-like papillae seen on the lateral margin of the posterior part of the tongue. They present as clefts/grooves and show taste buds on their lateral walls.
4. **Circumvallate papillae:** They are about 10 in number, situated just in front of V-shaped sulcus terminalis. These are large (2–4 mm), rounded

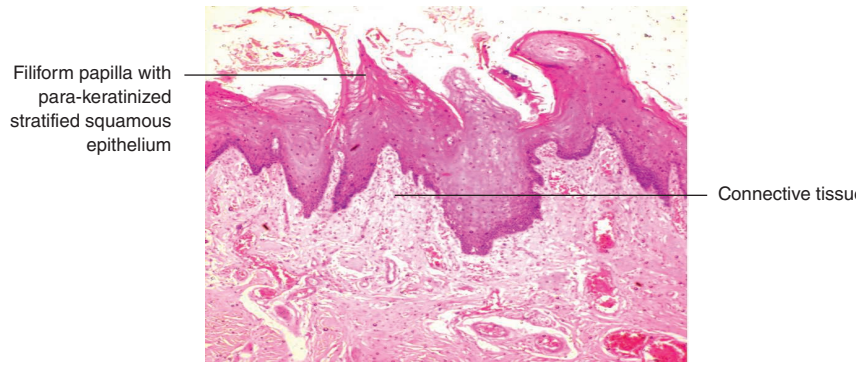


Figure 41.12 Filiform papilla (haematoxylin and eosin, 10X).

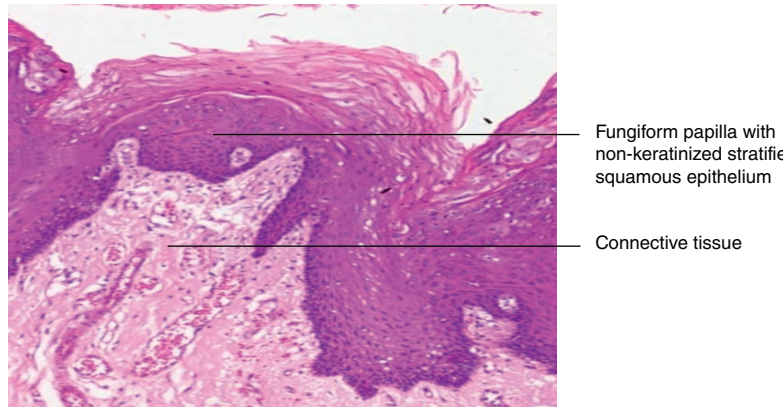


Figure 41.13 Fungiform papilla (haematoxylin and eosin, 10X).

and in level with the surface of the tongue. They are surrounded by a circular groove and a wall (vallum) and hence get their name 'circumvallate'. The ducts of the underlying serous glands—von Ebner's glands—open into these grooves surrounding the papilla. These papillae are covered by keratinized epithelium on their superior surface. The epithelium covering their lateral wall (facing the groove) is non-keratinized and has numerous taste buds (**Fig. 41.14**).

The features of specialized mucosa are given in **Table 41.4**.

Sensation of Taste (Fig. 41.15) The sense of taste is mediated by taste receptor cells present in the taste buds. The taste receptor cells within a bud are arranged such that their tips form a small taste pore, and through this pore, microvilli extend from the taste cells. The microvilli of the taste cells bear taste receptors. Taste cells are stimulated by binding of chemicals to their receptors. They depolarize, and this depolarization is transmitted to the taste nerve fibres resulting in an action potential that is ultimately transmitted to the brain.

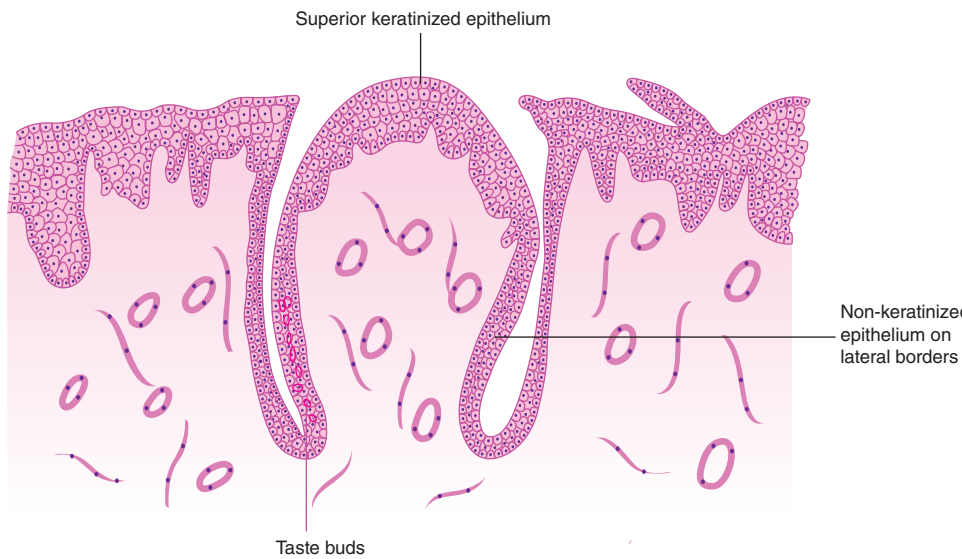


Figure 41.14 Circumvallate papillae.

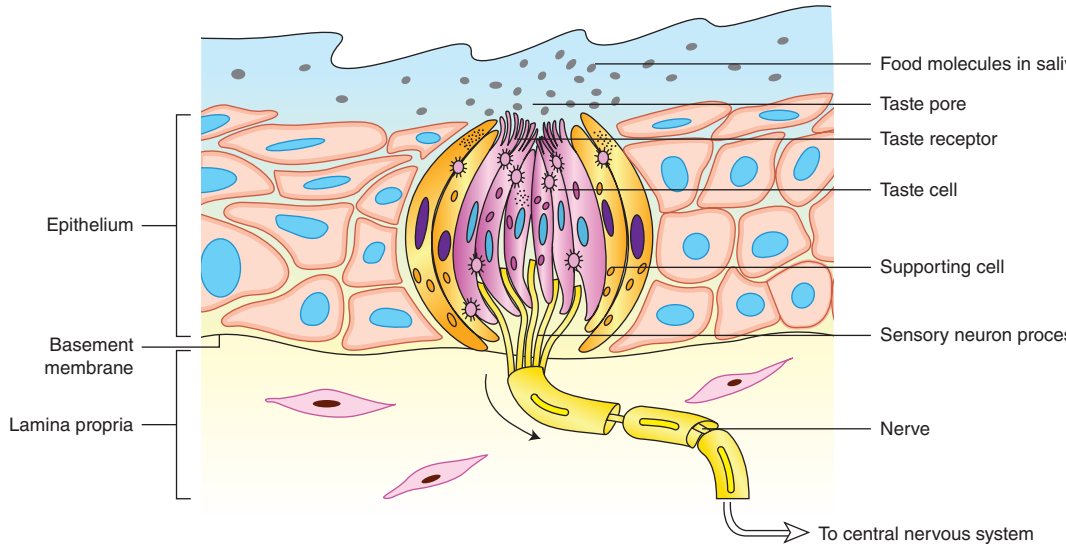


Figure 41.15 Occurrence of a taste sensation with a taste bud.

Table 41.4 Features of Specialized Mucosa

Features	Dorsal Surface of the Tongue
Covering epithelium	Stratified squamous epithelium
Epithelial thickness	Thick
Type of keratinization	Keratinized in anterior two-third and non-keratinized in posterior one-third
Lamina propria	
Types of fibres present	Collagen and some elastic fibres
Structure of papilla	In the anterior two-third, long papilla and in the posterior one-third, short papilla
Vascularity	Capillary plexus in papillary layer, large vessels lie deeper
Attachment to underlying structure	Not distinct; attached to underlying muscle

The sensation of taste is discussed in detail in Chapter 24.

AGE CHANGES IN THE ORAL MUCOSA

The following clinical and histological changes can be observed in oral mucosa as age advances.

Clinical Changes

1. Enlargement of lingual veins occur leading to lingual varicosities in the ventral surface of the tongue sometimes called *caviar tongue*.
2. Slowly, depapillation of tongue might set in consequently leading to reduction in taste buds. Subsequently, taste perception might also get diminished. Many a times, such a change in the tongue happens because of medications taken or an associated disease process in older individuals
3. Medications may also lead to hyposalivation and consequent dryness of the mouth
4. Stippling in the attached gingiva is diminished
5. Creasing in the labial commissures occurs due to loss of vertical dimension subsequent to loss of tooth and resorption of jaws
6. The repair and healing capability of oral mucosa is diminished

Histological Changes

1. The number and thickness of rete ridges reduce
2. Mitotic activity reduces
3. The degree of keratinization is diminished
4. Turnover time gets prolonged

5. Collagen bundles are thickened
6. The quality of elastic fibres is reduced leading to reduction in the resiliency of oral mucosa
7. Collagen turnover time is prolonged
8. Fibroblasts appear smaller and the activity is diminished

Applied Histology

Age Changes and Modifications in Dental Treatment Procedures

The age changes have to be kept in mind while treating older individuals by considering due precautions to avoid complications during the dental treatment procedures.

ADDITIONAL READING

Minimal Scar Formation in Oral Mucosa

Wounds in human oral mucosal heal with minimal scar formation than dermal wounds. The evolutionary hypothesis behind this fact could prevent scarring to enable food intake. Characterization of wound healing in oral mucosa has revealed the presence of a distinct fibroblast phenotype, the presence of bacteria that stimulate wound healing and growth factors present in saliva. Gingival fibroblasts proliferate faster and express significantly higher levels of molecules that are involved in modulation of inflammation and ECM remodelling (mineral metalloproteins) while dermal fibroblasts showed a significantly elevated expression of TGF-β signalling, ECM, myofibroblast and cell contractility-related genes. Due to their distinct phenotype, gingival fibroblasts are conducive to faster resolution of inflammation and ECM remodelling thus giving rise to scarless wound healing whereas dermal fibroblasts have a profibrotic or scar-prone phenotype (excerpts from Mah et al. 2014).

Oral Mucosa Harbours a High Frequency of Endothelial Cells

Endothelial stem cells/endothelial cells (EPCs/ECs) due to their inherent potential are used to treat pathological conditions such as cardiac infarction, muscle ischaemia and bone fractures. However, isolation is difficult due to low frequency of cells in the tissues. Studies in rat oral mucosa were found to be thousands of folds higher than those derived from donor bone marrow. Endothelial progenitor cells present in oral mucosa are positive for EC markers CD31, VE-Cadherin and VEGFR2. They also displayed a rapid uptake of acetylated low-density lipoprotein and formed stable capillary networks in three-dimensional culture. Angiogenic properties could be demonstrated by subcutaneous implantation of the endothelial cells which anastomosed with host blood vessels. Proliferative rates too were found to be higher than human umbilical vein endothelial cells. Endothelial progenitor cells obtained from oral mucosa have a higher potential for angiogenesis in tissue and organ regeneration (excerpts from Zhou et al. 2017).

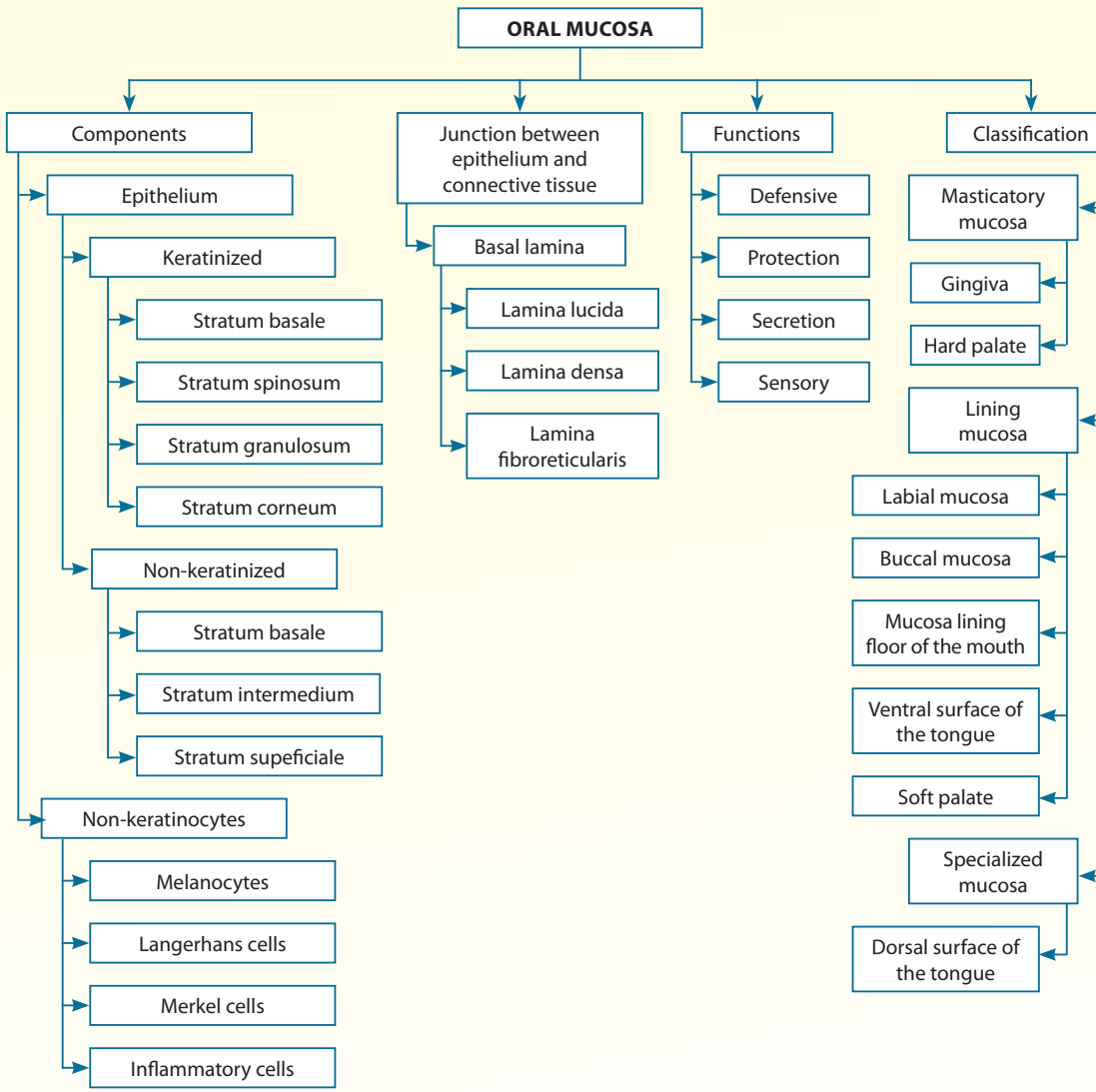
SECTION IV

Key Points

1. The oral mucosa consists of stratified squamous epithelium and the underlying connective tissue. The epithelium and connective tissue are attached to the underlying muscle by the submucosa.
2. The oral mucosa is classified into three types:
   (a) *Masticatory mucosa:* Gingiva, hard palate
   (b) *Lining mucosa:* Labial mucosa, buccal mucosa, mucosa lining the floor of the mouth, ventral surface of the tongue, soft palate
   (c) *Specialized mucosa:* Dorsal surface of tongue
3. The oral epithelium can be keratinized or non-keratinized.
4. The keratinized epithelium consists of four layers: stratum basale, stratum spinosum, stratum granulosum and stratum corneum.
5. The non-keratinized epithelium consists of three layers: stratum basale, stratum intermedium and stratum superficiale.

6. Melanocytes, Langerhans cells, Merkel cells and inflammatory cells are non-keratinocytes.
7. The connective tissue of oral mucosa is called lamina propria which is divided into two layers: papillary and reticular.
8. Submucosa serves to attach connective tissue to the underlying bone or muscle.
9. Cytokeratins are intermediate filaments seen in epithelial cells and also in contact places such as desmosomes and hemidesmosomes.
10. The zone between the labial mucosa and skin of lip is known as *vermilion zone.*
11. The dorsal surface of the tongue is divided into anterior two-third and posterior one-third by a V-shaped groove.
12. Four types of papillae are seen in the anterior two-third of the tongue: filiform, fungiform, circumvallate and foliate papillae.
13. Taste buds are few in fungiform papillae but numerous in circumvallate papillae.

Mind Map



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Multiple Choice Questions

1. Oral mucosa exhibits
   (a) Humoral immunity
   (b) Cell-mediated immunity
   (c) Both of the above
   (d) None of the above
2. The lining mucosa includes all except the
   (a) Lips
   (b) Cheeks
   (c) Floor of mouth
   (d) Dorsum of tongue
3. The oral mucosa is lined by the
   (a) Stratified squamous epithelium
   (b) Cuboidal
   (c) Columnar
   (d) None of the above
4. Mucoperiosteal attachment is seen in the
   (a) Gingiva
   (b) Lips
   (c) Cheek
   (d) All of the above
5. The epithelium of oral cavity is derived from the
   (a) Ectoderm
   (b) Endoderm
   (c) Mesoderm
   (d) None of the above
6. Hemidesmosomes help in
   (a) Adhesion between epithelium and connective tissue
   (b) Adhesion between cells in epithelium
   (c) Both a and b
   (d) None of the above
7. Desmosomes have
   (a) Two attachment plaques
   (b) One attachment plaque
   (c) Three attachment plaques
   (d) Four attachment plaques
8. Odland body is seen in the
   (a) Stratum spinosum
   (b) Stratum granulosum
   (c) Stratum intermedium
   (d) Stratum superficiale

9. The most prominent finding in stratum granulosum is
   (a) The presence of keratinosome
   (b) Keratohyaline granules
   (c) Langerhans cells
   (d) All of the above
10. Characteristic features of melanocytes are
   (a) Clear cells
   (b) Spider-like appearance in silver stains
   (c) Production of melanin pigment
   (d) All of the above
11. A characteristic of Langerhans cells is
   (a) The presence of Birbeck's granules
   (b) Antigen-presenting cells
   (c) They are derived from bone marrow
   (d) All of the above
12. Basal lamina has
   (a) Type I collagen
   (b) Type II collagen
   (c) Type IV collagen
   (d) All of the above
13. The epithelium present in the intermediate zone is
   (a) Non-keratinized
   (b) Orthokeratinized
   (c) Para-keratinized
   (d) None of the above
14. Taste buds are not present in the
   (a) Filiform papilla
   (b) Fungiform papilla
   (c) Circumvallate papilla
   (d) None of the above

CHAPTER 42



Histology of Salivary Glands

Overview

Saliva is the product of multiple salivary glands lying beneath the oral mucosa. It is made up of 99.5% water and 0.5% solutes. Each day, the human salivary glands produce almost 1200 mL of serous and mucinous saliva containing minerals, electrolytes, buffers, enzymes and enzyme inhibitors, growth factors and cytokines, immunoglobulins (e.g. secretory immunoglobulin A [sIgA]), mucins and other glycoproteins. Saliva is produced by the salivary glands. The basic unit of a salivary gland is secretory cell. The secretory cell can be either a serous cell or a mucous cell. An acinus consists of 8–12 secretory cells with a central lumen. The secretions of the acini travel through the ductal system categorized into intercalated, striated and excretory ducts. The ductal cells vary from each other morphologically as well as functionally resulting in the transport of ductally modified saliva. These ductal cells are supported by myoepithelial cells which incur the transport efficacy to the ducts. Salivary glands are classified into major salivary glands and minor salivary glands anatomically and into serous, mucous or mixed salivary glands functionally. Parotid, submandibular and sublingual glands are the major salivary glands, the ducts of which open at respective locations in the oral cavity. Ducts draining minor salivary glands open directly onto the mucosal surface. Thus, the saliva formed plays a vital role in maintaining the health of the oral cavity.

INTRODUCTION

Saliva is a complex fluid containing various organic and inorganic substances. It helps to maintain the well-being of the oral cavity and assists in the process of mastication, deglutition, digestion of food and speech.

Saliva is the product of salivary glands, which are compound, tubuloacinar, merocrine and exocrine glands, the ducts of which open into the oral cavity. The term *compound* refers to the fact that a salivary gland has more than one tubule entering the main duct, *tubuloacinar* describes the morphology of the secreting cells, *merocrine* means that only the secretion of the cell is released and *exocrine* means a gland that secretes fluid onto a free surface.

Salivary glands are classified into minor and major on the basis of their size. The major salivary glands are located outside the oral cavity and the minor salivary glands are distributed all over the oral cavity. The major salivary glands are the parotid, submandibular and sublingual glands, which contribute to about 80–90% of salivary secretions.

A mature salivary gland is composed of glandular secretory tissue and stroma. The secretory end pieces are connected to the oral cavity through a network of ducts. They consist of secretory cells organized in round clusters termed *acini* and tubular clusters called *tubules*.

STRUCTURE OF THE SALIVARY GLAND

The functional unit of the salivary gland is the acini (*sing.* acinus). An acinus consists of 8–12 cells with a central lumen. They are of three types—serous, mucous and seromucous—depending on the type of secretion. The acinus, through its lumen, empties its secretions into an intercalated duct, which in turn joins a larger striated duct. Both intercalated and striated ducts are intralobular. The striated ducts empty into the collecting ducts, which are interlobular (**Fig. 42.1**).

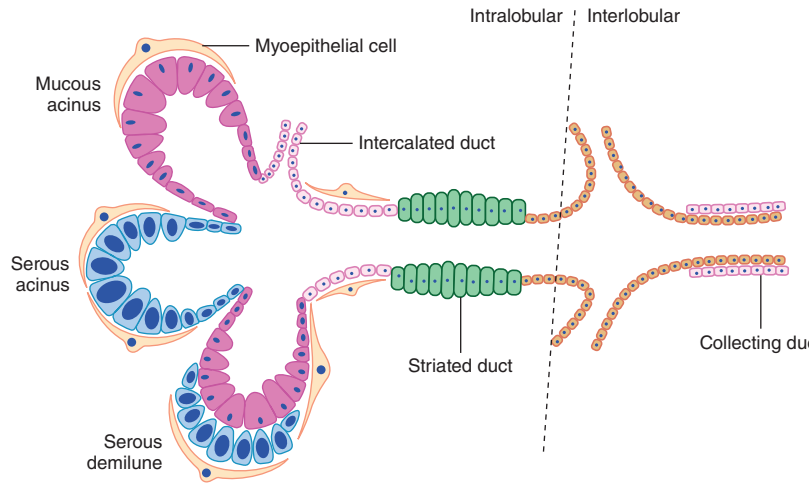


Figure 42.1 Secretory and ductal system in a mixed salivary gland.

Secretory Cells

The secretory cells of the salivary gland are the serous cells and the mucous cells. (**Table 42.1**)

Serous Cell

Serous cells are pyramid or wedge shaped with a large nucleus placed near the basal region of the cell. Serous secretions are rich in proteins and watery in nature. Serous cells are specialized for the synthesis, storage and secretion of proteins. They have an extensive rough endoplasmic reticulum arranged parallel to each other, below the nucleus. The serous cells have small secretory granules known as *zymogen granules* present in the apical end that stain dark with haematoxylin. These granules contain the macromolecular components of saliva. Prominent Golgi bodies are also seen either in the apical or lateral position to the nucleus.

The plasma membrane in the basal portion of the cell is thrown into folds which interdigitate with the folds of the neighbouring cells. The adjacent serous cells are joined to each other by intercellular junctions present on their lateral surfaces. The apical region of the cell has microvilli, which are directed towards the lumen (**Fig. 42.2**).

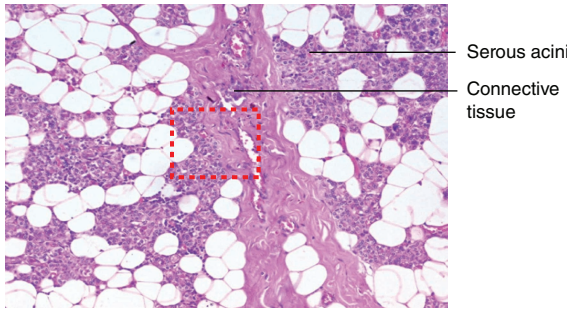
Table 42.1 Differences Between a Serous and a Mucous Cell

Serous Cell	Mucous Cell
Pyramidal or wedge shaped cells	Columnar cells
Large spherical nucleus basally located	Flattened nucleus basally located
Secretory granules—zymogen granules	Secretory granules—mucinogen
Plasma membrane at the basal portion are thrown into folds	Not seen in a mucous cell
Intercellular canaliculi present	Intercellular canaliculi absent
Serous acinus/serous secretory end pieces—typically spherical	Mucous acinus/secretory end pieces—typically tubular

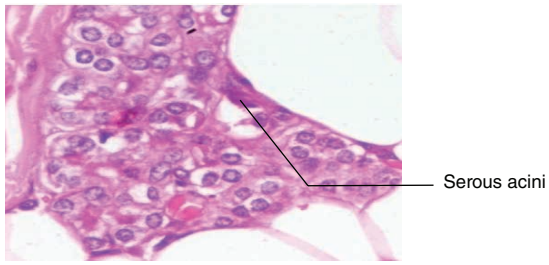
Mucous Cell

Mucous cells are columnar with the nucleus flattened to the base of the cell. They are larger than serous cells and contain numerous large granules which occupy almost two-third of the cell. Mucous secretions are rich in complex carbohydrates found as chains attached to mucin proteins which represent the mass of glycoproteins. The secretions are stored as *mucinogen granules* in the apical region of the cell. The viscous nature of the mucous secretion helps in lubrication.

The mucous cells appear empty in routine haematoxylin and eosin sections, as the mucinogen is lost during processing. To demonstrate mucin, special stains such as periodic acid–Schiff (PAS)/alcian blue can be used.

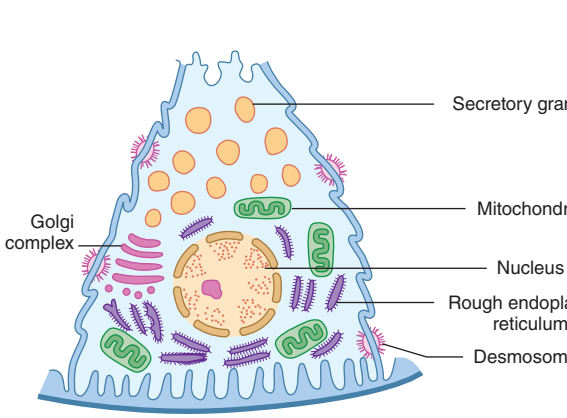


(i)



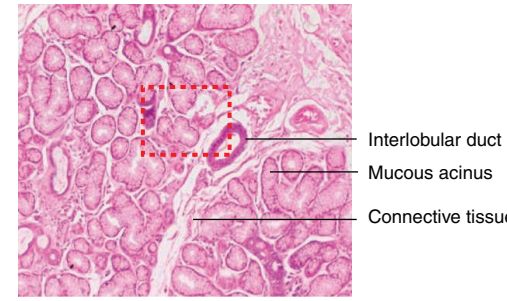
(ii)

(a)

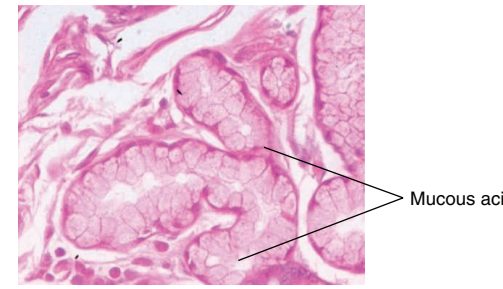


(b)

Figure 42.2 Serous cell: (a) photomicrographs and (b) schematic diagram. (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin, 10X; ii—haematoxylin and eosin, 40X).

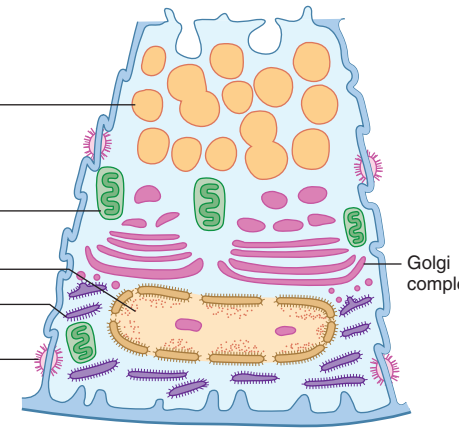


(i)



(ii)

(b)



(b)

Figure 42.3 Mucous cell: (a) photomicrographs and (b) schematic diagram. (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin, 10X; ii—haematoxylin and eosin, 40X).

Numerous cellular organelles such as Golgi bodies, endoplasmic reticulum and mitochondria are present near the base and lateral aspects of the cell. The Golgi bodies synthesize the glycoproteins by adding carbohydrate to the protein secreted by the endoplasmic reticulum. Intercellular communications between cells are few in number and intercellular canaliculi are absent in mucous cells (**Fig. 42.3**).

Protein Synthesis in Secretory Cells

The rough endoplasmic reticulum is involved in protein synthesis and determines the quality of

proteins. The messenger RNA carries the code for protein synthesis from the nucleus to the ribosomes present in the rough endoplasmic reticulum. The proteins which are synthesized in the ribosomes are transferred in the form of small vesicles to the Golgi bodies. Proteins undergo post-translational modification in the Golgi bodies, during which a carbohydrate, phosphate or a sulphate group is added to the amino acids. Addition of a carbohydrate group is more common in salivary cells, and this process is called *glycosylation*.

The secretory products are stored in the form of granules and are seen in the apex of the salivary secretory cells. They are expelled outside the cell by a process known as *exocytosis,* which involves discharging of membrane-bound vesicles through the cell membrane.

Myoepithelial Cell

Myoepithelial cells are contractile cells located between the basal lamina and the basal membrane of secretory acini and intercalated duct cells (**Fig. 42.4**). The myoepithelial cells are flattened cells with five to eight branching processes giving them a star/stellate shape. They are known as *basket/cradle cells,* as these processes surround and embrace the end pieces of the secretory cells (**Fig. 42.5**). They are also seen running along lengthwise with the intercalated ducts and exhibit fewer and shorter processes.

Myoepithelial cells are similar to smooth muscle cells as they contain actin, myosin microfilament bundles and caveolae in their membrane and exhibit contractile movements. They are joined to one another and to the adjacent epithelial cells by means of desmosomes. They are called myoepithelial cells as they are ectodermal derivatives, unlike smooth muscle cells, which are mesodermal derivatives.

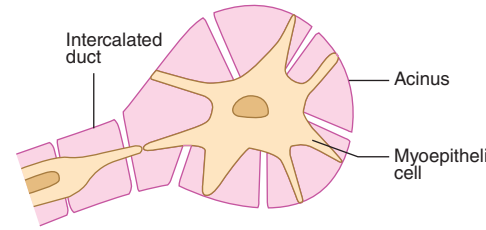


Figure 42.5 Myoepithelial cell surrounding the acinus.

Myoepithelial cells provide support to acinar cells and help in secretion by contraction. They squeeze the saliva from the acinar cells into the duct system. Myoepithelial cells found in relation to intercalated ducts help in shortening and widening of the ducts to maintain their patency.

Myoepithelial cells cannot be identified in routine haematoxylin–eosin sections. Special markers such as the alpha smooth muscle actin (αSMA), calponin, caldesmon, maspin, p63 and S100 help to identify myoepithelial cells.

In addition to the support and contractile functions, the myoepithelial cells also help in the structural organization of the secretory unit by maintaining cell polarity.

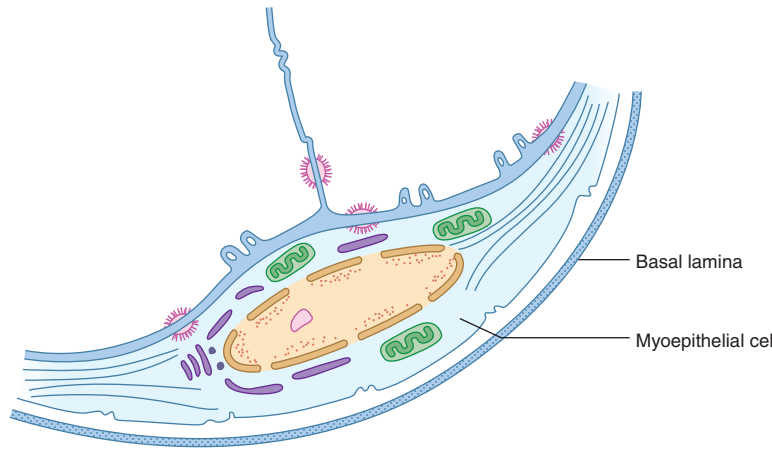


Figure 42.4 Myoepithelial cell.

DUCTAL SYSTEM

The ductal system of salivary glands is a highly branched network of tubules beginning at the secretory end pieces as very small intercalated ducts and ending at very large terminal ducts. The ductal system helps in the passage of saliva and actively participates in the production and modification of saliva.

The ductal pattern of a compound, tubuloacinar gland consists of intralobular ducts (intercalated ducts and striated ducts) which are found inside the lobes connecting the acini. The intralobular ducts lead to the interlobular duct or the excretory duct.

The duct system is of two types: secretory portion and excretory portion. The secretory portion is involved in modification of saliva by ion exchange. The intercalated and striated ducts come under the secretory part of the duct system. The excretory portion is predominantly involved in transport of saliva and the excretory duct forms this part of the duct system (**Fig. 42.6**).

Intercalated Ducts

Intercalated ducts are the smallest ducts and intralobular in location, i.e., they are located between a secretory acinus. The first-formed saliva produced in the acini passes through the intercalated duct. These ducts are more prominently seen in serous salivary glands than mucous glands, where they are short and difficult to identify (**Fig. 42.7**).

The intercalated ducts are lined by a single layer of simple cuboidal epithelium. The cuboidal cells contain a centrally placed nucleus with few cytoplasmic organelles. The apical surface of the cell contains short microvilli. The lateral surface of the cell is attached to the adjacent cells by desmosomes. The myoepithelial cells are located along the basal surface of the duct. The duct also contains stem cells which help replenish the damaged cells in the acini and the striated duct.

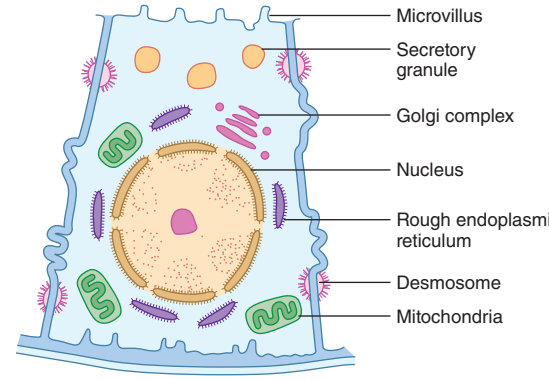


Figure 42.7 Intercalated duct cell.

The cells of the intercalated duct secrete bicarbonate ions, lysozyme and lactoferrin into the saliva secreted by the acini. They absorb chloride ions from the saliva.

Striated Ducts

Striated ducts are called so because of the striations seen in the cells lining the duct. They are larger in diameter when compared with the intercalated ducts. The striated duct is lined by a simple cuboidal epithelium and gradually takes up a columnar shape as it reaches the excretory duct (**Fig. 42.8**).

The nucleus is centrally located and the cellular organelles are more in number than in the

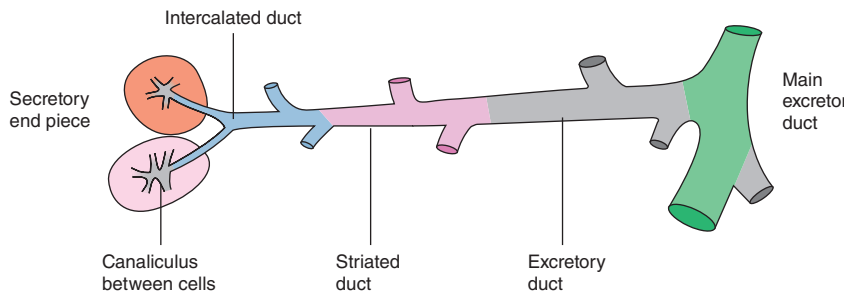


Figure 42.6 Ductal system of a salivary gland.

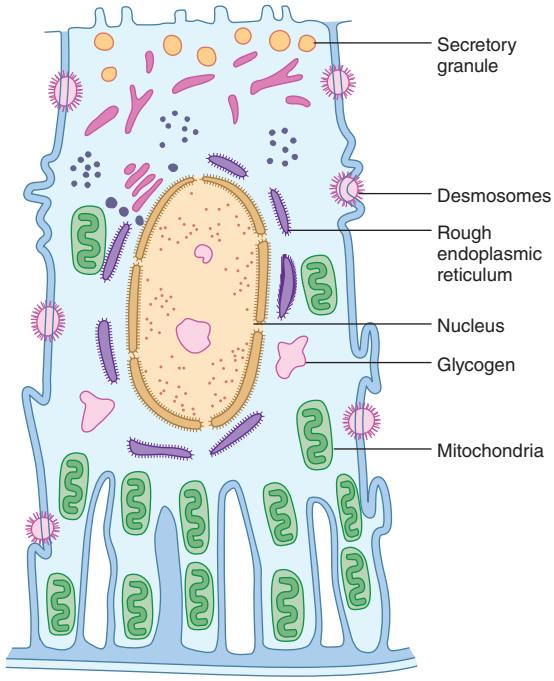


Figure 42.8 Striated duct cell.

intercalated ducts. The striations seen in the cell are the result of an infolded plasma membrane in the basal surface. Numerous mitochondria are seen in these infoldings. Basolateral folds are seen apart from the basal infoldings. These morphological specializations help in the modification of the salivary secretion.

The striated duct helps in the reabsorption of sodium ions from the saliva and the secretion of potassium and bicarbonate ions into the saliva.

Excretory Ducts

Excretory ducts are interlobular ducts of larger diameter than the secretory ducts. They are seen in the connective tissue septa between the lobules and lobes of the salivary gland. The excretory ducts are lined by cuboidal epithelium which gradually changes to pseudostratified columnar epithelium.

The smaller excretory ducts are similar to the striated ducts. As the ducts increase in size, the number of mitochondria and plasma membrane infoldings decreases while the number of basal cells increases. Mucous cells are also seen in the excretory duct. The basal cell layer has a high rate of proliferation and is attached to the basal lamina by hemidesmosomes. The epithelium of the main excretory duct may become gradually stratified or multilayered as it reaches the oral epithelium.

Like the striated ducts, the excretory ducts are involved in the modification of saliva. The luminal and the basolateral surfaces are involved in reabsorption of sodium and secretion of chloride, potassium and bicarbonate ions.

Applied Histology

Salivary Glands as a Gene Therapy Model

Through the cells and duct of the salivary gland, proteins secreted by the gland reach the oral cavity they can serve as a model for insertion of gene to produce a specific protein which they do not secrete routinely.

Supporting Stroma/Connective Tissue

The supporting stroma of the salivary glands consists of fibroblasts, macrophages, mast cells, occasional leukocytes, adipocytes, plasma cells and lymphocytes embedded in the ground substance. The plasma cells help to produce immunoglobulin A which is secreted into the saliva. The extracellular matrix consists of collagen and elastic fibres. Elastic fibres provide elasticity and resilience. The ground substance consists of proteoglycans and glycoproteins.

The capsule of the salivary gland is derived from the connective tissue. This surrounds the gland and separates it from the adjacent structures. Connective tissue septa from the capsule divide the gland into lobes and lobules and carry the blood vessels and nerves that supply the glandular components.

HISTOLOGY

Parotid Gland

The parotid gland is the largest of the salivary glands and is surrounded by the parotid capsule. The acini are predominantly serous. The acinar cells are pyramidal with a basally placed spherical nucleus. They have a granular appearance in haematoxylin and eosin sections because of the secretory granules. The granules take up haematoxylin

stain and the apical cytoplasm takes up eosin. Fat cells are commonly seen in the parotid gland.

Numerous long intercalated ducts are lined by cuboidal epithelial cells. They begin from the serous acini and join the striated ducts. The intercalated duct cells contain a prominent nucleus and a scanty cytoplasm. The striated ducts form a longer and more active component of the duct system as they are involved in the modification of saliva. They appear slightly acidophilic and are lined by simple columnar epithelial cells with a centrally placed, round nucleus.

The main excretory duct, *Stenson's duct,* opens into the oral cavity on the buccal mucosa opposite to the maxillary second molar. It contributes to 30% of the total salivary secretion.

Submandibular Gland

The submandibular gland is the second largest of the salivary glands and is also enclosed inside a well-defined connective tissue capsule. It is a mixed gland with both serous and mucous acini. Serous acini predominate in the ratio of 7:3, but the proportions may vary from one lobule to another. The serous acini are similar in structure to those found in the parotid gland. The mucous secretory cells appear pale because they are filled with pale staining mucinogen granules. The duct system is similar to that in the parotid gland but less numerous.

In haematoxylin and eosin sections, some of the mucous cells are seen to be capped by serous acini and appear as half-moon–shaped *serous demilunes*. Serous demilunes occur in haematoxylin and eosin sections because of the distension of mucous cells, which displaces the closely placed serous acini towards the distal end of the mucous acini. This appearance has been proved to be an artefact. Rapid freeze sections of salivary acini do not show such a structure (**Fig. 42.9**).

The main excretory duct, *Wharton's duct,* opens near a small papilla (*Caruncula sublingualis*) at the side of the lingual frenum on the floor of the mouth. It contributes to 60% of the total salivary secretion.

Sublingual Gland

The human sublingual salivary gland is made up of two parts, unlike the other major salivary glands: posterior part (greater sublingual gland) and anterior part (lesser sublingual gland). The sublingual glands consist of 8–30 small glands. Each part has its own duct system emptying into the sublingual fold.

The sublingual gland is also a mixed gland, but mucous acini predominate. Rarely, serous end pieces may be present. The intercalated and striated ducts are fewer and poorly developed than in the parotid and submandibular glands and are difficult to recognize.

The capsule is poorly developed, but the connective tissue septa are prominent. The main duct, *Bartholin's duct,* opens with or near the submandibular duct, and several smaller ducts, *ducts of Rivinus,* open independently along the sublingual fold. It contributes to less than 5% of the salivary secretion.

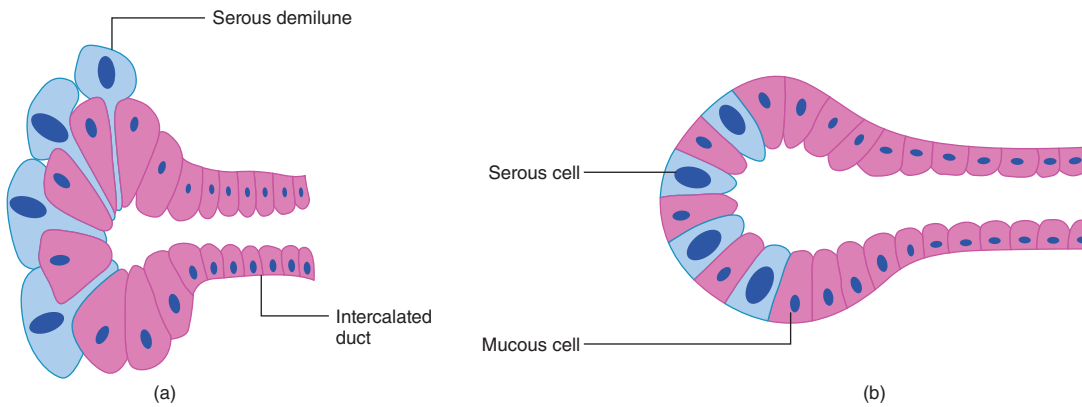


Figure 42.9 (a) Serous demilunes in haematoxylin and eosin section. (b) Absence of serous demilunes in rapid freeze section.

Applied Histology

Sialolithiasis

Obstruction of the salivary duct by calcific material is called sialolithiasis/salivary stones. This obstruction can lead to pain and swelling of the respective gland. This leads to dysfunction of the gland affected.

Salivary Gland Infections

Viral infections such as mumps and bacterial infections of glands may cause inflammation resulting in a painful swelling

Salivary Ductal Opening and Dental Diseases

Saliva can influence periodontal diseases since there is an increased amount of plaque and calculus formation on the surface of the teeth opposite to the ductal openings of the major salivary glands.

Location of Salivary Glands and Diagnosis of Oral Diseases

Except for the anterior part of the hard palate, salivary glands are present all over the oral cavity. Hence it is prudent to include salivary gland diseases as one of the differential diagnoses in the mind while examining oral diseases.

Histology of Minor Salivary Glands

The minor salivary glands are distributed all over the oral cavity except gingiva, anterior raphe of the hard palate and anterior two-third of the dorsum of the tongue. These glands do not contain a distinct capsule but are intermingled in the submucosa of the connective tissue.

The minor salivary glands consist of secretory end pieces and ducts organized into small lobule-like structures. The ducts draining them open directly onto the mucosal surface. The secretory end pieces are mucous or have a small serous component. Intercalated ducts are poorly developed and larger ducts may lack the infolded basal membranes of the striated ducts of the major glands.

The posterior lingual serous glands, *von Ebner's glands*, are an extensive group of purely serous glands located between the muscle fibres of the tongue below the circumvallate papillae. Their ducts open into the trough of the vallate papillae and at the rudimentary foliate papillae on the sides of the tongue.

The secretions of von Ebner's glands serve to wash the trough of the vallate papillae and prepare the taste receptors for a new stimulus (taste buds are located in the epithelium of trough of vallate papillae). Von Ebner's glands secrete antibacterial enzymes, peroxidase and lysozyme. They also secrete an enzyme with lipolytic activity, lingual lipase, which, along with pancreatic lipase, aids in the digestion of lipids. In newborns, when the fat intake is high and the pancreatic lipase is low, lingual lipase may play a significant role in lipid digestion.

The minor salivary glands located in the apex of the tongue are called *Blandin and Nuhn's glands*. Their secretions are predominantly mucous in nature. The ducts of these glands open on the ventral surface of the tongue near the lingual frenum.

Applied Histology

Mucoceles

Minor injury to the acini or the ducts of the minor salivary glands can lead to retention of the glandular secretions leading to mucocele in the oral cavity. The most common site of occurrence of this cyst is the lower lip.

COMPOSITION AND FUNCTIONS OF SALIVA

Saliva is the product of multiple salivary glands lying beneath the oral mucosa. It is made up of 99.5% water and 0.5% solutes. Each day, the human salivary glands produce almost 1200 mL of serous and mucinous saliva containing minerals, electrolytes, buffers, enzymes and enzyme inhibitors, growth factors and cytokines, immunoglobulins (e.g. secretory immunoglobulin A [sIgA]), mucins and other glycoproteins.

Applied Histology

Xerostomia (Dry Mouth)

Many drugs can cause dry mouth. Loss of function of salivary glands occurs after radiation therapy given for cancers of the head and neck. The salivary glands are commonly affected in such therapeutic radiation as they are present in the radiation field and are highly sensitive to the harmful effects of radiation. Autoimmune diseases such as Sjögren's syndrome may also destroy the secretory cells of the salivary glands leading to dry mouth. Dry

(*Continued*)

(*Continued*)

mouth leads to infection of oral tissues due to lack of protective effects of saliva. Speech, eating and swallowing become painful and difficult. The teeth are highly susceptible to caries due to lack of the cleansing action of saliva.

Formation of Saliva

Saliva secretion occurs in two stages. The secretory end-pieces secrete primary saliva which is isotonic (Stage I) following which the secreted primary saliva undergoes ductal modification with selective reabsorption and secretion of ions leading to excretion of hypotonic saliva (Stage II). The following table summarizes the events in the two stages of saliva formation.

Stage I (isotonic primary saliva)	Secretory end pieces	Form primary saliva
Stage II (hypotonic saliva)	Intercalated duct	• Secrete bicarbonate ions, lysozyme and lactoferrin into the saliva • Absorb chloride ions from the saliva
	Striated duct	• Reabsorb sodium ions from the saliva • Secrete potassium and bicarbonate ions into the saliva
	Excretory duct	• Reabsorb sodium ions from saliva • Secrete chloride, potassium and bicarbonate ions

Modulation of Ionic Transport in Saliva Formation

The modulation of formation of primary saliva and further modifications in the ductal system leading to excretion of hypotonic saliva are found to occur through the following channels which involve removal and addition of certain ions. These channels are active in the acinar cells and ductal cells.

1. Na^+/K^+ ATPase
2. $Na^+/K^+/Cl^-$ co-transport system
3. Na^+/K^+ exchanger modulates bicarbonate secretion
4. Na^+/H^+ and Cl^-/HCO_3^- exchangers modulate chloride secretion
5. Ca^{++} regulated K^+ and Cl^- channels
6. Osmotic gradients
7. Paracellular Na^+ and water transport
8. K^+/H^+ exchanger

Applied Histology

Cystic Fibrosis (CF)

CF is a genetic disease caused by mutation in the CF transmembrane conductance regulator gene (CFTR) which is a chloride channel. This serves as a centre to chloride and bicarbonate secretion not only in salivary glands but also in the gastrointestinal and respiratory systems. The mutation in this gene results in plugging of acini and duct by precipitated proteins. The sodium content of the saliva is markedly elevated and histologically acini are plugged with eosinophilic material.

Neural Modulation of Salivary Secretion

Sympathetic and parasympathetic nerve supply play a role in the quantity and quality of saliva secreted. Sympathetic supply (β adrenergic stimulation) results in more organic secretion of saliva while parasympathetic supply results in largely watery saliva.

Composition of Saliva

The composition of saliva varies with each gland. Once it is secreted into the oral cavity, it is known as *whole saliva* or *oral fluid* as it mixes with the secretions of the minor salivary gland, desquamated epithelial cells, microorganisms, serum components and inflammatory cells. Saliva is studied in terms of whole saliva as it gives a better judgment about the nature of the oral environment.

The composition of saliva is categorized into organic and inorganic components as given in **Table 42.2**.

Table 42.2 Inorganic and Organic Components of Saliva

Inorganic Components	Organic Components
Calcium	Mucins
Phosphate	Proline-rich proteins
Bicarbonate	Amylase
Fluoride	Lipase
Thiocyanate	Peroxidase
Sodium	Lysozyme
Potassium	Lactoferrin
Chloride	IgA
Lead	Histatins
Cadmium	Statherin
Copper	Gustin
	Others: Blood group substances, sugars, steroid hormones, amino acids, ammonia, urea, epidermal growth factor, vascular endothelial growth factor

Inorganic Components

1. **Calcium and phosphate:** They are responsible for protecting the mineralized surface enamel by preventing the dissolution of enamel. The calcium ion concentration in saliva is in the range of 1.5 mmol/L and phosphate concentration is in the range of 5.6 mmol/L. At neutral pH, the natural level of calcium phosphate in saliva is sufficient to supersaturate it with respect to hydroxyapatite.
2. **Fluoride:** The levels of fluoride concentration are lower than in the plasma and extracellular fluids. The concentration of fluoride is about 1.5 mM/L. The main function of fluoride is to promote remineralization of teeth which have been subjected to caries or decay.
3. **Hydrogen carbonate:** It is the major buffering agent of saliva. The concentration of hydrogen carbonate is about 2.9 mM/L and it increases when the flow rate increases. It plays an important role in neutralizing the acids produced by bacteria.
4. **Thiocyanate:** It is present in saliva in a free or loosely bound form. Thiocyanates are oxidized by salivary peroxides to form hypothiocyanate, which acts as an antibacterial agent. Its level in saliva is about 2.5 mM/L.

   Thiocyanate is a product of detoxification of hydrogen cyanide present in cigarette smoke. Hence, its level in saliva serves as a useful marker of exposure in smokers and non-smokers.
5. **Other inorganic components**
   (a) Sodium ions are usually minimal in saliva, as they are reabsorbed in the striated ducts. Their concentrations increase when the flow rate increases.
   (b) Potassium ions form the major inorganic constituent of saliva, as they are secreted throughout the ductal system.
   (c) Other inorganic components such as lead, cadmium and copper reflect the systemic concentrations and help in diagnosis when their levels rise.

Organic Components

The organic components of saliva are grouped into proline-rich proteins, glycoproteins, amylases and mucins.

1. **Amylase:** It forms the major component of salivary proteins, about 50%. This enzyme has the property to digest starch. It breaks starch into maltose and long-chain polysaccharides. It becomes inactive in stomach because of the acidic pH. Most of salivary amylase is secreted from the parotid salivary gland.
2. **Proline-rich proteins:** They form about 40–45% of salivary proteins. They are present in the salivary pellicle which forms on the surface of the teeth and inhibits calcium and phosphate crystal growth. Pellicle is formed by selective adsorption of hydroxyapatite-reactive salivary proteins, serum proteins and microbial products such as glucans and glucosyltransferase. Pellicle acts as a diffusion barrier, slowing both attacks by bacterial acids and loss of dissolved calcium and phosphate ions.
3. **Mucins:** Mucus is a 'slimy' material containing large, heavily glycosylated proteins. Mucus

adheres and coats epithelial surfaces. It serves as a diffusion barrier against contact with noxious substances and as a lubricant to minimize shear stresses. They form about 5–10% of salivary proteins.

The principal mucins identified in saliva are MG1 and MG2. MG1 has more lubricating properties than MG2.

4. **Lingual lipase:** It is secreted by von Ebner's glands and the parotid gland. It is involved in the initial phase of fat digestion. The enzyme hydrolyses medium- to long-chain triglycerides into diglycerides and free fatty acids. It plays an important role in the digestion of milk fat in newborns. Unlike other mammalian lipases, it is highly hydrophobic and readily enters fat globules.
5. **Statherins:** Statherin is a multifunctional molecule that possesses a high affinity for calcium and phosphate minerals. It maintains the mineral content of enamel and functions as a lubricant on the enamel surface.

   Statherins prevent precipitation or crystallization of supersaturated calcium phosphate in ductal saliva and oral fluid.
6. **Lysozyme:** They are a family of enzymes with antimicrobial activity characterized by the ability to damage the cell wall of bacteria. The enzyme acts by catalysing the hydrolysis of 1, 4-beta linkages between *N*-acetylmuramic acid and *N*-acetyl-D-glucosamine residues present in the cell wall of bacteria.
7. **Lactoferrin:** It is an iron-binding protein with antibacterial properties. Lactoferrin acts on specific receptors on the cell surface of microorganisms by binding to lipopolysaccharide of bacterial walls. The oxidized iron part of the lactoferrin oxidizes bacteria by formation of peroxides. This affects the membrane permeability and results in cell breakdown.
8. **Histatins:** They are a group of antimicrobial peptides which possess antifungal properties. Histatins bind to a receptor on the fungal cell membrane and enter the cytoplasm where they target the mitochondrion. They induce the non-lytic loss of ATP from actively respiring cells, which can lead to cell death. In addition, they have been shown to disrupt the cell cycle and lead to the generation of reactive oxygen species.
9. **Other organic components**
   (a) Certain blood group antigens are secreted in the saliva making it an interesting forensic evidence.
   (b) Sugars such as glucose are secreted in the saliva. They help in monitoring glucose levels in the body.
   (c) Steroid hormones such as cortisol, oestrogen and testosterone are secreted in low quantities.
   (d) Ammonia and urea are also present in minute quantities.

Functions of Saliva

1. **Physicomechanical flushing of the oral cavity:** The watery nature of saliva helps in providing a flushing action on the teeth. It helps in removing the non-adherent forms of bacteria and food debris that collects on teeth.
2. **Lubrication and permeability barrier:** Saliva coats the oral tissues with mucus and other glycoproteins which help provide lubrication during speech. It helps in chewing of food and making it into a bolus that can easily slide into the oesophagus without traumatizing the mucosal lining.
3. **Antimicrobial action:** The components of saliva with an antimicrobial property are lysozyme, lactoferrin, histatins and salivary peroxidases. Histatins, mucins and peroxidases are antibacterial. Histatins also possess antifungal activity and inhibit the growth of *Candida*.

   The immunoglobulin IgA present in saliva provides antimicrobial action by agglutinating certain microorganisms and preventing their adherence to the oral mucosa.
4. **Buffering action:** The bicarbonate ions help in providing buffering action. They neutralize the acids produced by bacteria which can cause dissolution of teeth and hence protect the teeth from dental caries. This process also helps in maintaining the pH at an optimum level between 6.5 and 7.5.

5. **Digestion:** The digestive enzymes present in saliva—amylase and lipase—initiate the digestion process in the oral cavity by breaking starch into maltase and lipids into diglycerides and free fatty acids, respectively.
6. **Mineralization:** The tooth surface is bathed by saliva. As saliva is supersaturated with calcium and phosphate ions, they help in increasing the surface hardness of teeth. This also increases the resistance of teeth to demineralization. Along with calcium and phosphate ions, fluoride ions also play an important role in increasing the surface hardness.
7. **Taste:** Saliva plays an important role in perceiving the sensation of taste. It helps by dissolving the food substances so that they are perceivable by the receptors located in the taste buds. Decreased salivary secretion leads to decrease in taste sensation.
8. **Tissue repair:** Epidermal growth factor (EGF) and vascular endothelial growth factor (VEGF) present in saliva help in repair and regeneration of oral tissues.

SALIVA AS A DIAGNOSTIC FLUID

The components of saliva not only protect the integrity of the oral tissues, but also provide clues to local and systemic diseases and conditions. These components are referred to as the 'salivary biomarkers' as they help in monitoring general health and in the early diagnosis of disease. Tests using saliva as a diagnostic tool have made substantial inroads into an array of clinical and research areas, such as virology, immunology, microbiology, endocrinology, epidemiology and forensics. In the past, serum has been the fluid most often used in disease diagnosis; however, saliva has many advantages over both serum and urine.

The ease of collection of saliva and the costs involved in storage are lower than those for serum and urine. Salivary assays for antibodies (to viruses and bacteria), unconjugated steroid hormones (e.g. oestrogen, testosterone and progesterone), environmental toxins (e.g. cadmium, lead and mercury), tobacco (cotinine) and certain drugs (e.g. ethanol, theophylline and lithium) are sufficiently sensitive to accurately reflect the blood concentrations of these substances.

AGE CHANGES

With advancing age, the following changes occur in the salivary glands:

1. Decrease in the amount of salivary secretion (also because of the old age ailments and consequent drug therapy)
2. Atrophy of acinar cells
3. Fibrosis
4. Gradual replacement of secretory components by adipose tissue
5. Increase in intercalated ducts
6. Dilation of striated ducts
7. Appearance of oncocytes (enlarged inactive cells with pyknotic nucleus)

ADDITIONAL READING

Functional Differences in the Acinar Cells of Major Salivary Glands

Salivary secretion is predominantly contributed by the major salivary glands: parotid (PG), submandibular (SMG) and sublingual glands (SLG). The Cl^- dependent mechanism plays an important role in salivary secretion in these glands. Differences in ion-transporting pathways in acinar cells have been found to exist among the major salivary glands. Saliva induced by the drug Pilocarpine was more in parotid than in submandibular and sublingual glands. Carbachol-induced salivary secretion due to an increase in the intracellular $[Ca^{2+}]$ was found to be more in parotid than in submandibular and sublingual gland acinar cells. Carbachol-stimulated Cl^- efflux, Ca^{2+}-activated Cl^- channel TMEM16A, major apical Cl^- efflux pathway in salivary acinar cells, transporter activity of the $Na^+K^+Cl^-$ cotransporters (NKCC1), anion exchangers (AE) and the two primary basolateral Cl^- uptake mechanisms in acinar cells were higher in parotid than in submandibular and sublingual glands. These functional differences between the major salivary glands account to their unique functional properties related to Cl^- movement, including the transporter activities of the Cl^- uptake and efflux pathways, and intracellular Ca^{2+} mobilization (excerpts from Kondo et al. 2015).

Salivary Gland Organoid

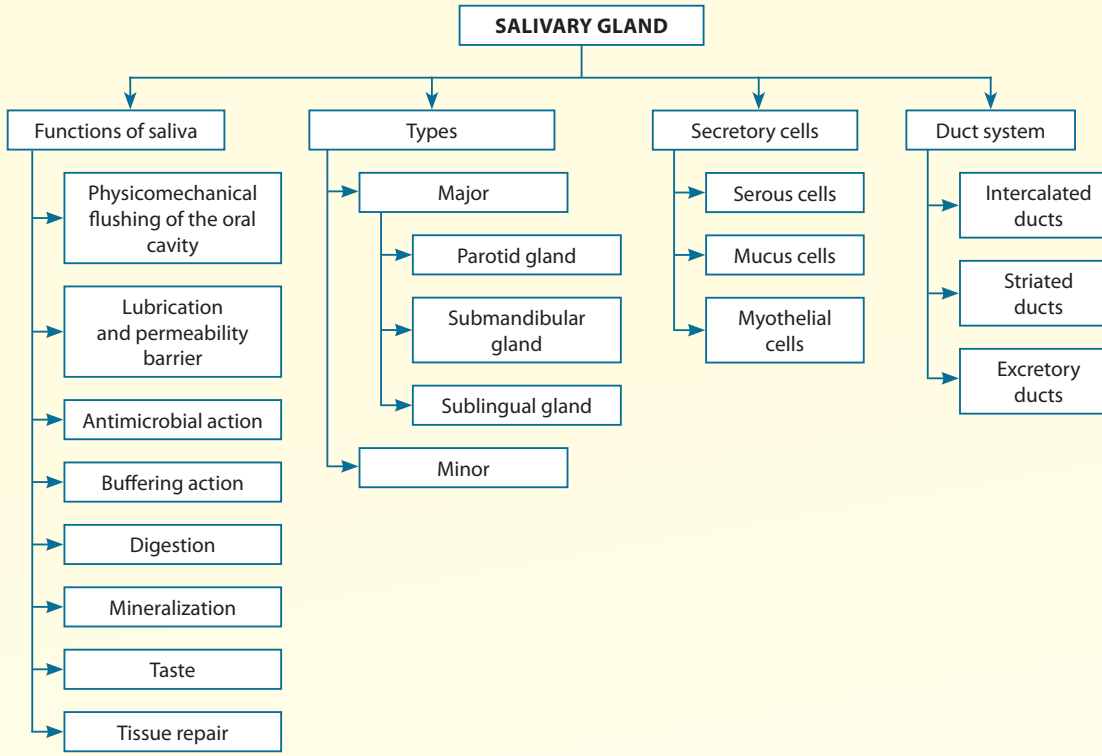
Whole-organ regeneration of the salivary gland has been a significant breakthrough. It was derived from foetal epithelium and mesenchyme. It was further functionally adapted in an adult mouse to form a new whole functional gland in the adult microenvironment. The organoid model of the salivary gland consisted of embryonic cells, including progenitors of epithelial, mesenchymal, endothelial and neuronal cells.

The gland established connection with the existing ductal system and was found functional in terms of saliva secretion, protection of the oral cavity from bacteria and restoration of normal swallowing. Efficient implantation of the organoid in the host environment for integration with the existing circulatory and nervous system structures and for alignment with endogenous salivary ductal structures is vital. Translating the salivary mouse organoid to clinical use needs more validation. However, this major research advancement paves way for the development of three-dimensional organotypic cultures to produce salivary gland organoids or mini-glands that can recapitulate the in vivo native environment and SG morphology and architecture (excerpts from Ferreira et al. 2016).

Key Points

1. Salivary glands are compound, tubuloacinar, merocrine and exocrine glands, the ducts of which open into the oral cavity.
2. The two types of secretory cells present in the salivary glands are serous and mucous cells.
3. Advances in tissue preparations have demonstrated that the structure of mucous and serous cells is similar.
4. The most prominent feature of the mucous cells is the presence of large amounts of secretory product, in the form of mucinogen granules containing mucin, in the apical cytoplasm.
5. The Golgi complex plays an important role in mucous cells because of the large amount of carbohydrate that it adds to secretory products.
6. The ratio of carbohydrate to protein is more in mucous cells.
7. Apart from their ability to contract, myoepithelial cells also send signals to acinar cells, which are important for maintaining cell polarity and structural organization of the secretory end piece.
8. The ductal system not only helps in the passage of saliva but also actively participates in the production and modification of saliva.
9. The plasma membrane infoldings together with mitochondria account for the striations in the striated ductal cell when seen under a light microscope.
10. Excretory ducts are located in the connective tissue septa between lobules of the gland and are interlobular in location.
11. The capsule, which is a connective tissue component, surrounds the gland and demarcates the gland from the adjacent structures.
12. The main immunoglobulin present in saliva is secretory IgA.
13. Fat cells are often seen in parotid gland.
14. The minor salivary glands are located below the epithelium in almost all parts of the oral cavity except gingival and the anterior parts of the hard palate.
15. von Ebner's glands secrete peroxidase and lysozyme (antibacterial enzymes) and lingual lipase (enzyme with lipolytic activity).
16. Dry mouth is called xerostomia.

Mind Map



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Multiple Choice Questions

1. Zymogen granules are seen commonly in the
   (a) Serous cell
   (b) Mucous cell
   (c) Myoepithelial cell
   (d) All of the above
2. Basket cells are
   (a) Serous
   (b) Mucous
   (c) Myoepithelial
   (d) Ductal
3. Striations seen in the striated duct are due to
   (a) Basal cell membrane infoldings
   (b) Lysosomes
   (c) Mitochondria
   (d) Both a and c
4. Which of the following glands are purely serous in nature?
   (a) Parotid
   (b) von Ebner's
   (c) Buccal
   (d) Both a and b
5. The following areas are devoid of salivary glands:
   (a) Gingiva
   (b) Soft palate
   (c) Anterior hard palate
   (d) Both a and c
6. The approximate amount of saliva produced by salivary glands is
   (a) 1200 mL
   (b) 1700 mL
   (c) 1000 mL
   (d) 1500 mL
7. The lingual lipase enzyme is secreted by the
   (a) Parotid gland
   (b) Submandibular gland
   (c) Parotid and von Ebner's glands
   (d) None of the above
8. Antifungal property is present in
   (a) Peroxidase
   (b) Mucins
   (c) Lactoferrin
   (d) Histatin
9. The optimum pH level of saliva is
   (a) 6–7
   (b) 6.5–7.5
   (c) 5.5–6.5
   (d) 7.5–8.5
10. The enzyme which plays a major role in starch digestion is
    (a) Amylase
    (b) Maltase
    (c) Lactase
    (d) All of the above



CHAPTER 43

Eruption

Overview

The movement of the teeth from the developmental position inside the jaw to their functional position in the oral cavity is considered the main event and is called eruption. Various theories are proposed for tooth eruption such as root formation theory, bone remodelling theory, vascular pressure theory and ligament traction theory. The remodelling bone, forming root, organizing periodontal ligament and myofibroblasts together bring the tooth to the oral cavity until it reaches the occlusal plane to meet the opposing tooth. The tooth movements can be classified into pre-eruptive and post-eruptive tooth movements. Pre-eruptive tooth movements include bodily movement and eccentric growth. Post-eruptive movements are tooth movements occurring after tooth eruption which tends to compensate for loss of tooth structure or loss of tooth.

INTRODUCTION

Have you wondered how teeth break open the gingiva and appear in the oral cavity without causing any bleeding? It is interesting to know how the deciduous teeth fall off and make way for the permanent teeth. These events are discussed in detail in this chapter.

One might have observed that once formed, the teeth do not increase in size. As growth occurs, the small primary teeth fail to perform effectively. As the jaws increase in size, the masticatory load also increases. To accommodate this, the primary teeth exfoliate and are replaced with the larger permanent teeth. This physiologic phenomenon is *shedding*. Thus, we have two sets of dentition; humans are diphyodont.

The tooth germs are formed within the jawbone. Their formation begins at around the sixth week of embryogenesis. Initially, these are small in size, arranged close together. As the formation continues, the tooth germs increase in size and start moving apart to occupy their respective future positions in the jaw. During eruption, they move from their developmental position inside the jaws to their functional position in the oral cavity.

During the masticatory function, the teeth undergo incisal, occlusal and proximal wearing away. To maintain the arch integrity and the occlusal height, teeth show some movements. Thus, the movements of the teeth are continuous and complex in nature.

The movement of the teeth from the developmental position inside the jaw to their functional position in the oral cavity is considered the main event and is called *eruption* (Latin: *erumpere- 'to breakout'*). All movements are grouped in relation to the main event and are as follows:

1. Pre-eruptive tooth movements
2. Eruptive tooth movements
3. Post-eruptive tooth movements

PRE-ERUPTIVE TOOTH MOVEMENTS

The tooth germs of both primary and permanent dentition show movements within the jaws as they are being formed. These movements happen simultaneously with jaw growth in length, width and height. These movements make it possible for the tooth germs to occupy their future position within the jaw inside their own bony crypt until it is time to emerge into the oral cavity.

The tooth germs achieve their movements in two ways:

1. **Bodily movement:** This happens as a result of the resorption of the bony crypt on one side and deposition on the other side. For example, if the tooth has to move to the mesial side, the growth of the tooth germ exerts pressure on the mesial side wall of the bony crypt. Resorption of this side of the wall takes place while the distal side wall shows the deposition of the bone.
2. **Eccentric growth:** The base of the tooth germ is fixed. The growth of the germ is eccentric, exerting pressure resulting in the resorption at the required side. This changes the shape of the bony crypt.

Primary Teeth

In the early period of tooth formation, the tooth germs are small in size. Soon, with the growth of the tooth germs, crowding occurs in the anterior portion of the jaws. Simultaneously, the growth of the jaw also takes place in a three-dimensional manner, with increase in length, width and height. Then, the tooth germs can move and occupy the available space. When the primary tooth germs move apart, crowding disappears. Utilizing the space made available because of the growth of the jaws, the tooth germs also move outwards and upwards or downwards.

Permanent Teeth

The permanent tooth germs also show some pre-eruptive tooth movements. The permanent tooth germs are lingually placed to their predecessors in the same bony crypt initially. As the jaw size increases and eruption of the primary teeth takes place, the permanent tooth germs move and occupy their position on the lingual side, apical to the root of the primary teeth in case of the anteriors. The premolar tooth germs move and reside between the two roots of the primary molars. The permanent molars, which do not have the predecessors, develop from the distal extension of the dental lamina, move distally and occupy their position in the jaws. Initially, due to lack of space, the occlusal surface of the maxillary molars is positioned distally and the mandibular molars are positioned mesially. This is corrected as the jaws grow further in size; the molars swing in and become vertical.

By pre-eruptive movements, the permanent tooth germs occupy their position for the eruptive movement and are able to reside in their own bony crypts. It is worth recollecting that the permanent dental lamina was connected to the primary dental lamina until the bell stage.

Applied Histology

Teething

Eruption of the deciduous incisors or molars may cause mild disturbances in the infants. Fever, malaise and irritability of the gums may be seen. These symptoms are known as 'teething'.

ERUPTIVE MOVEMENTS

As already explained, eruption is the movement of the tooth from the developmental position in the jaw to the functional position in the oral cavity. It is in this phase that the tooth actually moves, as a result of the pull or traction created by the surrounding structures overlying and underlying it.

The tooth starts erupting while the root formation continues. As soon as the root formation begins, the tooth begins to move in an axial or occlusal direction. Thus, root formation and the eruption of the tooth take place concurrently.

The eruption has intraosseous and extraosseous phases; the average rate of eruption is 1–10 μm/day in the intraosseous and about 75 μm/day in the extraosseous phase. Eruption is a rhythmic process which has periods of active movement followed by quiescence. Recent observations suggest that the eruption activities are more at night than during the day.

Many investigators have opined that tooth eruption is a multifactorial phenomenon. There is a great amount of genetic and environmental influence. Histologic changes seen at the time of eruption suggest that tissues such as the bone, root and dental follicle–periodontal ligament play a role in the mechanism of eruption. Many hypotheses are put forth on the basis of these observations.

The following hypotheses are popularly known as theories of eruption:

1. Root formation theory
2. Bone-remodelling theory
3. Vascular pressure theory
4. Ligament traction theory

Theories of Eruption

1. **Root formation theory:** The root formation theory proposes that the tooth movement in the axial or occlusal direction is mainly because of the formation of the root. The simultaneous occurrence of these two activities primarily gives the impression that root formation is an important prerequisite for the eruption of teeth. Some points contradicting this theory are as follows:
   (a) If root formation were to cause the pushing force for the eruption of the tooth, the root has to form on a fixed base. Only then can it exert a force in the opposite direction. The histology of root formation does not suggest any such fixed base. To counterargue this, some investigators suggested that a structure called the *cushion–hammock ligament* may be acting as a fixed base at the apex of the forming tooth. This concept is not accepted as the cushion–hammock ligament is only a soft tissue separating the pulpal and periapical tissues and it cannot act as a fixed base.
   (b) In certain developmental disturbances, the teeth are rootless, but they erupt into the oral cavity. This suggests that root formation although occurring simultaneously with the eruption might not be the only factor influencing eruption.
   (c) There was no direct relationship observed between the length of the root and the distance travelled by the tooth during eruption. Some teeth move a greater distance than their root length.
   (d) Experimental intervention leading to stoppage of root formation did not cause failure of eruption.
   (e) Experiments also demonstrated that a tooth still erupts even after the completion of root formation.
2. **Bone-remodelling theory:** Bone-remodelling theory explains that the eruption takes place in a manner similar to the pre-eruptive movements. The resorption of the bone at the site of pressure and the deposition of the bone at the site of tension may cause eruption. The pressure exerted by the growing tooth germ in the axial direction initiates the remodelling of the bone to create a pathway for the erupting tooth. Placement of silica replica as a substitute to tooth germ with a dental follicle eruptive pathway was evident. On experimental removal of the dental follicle, there was no eruptive pathway. This shows that bone remodelling alone is not solely responsible for tooth movement, and the dental follicle plays a vital role in the eruption of the tooth. Through subsequent studies, it was established that dental follicle conduits osteoclasts which are responsible for bone resorption and also supplies bone forming cells.
3. **Vascular pressure theory:** The vascular pressure theory suggests that the change in the arterial pressure of the surrounding vessels could be responsible for the eruption. Experiments conducted in dogs revealed that the ground substance can swell by 50% on addition of water which would cause a differential pressure. This pressure difference was proved to be sufficient enough to cause tooth movement. Hypotensive drugs can cause vasodilatation. This vasodilatation can increase the hydrostatic pressure. Experimentally, this pressure was shown an increased rate of tooth eruption. Stimulation of sympathetic nerves can cause vasoconstriction. This vasoconstriction can decrease the hydrostatic pressure. Experimentally, this decrease in pressure was shown a decreased rate of tooth eruption. However, many investigators feel that this change is too small to cause a movement as large as that required for eruption.
4. **Ligament traction theory:** This theory states that the dental follicle–periodontal ligament complex pulls the tooth into the oral cavity, similar to traction. Many histologic changes

are observed in the developing tooth to support this theory. These are discussed in detail later. Strong evidence in support of this theory is that when a silica replica was planted in place of a tooth with the follicle tissue intact and all other tissues removed, the replica erupted into the oral cavity. This experiment proved that the dental follicle plays a major role in the eruption of the teeth. A disc of root tissue placed on ligament fibroblasts, on further experimental induction, exhibited contractile movement. Further, it was shown that the drugs that interfere with collagen formation in the periodontal ligament interrupted tooth eruption. This theory is the most accepted one.

Histologic Features During Eruption

As discussed earlier, it is clear that the eruption takes place concurrently with the root formation process. Surrounding the forming root, dental follicle cells show several changes at the time of eruption. The follicle cells become organized and start producing delicate collagen fibres. These fibres become more and more organized and get oriented as tooth eruption occurs. These fibres form the principal group of fibres of the periodontal ligament. The histology of the periodontal ligament reveals several interesting features during eruption:

1. There are many fibroblasts called *myofibroblasts* with a contractile property. The communication between the fibroblasts becomes extensive. They become attached to one another and secrete a proteinaceous material called *fibronectin*. The network of these cells and the binding material is called the *fibronexus*. These changes show that the cells communicate and organize themselves for further action of pulling the tooth into the oral cavity.
2. As the axial movement continues, the dental follicle above the formed tooth structure starts making way for the tooth. The release of enzymes degenerates the collagen bundles above the erupting tooth. The reduced enamel epithelium fuses with the gingival epithelium. This forms a soft-tissue channel into which the tooth enters and emerges into the oral cavity without any bleeding.
3. The eruption of the permanent successor teeth slightly differs from that of the primary teeth. There is an eruptive guidance to the permanent teeth from their predecessors. Evidence for this is obtained from the skull bones which show the openings on jawbones lingual to the position of the primary teeth. These are known as *gubernacular canals*. It is believed that they host the gubernacular cord, which is a soft, fibrous tissue guiding the permanent tooth into the eruptive pathway.

Thus, the remodelling bone, forming root, organizing periodontal ligament and myofibroblasts bring the tooth to the oral cavity until it reaches the occlusal plane to meet the opposing tooth.

Readers are advised to recollect the eruption sequence and the eruption dates of the teeth of both sets of dentition from Chapter 11 in Section II. Eruption pattern, sequence and time is important for proper dental treatment. The development of occlusion greatly depends on this and so does the orthodontic treatment. The first tooth which erupts to the oral cavity is the deciduous mandibular central incisors. Generally, the left and the right side teeth erupt simultaneously. The mandibular teeth erupt before the maxillary teeth. The eruption of permanent teeth is earlier in girls.

Applied Histology

Significance of Chronology of Human Dentition

Chronology aids in identifying premature/delayed/failed eruption. Further, chronology help in dental age assessment. This along with the skeletal age is an index of maturity.

Primary Teeth 6/4 Rule

Four primary teeth emerge for each 6 months of age.

Months	Teeth
6	4
12	8
18	12
24	16
30	20

(Continued)

(Continued)

Permanent Teeth Rule of 'Fours'

Permanent tooth development (except third molars) usually abides by the rule of 'fours'.

- Four first molars' calcification is initiated at birth.
- All crowns have initiated calcification at 4 years of age.
- All crowns are complete at 8 years of age.
- All roots are complete at 16 years of age.

Causes for Delayed Tooth Eruption

- Gardener syndrome
- Down syndrome
- Hypopituitarism
- Vitamin D resistant rickets
- Cleidocranial dysplasia
- Sclerosteosis
- HIV infection
- Nutritional deficiency
- Arch-length deficiency
- Genetic predisposition
- Radiation damage
- Traumatic displacement of the secondary tooth germ
- Premature loss of the primary tooth
- Gingival hyperplasia
- Ankylosis
- Cysts and tumours

Premature Eruption

- Dental open bite
- Obesity
- Diabetes
- Increased adrenal androgen secretion

Pericoronitis

The permanent third molars are the last teeth to erupt. Because of the lack of space, these teeth get impacted in the jaws. The eruption of these teeth sometimes leads to inflammation and infection of the soft tissue surrounding the tooth. Clinically, this is known as 'pericoronitis'.

POST-ERUPTIVE MOVEMENTS

Once a tooth reaches the occlusal plane, it meets the opposing tooth. It is necessary that the position of the tooth be maintained here. The movements after eruption are required to accommodate the growth in the height of the jaws and to compensate for the incisal, occlusal and proximal wearing away of the teeth which happens due to the masticatory and other functions of the teeth.

The teeth accommodate themselves for the increase in the height of the jaws by bone remodelling of the socket at the base and at the crest. There is a slight occlusal movement by the teeth to compensate for the wearing away of the teeth. There is formation of excessive amount of cementum (hypercementosis) whenever the teeth move to a greater distance such as in the case of the missing opposing tooth.

The loss of tooth structure happens on the sides (proximal) too. To maintain the arch integrity, the teeth should remain connected to each other. The masticatory force which is exerted vertically on the tooth surface has a mesial component which results in the mesial drift of the teeth. It means that generally all the crowns of teeth show a mesial tilt and contact the adjacent tooth (the roots are distally tilted). This mechanism compensates for the proximal wearing away of the teeth. The trans-septal fibres of the periodontium run from one tooth to the other. They help in maintaining the connection of the teeth to one another. Loss of the opposing tooth results in the eruption of the occluding tooth beyond the occlusal plane. This is called supraeruption.

Hence, the post-eruptive movements are continuous until the teeth are in the oral cavity.

ADDITIONAL READING

Molecular Insights into Tooth Eruption

Theories of eruption emphasize the role of dental follicle cells in bone remodelling during tooth eruption. Degradation of the extracellular matrix (ECM) is also an essential component for tooth eruption. Molecular events occurring during tooth eruption are categorized into molecules involved in bone resorption (occurring in the coronal half), bone formation (occurring in the basal end) and ECM degradation.

Bone Resorption

The primary event during bone resorption is recruitment of mononuclear cells to the dental follicle. The molecules mediating this event are colony stimulating factor-1 (CSF-1) and monocyte chemotactic protein-1 (MCP-1). These molecules are further enhanced by the presence of interleukin α (IL α). Transforming growth factor β (TGF β), epidermal growth factor (EGF) and parathyroid hormone related protein (PTHrp) induce IL α production that promotes the recruitment of mononuclear cells. Further to the recruitment of mononuclear cells, differentiation into osteoclasts and their activation to induce bone resorption takes place. The key molecules involved in the differentiation and activation of osteoclasts are RANKL (receptor activator of nuclear factor kappa B ligand) and OPG (osteoprotegerin). Vascular endothelial growth factor (VEGF) secreted by dental follicular cells also enhances RANKL activity.

Bone Formation

The bone-forming cells—the osteoblasts—are controlled by *Cbfa1/Runx2*. Bone morphogenetic protein-2 (BMP 2) activates this gene to initiate bone formation.

ECM Degradation

Eruption of the tooth into the oral cavity requires soft-tissue degradation which is mediated by matrix metalloproteinase-8 (MMP-8). This molecule brings about collagen degradation.

Runx2 and Tooth Eruption

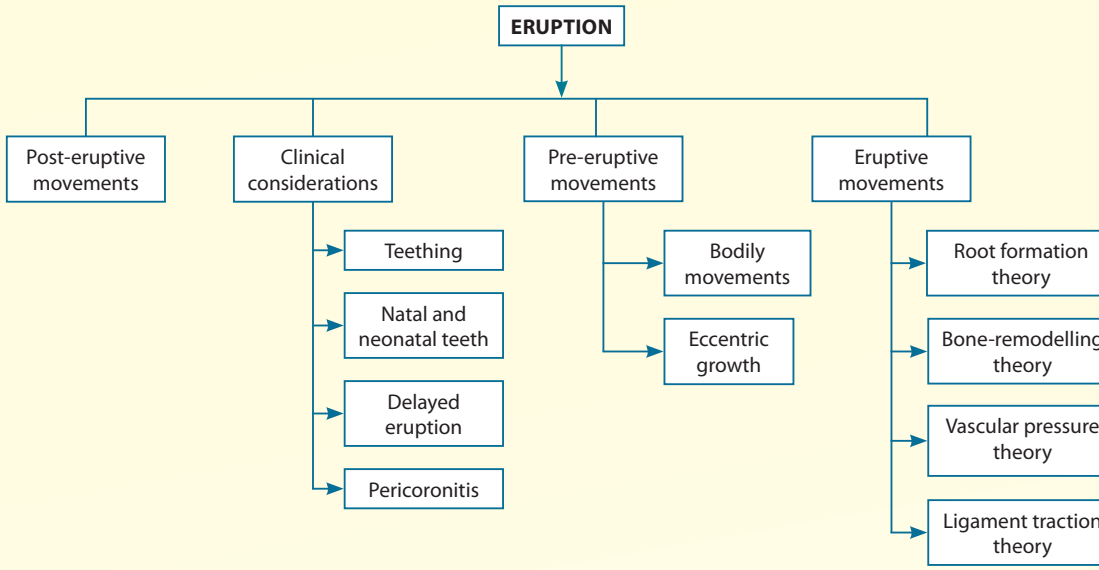
The master transcription factor of bone—*Runx2 gene*—plays an important role in all stages of bone formation, bone remodelling, tooth formation and tooth eruption. It is also essential for the later stages of tooth formation, is intimately involved in the development of calcified tooth tissue, and exerts an influence on proliferation of the dental lamina. Regulation of the alveolar remodelling process is vital during tooth eruption and maintenance of the periodontal ligament. *RUNX2* mutations cause skeletal disorders such as cleidocranial dysplasia (CCD), which is characterized by delayed permanent tooth eruption and other dental abnormalities. MiR-31 is a key regulatory circuit for *RUNX2*. MiR-31 and special AT-rich binding protein 2 (SATB2) act in concert in mesenchymal stem cell homeostasis and functions.

Dental follicle cells from cleidocranial dysplasia exhibit significantly lower osteogenic, osteoclast-inductive and matrix-degrading capacities and had lower *RUNX2* (a transcriptional inhibitor of miR-31), higher miR-31 and down-regulated *SATB2*. *RUNX2* mutation inactivates osteoclast-inductive signalling in dental follicle cells and is a crucial factor in causing delayed tooth eruption in cleidocranial dysplasia patients. Targeting the RUNX2-miR-31-SATB2 loop could be a potential path to facilitate tooth eruption in cleidocranial dysplasia patients.

Key Points

1. The types of movements of the teeth are (i) pre-eruptive tooth movements, (ii) post-eruptive tooth movements and (iii) eruptive tooth movements.
2. Pre-eruptive movements are achieved by (i) bodily movement of the tooth germs and (ii) eccentric growth of the tooth germ.
3. Eruption is the axial/occlusal movement of the tooth from its developmental position within the jaws to its functional position in the oral cavity.
4. Theories of eruption are (i) root formation theory, (ii) bone-remodelling theory, (iii) vascular pressure theory and (iv) ligament traction theory (the most accepted theory)
5. Post-eruptive movements take place to accommodate and compensate for (i) growth of the jaw, (ii) proximal wearing away and (iii) incisal/occlusal wearing away.

Mind Map



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Multiple Choice Questions

1. Which of the following is a widely accepted theory of eruption?
   (a) Root formation theory
   (b) Bone-remodelling theory
   (c) Vascular pressure theory
   (d) Ligament traction theory
2. The cell which resorbs dentin is
   (a) Fibroblast
   (b) Ameloblast
   (c) Odontoclast
   (d) Osteoclast
3. Fibronexus is seen in the
   (a) Periodontal ligament
   (b) Alveolar bone
   (c) Pulp
   (d) Gingiva
4. The most commonly retained primary tooth is the
   (a) Maxillary lateral incisor
   (b) Maxillary first molar
   (c) Mandibular central incisor
   (d) Mandibular canine
5. The first tooth which erupts into the oral cavity is the
   (a) Mandibular first molar
   (b) Maxillary first molar
   (c) Primary mandibular central incisor
   (d) Primary mandibular canine



CHAPTER 44

Shedding

Overview

The physiologic process by which deciduous teeth are removed to allow the succeeding permanent teeth to take their functional position is known as shedding or exfoliation. This occurs because of the progressive resorption of the roots of deciduous teeth and their supporting tissue. Odontoclasts are the cells responsible for the resorption of tooth while soft tissue is resorbed by apoptotic cell death. Disturbances in the shedding pattern or sequence may result in a retained deciduous tooth which may interrupt the eruption or the direction of the eruption of the permanent successor eventually resulting in malocclusion.

INTRODUCTION

The human dentition consists of two sets of teeth: primary (deciduous) dentition and secondary (permanent) dentition. As the jaw increases in size, it requires a larger number of teeth to function properly. This means that the primary dentition should be replaced by secondary dentition. The physiologic process by which the deciduous teeth are removed to allow the succeeding permanent teeth to take their functional position is known as shedding or exfoliation. This occurs because of the progressive resorption of the roots of deciduous teeth and their supporting tissue.

SHEDDING PATTERN

The pressure exerted by the growing and erupting permanent teeth decides the pattern of resorption of deciduous teeth. The developing teeth germs of the permanent incisors and canines are positioned lingual to their corresponding deciduous teeth. During eruption, these permanent teeth undergo physiologic movement in occlusal and vestibular directions initiating resorption of the roots of the corresponding deciduous teeth on their lingual surface (**Fig. 44.1a**). Further, eruptive movement of the permanent teeth germs, which are then positioned directly beneath the roots of the deciduous teeth, causes resorption, affecting the whole cross-section of the deciduous roots (**Fig. 44.1b**). Thus, the permanent teeth erupt in the position occupied by the corresponding deciduous teeth (**Fig. 44.1c**).

Applied Histology

Lingually Erupting Permanent Tooth

If the permanent tooth germs do not undergo movement to become positioned beneath the deciduous tooth, the tooth erupts lingual to the deciduous tooth (e.g. permanent mandibular incisors).

In case of deciduous molars, the developing premolars are located between the roots of the deciduous teeth. The growth of these permanent teeth will cause resorption of the inner surface

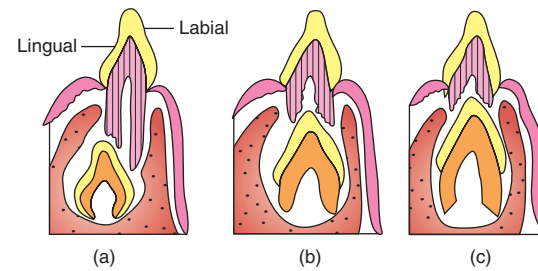


Figure 44.1 Relative position of a permanent anterior tooth to its primary predecessor during the shedding process.

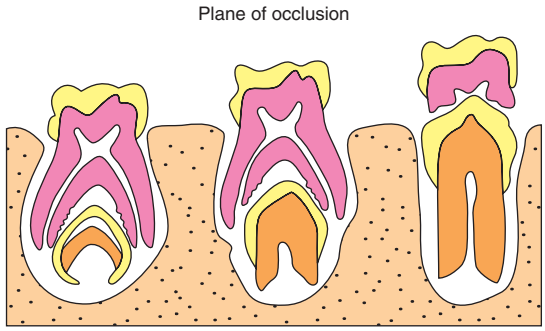


Figure 44.2 Relative position of a premolar to a primary molar during the shedding process.

of the roots of the deciduous molars (**Fig. 44.2**). However, due to the growth of the jaws and the occlusal movement of the deciduous molars, the permanent teeth germs are positioned apical to the deciduous molars rather than being situated between the roots of the deciduous teeth. This prevents further resorption as the developing teeth buds are moved down to an apical position. Small areas of early resorption which occurred when the teeth buds were located between the roots are also repaired by a cementum-like tissue. Much later, when the premolar teeth start erupting, they initiate resorption of the roots of the deciduous molar. This time the resorption is continuous, leading to the shedding of the deciduous molars, and the premolars erupt in the place of the deciduous molars.

ODONTOCLASTS

Odontoclasts are large, multinucleated cells responsible for the resorption of dental hard tissue. Histologically, they are similar to bone-resorbing osteoclasts. They are derived from tartrate-resistant acid phosphatase (TRAP)-positive circulating monocytes and are present within resorption bay (Howship's lacunae).

Odontoclasts have a vacuolated cytoplasm and their cell membrane which is adjacent to the resorbing hard tissue shows extensive folding into a series of invaginations, 2–3 μm deep, called the *ruffled border*. They have large numbers of ribosomes and mitochondria. Vacuoles are seen adjacent to the ruffled border, exhibiting acid phosphatase activity.

A clear zone, peripheral to the ruffled border, represents the attachment apparatus. It is devoid of organelles but is rich in filaments consisting of contractile proteins, actin and myosin (**Fig. 44.3**).

Distribution

The distribution of odontoclasts differs as different patterns of resorption are seen for different teeth. Odontoclasts are seen on the surfaces of the root of single-rooted deciduous teeth which shed even before their root resorption is complete. In case of deciduous molars, the roots are usually completely resorbed and the crown is also partially resorbed before shedding. Here, the odontoclasts may be seen replacing the odontoblasts and resorbing the coronal dentin.

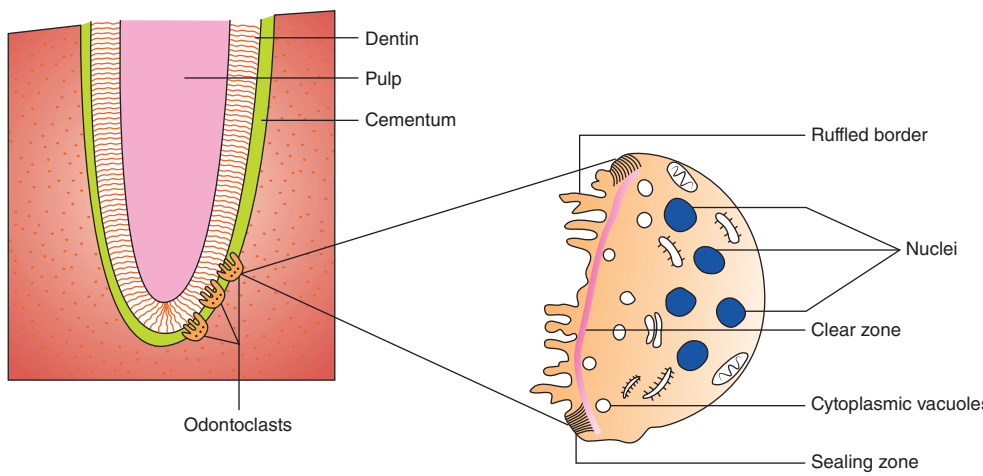


Figure 44.3 Odontoclast.

MECHANISM OF RESORPTION

Resorption in bone occurs by the action of hormones causing bone resorption and cytokines. They act on the osteoblast to form pores on its surface to which the osteoclasts bind and cause resorption. Unlike bone, resorption of tooth is mainly initiated by pressure from the erupting permanent successor. This view is strengthened by the fact that odontoclasts have been identified at the site of pressure. The cementoblast present on the surface of the root does not respond to hormones causing resorption of bones. For resorption to take place, the hormones and cytokines have to disrupt the cementoblast surface. Either the substance released from the reduced enamel epithelium covering the erupting permanent teeth or inflammation causes damage to the cementoblastic layers. The odontoclasts then attach to the hard tissue to be resorbed through the clear zone. This creates a sealed space lined by the ruffled border of the cell, which acts like a proton pump. It pumps H^+ ions into this extracellular microenvironment, thereby acidifying the environment leading to demineralization. The broken-up minerals are taken up by the odontoclast and digested inside the cytoplasmic vacuoles. The organic matrix is degraded by the action of substances released into this environment by lysosomes.

The roots of deciduous teeth do not undergo resorption continuously. Resorption takes place intermittently with periods of activity followed by rest. During the resting phase, the resorbed areas are repaired to a certain degree by the deposition of cementum. However, over a period of time, resorption predominates over repair.

Applied Histology

Submerged Tooth

Sometimes as a result of an overactive repair process, localized union of repairing cementum and the adjacent bone occurs, leading to ankylosis of deciduous teeth. This prevents the eruption of the underlying permanent teeth which in some cases may lead to eruption in an abnormal direction or the tooth may not erupt at all. In this case, the deciduous tooth does not shed and remains in the arch at a lower level than the adjacent permanent teeth. This retained deciduous tooth is called submerged tooth. The submerged tooth will prevent either the normal growth or the eruption of its permanent successor and hence should be removed early.

Although pressure from the erupting permanent successor is mainly responsible for causing resorption of deciduous teeth, other factors also contribute. It is found that the resorption of deciduous teeth was delayed but occurred even when the underlying permanent teeth germs were completely absent or abnormally positioned or surgically removed. Another factor that plays a role in the resorption of deciduous teeth, apart from pressure exerted by the underlying permanent teeth, is the increased masticatory force applied to the deciduous teeth. With the growth of the face and jaws, there is a corresponding increase in the size and strength of the masticatory muscles. The periodontal ligament of the deciduous teeth cannot withstand the increased masticatory force. This causes trauma to the ligament which initiates resorption. Experimentally, it has been shown that resorption did not occur when the underlying permanent teeth were removed and a splint bridge placed preventing masticatory forces from being applied onto the deciduous teeth.

Thus, both the factors are likely to determine the pattern and rate of resorption of deciduous teeth. Pressure from the erupting permanent teeth causes loss of root surface, and hence loss of supporting tissue. Due to these, the teeth are unable to withstand the increased masticatory forces. This accelerates resorption.

The resorption of soft tissue—periodontal ligament and pulp—is thought to occur by apoptotic cell death, which involves shrinkage of the cell and its subsequent phagocytosis by the neighbouring cells.

Applied Histology

Remnants of Deciduous Teeth

Sometimes, the root fragments of deciduous teeth may not be in the path of eruption. These fragments become embedded in the jaws instead of being resorbed. Such embedded

(*Continued*)

(*Continued*)

root fragments are more frequently seen in the region of the lower second premolar, as the distance between the roots of deciduous molars is more than the distance between the crowns of the erupting premolars. These remnants are usually asymptomatic. They may exfoliate slowly if they are close to the surface of jaws or may undergo resorption and become replaced by bone and disappear completely.

Retained Deciduous Teeth

In certain cases, the deciduous teeth do not undergo resorption beyond their shedding time. This may be due to the following reasons:

1. **Congenital absence of the underlying permanent teeth:** Permanent upper lateral incisors and lower second premolars are some of the permanent teeth which may be congenitally absent and hence deciduous upper lateral incisors and deciduous lower second molars may be retained for a long time.
2. **Impacted permanent teeth:** Sometimes, the permanent upper canine may be impacted and hence the deciduous upper canine may be retained.
3. Ankylosis of a deciduous teeth or permanent teeth

The deciduous teeth which come under the first two categories remain functional for many years but are eventually lost because of resorption of their thin roots. This resorption is caused by heavy masticatory forces of adult life being applied on these teeth with small roots.

ADDITIONAL READING

Apoptosis in Pulp Elimination During Physiological Root Resorption in Human Primary Teeth

Primary dentition undergoes physiological root resorption where all the tissues of the root—cementum, dentin and pulp—are removed. Resorption is associated with external events, inadequate occlusal forces, periodontal pathology, microtrauma and ectopic eruption of the neighbouring teeth. The hard tissues of the root—cementum and dentin—are resorbed by the action of odontoclasts or osteoclasts. The process of initiation and activation of the odontoclasts is still not clear. Regulation of the resorption of cementum and dentin is similar to bone remodelling. The permanent tooth follicle and its supporting structures close to the primary tooth also play an important role in recruitment, development and activation of odontoclasts. Apoptosis is the mechanism involved in the physiological death and resorption of pulp cells. Evidence of the apoptotic mechanism in primary tooth pulp has been observed by absence of inflammation and intense DNA internucleosomal fragmentation in DNA electrophoresis.

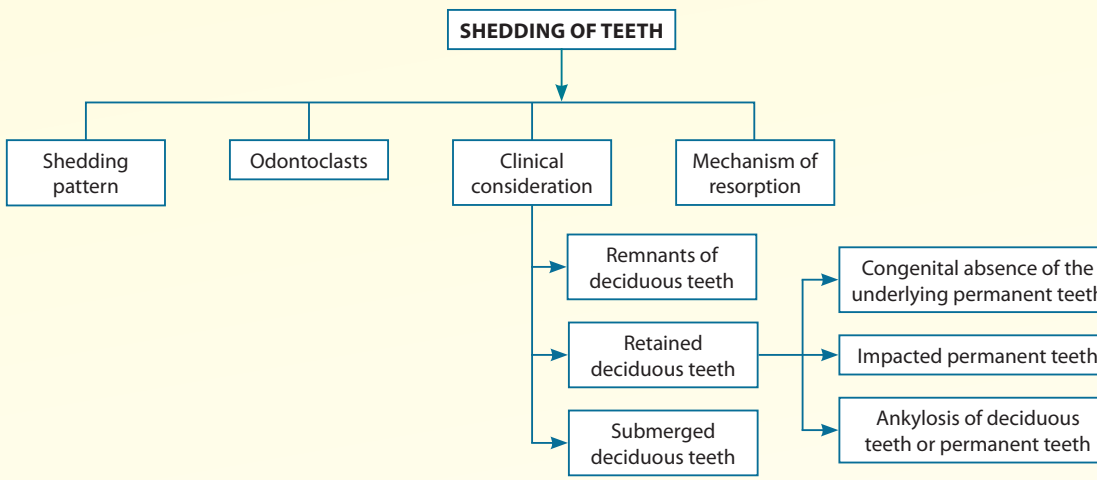
Axonal Degeneration in Dental Pulp Precedes Human Primary Teeth Exfoliation

Pulp innervation in the primary tooth decreases during advanced stages of root resorption. The mechanisms of axon loss in exfoliated primary teeth are yet to be studied in depth. Innervation of the dental pulp is intense at the coronal pulp–dentin interface. Degeneration of the axons occurs in a progressive Wallerian-like scheme. Fragmentation of neurofilaments is accompanied by myelin degradation and a progressive loss of myelinated axons. Autophagic activity by Schwann cells helps in degradation of the myelin sheath. Schwann cells exhibited a sequence of responses comprising dedifferentiation, proliferative activity, GAP-43 overexpression and Büngner band formation. Advanced stages of resorption are characterized as an inflammatory condition involving immune cell recruitment within the dental pulp and major histocompatibility complex (MHC) class II upregulation by Schwann cells. Progressive reduction of sensory function of the dental pulp during pre-exfoliative stages occurs due to loss of dental pulp axons (excerpts from Suzuki et al. 2015).

Key Points

1. The physiologic process by which deciduous teeth are removed to allow the succeeding permanent teeth to take their functional position is known as shedding or exfoliation.
2. Odontoclasts, involved in resorption of dental hard tissue, are derived from tartrate-resistant acid phosphatase (TRAP)-positive circulating monocytes.
3. Ankylosis of deciduous teeth occurs as a result of the localized union of the repairing cementum and the adjacent bone. This can prevent eruption of the underlying permanent teeth or cause eruption in an abnormal direction.
4. The factors responsible for resorption of deciduous teeth are as follows:
   - Pressure from the erupting permanent successor
   - Increased masticatory force
5. The resorption of soft tissue such as the periodontal ligament and pulp occurs by apoptotic cell death.

Mind Map



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Multiple Choice Questions

1. Shedding is
   (a) Pathologic
   (b) Physiologic
   (c) Anatomical
   (d) All of the above
2. The initial resorption of roots of deciduous teeth occurs on the
   (a) Labial aspect
   (b) Lingual aspect
   (c) Mesial aspect
   (d) Distal aspect
3. Odontoclasts are
   (a) Resorptive cells
   (b) Formative cells
   (c) Blood-forming cells
   (d) Defence cells
4. Howship's lacunae is the
   (a) Resorption bay
   (b) Elevated area
   (c) Clear zone
   (d) Attachment apparatus
5. The origin of odontoclasts is from
   (a) Lymphocytes
   (b) Macrophages
   (c) Dendritic cells
   (d) Circulating monocytes
6. Resorption is a
   (a) Continuous process
   (b) Active process
   (c) Periods of activity and intervening rest period
   (d) None of the above
7. Ankylosis is
   (a) Union of dentin and cementum
   (b) Union of cementum and bone
   (c) Union of all—dentin, cementum and bone
   (d) None of the above
8. The remnants of deciduous teeth are more common in the
   (a) Lower second premolar region
   (b) Lower anterior region
   (c) Upper anterior region
   (d) Upper posterior region
9. The most common congenitally missing teeth are the
   (a) Permanent upper laterals
   (b) Permanent lower laterals
   (c) Permanent lower first molars
   (d) Permanent upper canine
10. Submerged teeth
    (a) Appear at a lower level
    (b) Prevent normal growth of permanent successor
    (c) Prevent eruption of permanent successor
    (d) All of the above



CHAPTER 45

Temporomandibular Joint

Overview

A junction or union of two or more bones of the body is called joint. There are three main types of joints: fibrous, cartilaginous and synovial joints. The temporomandibular joint (TMJ) is a type of synovial joint. *Since it has both the ginglymus (a freely moving joint in which the bones are so articulated as to allow extensive movement in one plane) and the arthroidia (a hollow area onto which the head of the other bone joins), it is also referred to as the* ginglymoarthrodial joint. *The temporomandibular joint involves the mandible and the temporal bone; hence, it is designated as TMJ. As the TMJ connects the mandible to the skull, important functions such as speech and mastication are possible. The synovial joint consists of a bearing surface of the opposing bones covered with smooth, resilient, hyaline cartilage. The joint cavity is divided into two parts by an articular disc and is surrounded by a capsule forming a joint cavity which is filled with synovial fluid. The ligaments which are present help in preserving the integrity of the joint and limit the joint movements.*

INTRODUCTION

A joint is a junction or union of two or more bones of the body. The primary functions of joints are to provide motion and flexibility to the skeleton and to allow growth.

Joints have a complex internal structure. They are composed not only of ends of bones but also of the following structures:

1. **Ligaments:** Tough, white fibres that bind the bones together
2. **Cartilage:** Connective tissue that covers and cushions the bone ends
3. **Articular capsule:** Fibrous tissue that encloses the ends of the bones
4. **Synovial membrane:** Lines the capsule and secretes a lubricating fluid (synovia)

There are three main types of joints: *fibrous* (immovable), *cartilaginous* (partially movable) and *synovial* (freely movable) joints.

The TMJ is a type of *synovial joint.* It is also referred as the *ginglymoarthrodial joint* because it has both the ginglymus (a freely moving joint in which the bones are so articulated as to allow extensive movement in one plane) and the arthroidia (a hollow area onto which the head of the other bone joins). This joint involves the mandible and the temporal bone and hence is designated as the TMJ. The TMJ connects the mandible to the skull and regulates the movement of the mandible to perform important functions such as speech and mastication. It is a *bicondylar joint* as it is two in number, located at either end of the mandible.

The basic design of a synovial joint consists of a bearing surface of the opposing bones covered with smooth, resilient, hyaline cartilage. The joint is surrounded by a capsule forming a joint cavity which is filled with synovial fluid. The joint cavity is divided into two parts by an articular disc. Ligaments connect the articulating bones and help in preserving the integrity of the joint and limit the joint movements.

COMPONENTS OF THE TEMPOROMANDIBULAR JOINT (Fig. 45.1)

The TMJ consists of the following hard-tissue and soft-tissue components:

1. **Bone/hard-tissue components**
   (a) Mandibular condyles
   (b) Glenoid fossa of the temporal bone
   (c) Articular eminence

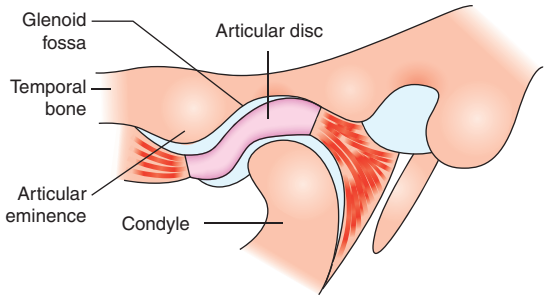


Figure 45.1 Components of the temporomandibular joint.

2. **Soft-tissue components**
   (a) Articular capsule
   (b) Articular disc
   (c) Ligaments
   (d) Muscles

Mandibular Condyle

The condyles are ovoid, convex processes that are broad laterally and narrow medially. They are connected to the body of the mandible by a narrow neck on both sides. The condyle is strongly convex anteroposteriorly and mildly convex mediolaterally. Condyle measures about 15–20 mm mediolaterally and 8–10 mm in the anteroposterior direction. The anterior surface of the condyle has a shallow depression called the *lateral pterygoid fovea* (*see* **Fig. 45.3**) to which the lateral pterygoid muscle is attached.

The condyle is covered by a thin, fibrous layer which consists of poorly vascularized, dense connective tissue with few fibroblasts and chondrocytes. This layer is called *lamina splendens*. Type I collagen forms the major component of this layer. The condyle, in the earlier stages, has a layer of proliferating hyaline cartilage underlying its fibrous covering. The cartilage acts as an active site of growth in the newborn and is later replaced by bone.

The fibrous layer consists of an outer layer of dense collagen fibres arranged parallel to the surface. Under this layer is a transitional layer composed of fibres arranged in an oblique direction not as dense as the superficial layer. Below this transitional zone, fibres are arranged as a vertical layer, which is then followed by the calcified cartilage layer overlying the cortical bone. The thin layer of cortical bone is supported by the trabeculae of spongy bone (**Fig. 45.2**).

The condyle receives its nourishment from three sources. The most superficial part of the intra-articular cortical bone is nourished by the synovial fluid. (The part of the condylar cortex and marrow contained within the joint capsule is dependent on the perforating blood vessels from the insertion of the lateral pterygoid muscle for its blood supply.) The extra-articular parts of the condylar head and neck receive direct blood supply from the periosteum and adjacent muscle tissues.

Glenoid Fossa of the Temporal Bone

The articular surface of the temporal bone is situated on the inferior surface of the squamous part of the temporal bone. This area which articulates with the mandibular condyle is called the *glenoid fossa*.

The glenoid fossa is related anteriorly to the articular eminence, medially to the spine of sphenoid, laterally to the root of the zygomatic process of the temporal bone and posteriorly to the

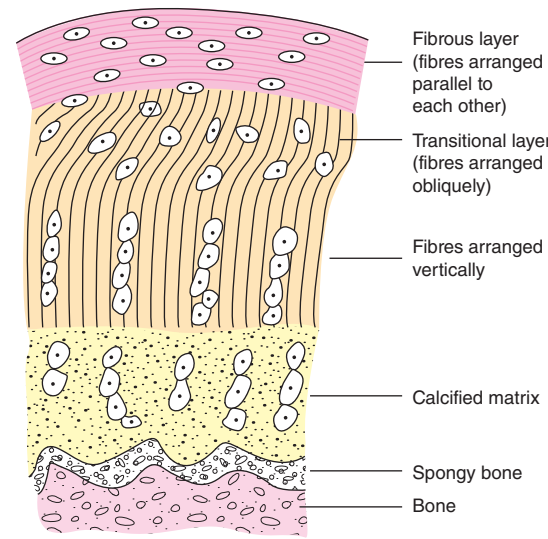


Figure 45.2 Histology of condyle.

squamotympanic and petrotympanic fissures. The floor of the fossa is formed by a thin plate of bone.

The glenoid fossa is also covered by a fibrous layer similar to that of the condyle. It is thin in the articular fossa and thickens in the posterior region of the articular eminence.

Applied Histology

Trauma to the Temporomandibular Joint

Any traumatic blow involving the joint can cause damage to the brain as the bone in the articular fossa is thin and fractures easily.

Articular Eminence

The articular eminence of the temporal bone binds the mandibular fossa anteriorly and forms the anterior root of the zygomatic process. The articular eminence is convex anteroposteriorly and concave in the transverse direction. It is enclosed by the articular capsule of the TMJ.

Articular Capsule (Fig. 45.3)

The articular capsule is a thin sleeve of dense, cartilaginous tissue enclosing the joint cavity. The capsule is attached to the margins of the glenoid fossa, the articular eminence above and the neck of condyle below. The anterolateral part is thickened to form the temporomandibular ligament. The posterior part blends with the articular disc.

The articular capsule consists of two layers:

1. An outer layer (stratum fibrosum) composed of avascular, white fibrous tissue
2. An inner layer (stratum synoviale) which is a secreting layer usually described separately as the synovial membrane

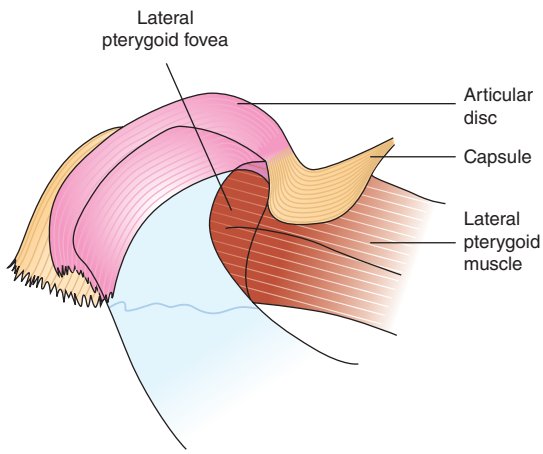


Figure 45.3 Articular disc and capsule.

Synovial Membrane

The synovial membrane is a thin and flexible layer lining the inner surface of the joint capsule. The articulating surfaces and the articulating disc are not covered by the membrane.

The synovial membrane consists of two layers:

1. **Cellular intimal layer:** The intimal layer consists of one to two layers of synovial cells in an amorphous intercellular matrix. There are two types of cells present in this layer:
   (a) Macrophage-like cells for phagocytosis
   (b) Fibroblast-like cells for repair and regeneration

   The intimal layer is thrown into villi-like folds.
2. **Vascular subintimal layer:** This layer, resembling the endothelium, is embedded in an amorphous matrix over a vascular bed. The subintimal layer consists of loose connective tissue with blood vessels, fibroblasts, macrophages and mast cells.

The function of the synovial membrane is to produce fluid which helps in lubricating the joint, repairing the wear and draining the detritus (non-living particulate organic material) accumulating from normal function.

Articular Disc (Fig. 45.4)

The articular disc/intra-articular disc is a roughly oval, firm, thick plate of dense, fibrous cartilage, located between the condyle and the articulating surface of the temporal bone. The disc divides the joint cavity into two compartments: superior and inferior. Its viscoelasticity helps it to act as a shock absorber and stress distributor. The disc provides a gliding motion during the opening and closing of the jaw. It is thick at its periphery and thin at the centre. The upper surface of the disc is

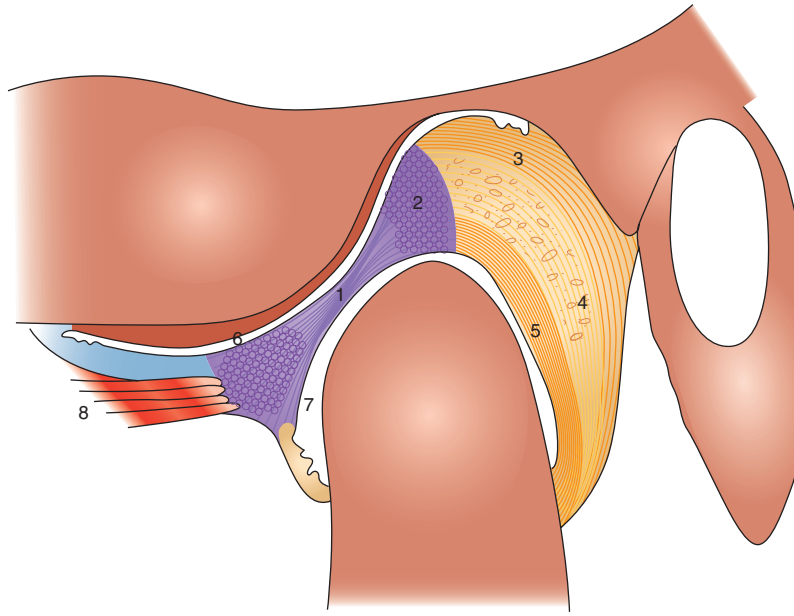


Figure 45.4 Arrangement of tissues in the articular disc. 1, thin central portion of the disc; 2, thicker margin of the disc with transverse fibres; 3, upper elastic bilaminar zone; 4, spongy tissue; 5, lower inelastic bilaminar zone; 6, upper joint cavity; 7, lower joint cavity; 8, lateral pterygoid muscle.

concavoconvex to fit the upper articular surface of the joint, and the lower surface is concave for the head of the condyle to fit in. The articular disc is predominantly avascular; blood vessels are seen at the margins of the disc.

The articular disc is divided into four parts:

1. Anterior band
2. Intermediate band
3. Posterior band
4. Bilaminar zone

The intermediate band consists of collagen fibres running anteroposteriorly. It is thin when compared with the anterior and posterior bands. The anterior and posterior bands consist of fibres which run in the anteroposterior direction and in the transverse or mediolateral direction.

The superior surface of the disc is made up of fine collagen fibres criss-crossing in a diagonal fashion. Below this layer, strong collagen fibres run in an anteroposterior direction; these fibres extend anteromedially to the upper attachment of the lateral pterygoid muscle. The posterior margin consists of a thick band of coarse fibres. The anterior margin also consists of transverse bundles of coarse fibres (**Fig. 45.4**).

The disc is attached to the capsule posteriorly by a spongy *retrodiscal pad*. The retrodiscal pad increases in volume during opening movement of the joint because of pooling of venous blood. As the joint closes, the blood flows out of the retrodiscal pad. The retrodiscal pad is attached posteriorly to the capsule by a *bilaminar zone*. This region has an upper and lower layer of connective tissue fibres. The upper layer/lamina of the bilaminar zone consists of elastic fibres whereas the lower layer/lamina consists of inelastic fibres. This unique shape of the disc permits the mechanical movement of the condyle in a front and back movement.

Articular Ligaments

The TMJ is associated with four ligaments: one major and three minor ligaments. The temporomandibular ligament is the major ligament. The sphenomandibular ligament, stylomandibular ligament and pterygomandibular raphe are minor ligaments.

Temporomandibular Ligament (Fig. 45.5a)

The temporomandibular ligament is a fan-shaped ligament present in the lateral aspect of the articular capsule. It extends as a thickening of the capsule obliquely in a backward and downward direction from the lateral aspect of the articular eminence to the posterior part of the condylar neck.

The temporomandibular ligament consists of two parts:

1. The outer part fibres are arranged obliquely and extend from the outer surface of the articular eminence to the outer surface of the condylar neck.
2. The inner part fibres are arranged horizontally and extend from the outer surface of the articular eminence to the lateral surface of the condyle.

This ligament helps in preventing displacement in posterior and inferior directions. Because the TMJ is a bilateral joint, the ligaments help in preventing the lateral displacement of one joint and the medial displacement of the other. Displacement of TMJ happens only in the anterior or forward direction.

Sphenomandibular Ligament (Fig. 45.5b)

The sphenomandibular ligament is a flat, thin band which is attached to the spine of the sphenoid above and to the lingula of the mandible below. The function of this ligament is to limit distension of the mandible in an inferior direction.

Stylomandibular Ligament (Fig. 45.5b)

The stylomandibular ligament is a specialized band, or the free border, of the cervical fascia, which extends from the apex of the styloid process of the temporal bone to the posterior border of the angle of the mandible, between the masseter and internal pterygoid.

This ligament, along with the sphenomandibular ligament, limits excessive opening of the mandible.

Pterygomandibular Raphe

The pterygomandibular raphe is a tendinous band of the buccopharyngeal fascia attached by one extremity to the hamulus of the medial pterygoid plate and by the other extremity to the posterior end of the mylohyoid line of the mandible.

Muscle of the Joint

The muscle closely associated with the TMJ is the *lateral pterygoid muscle*. This muscle has upper and lower heads. The upper head originates from

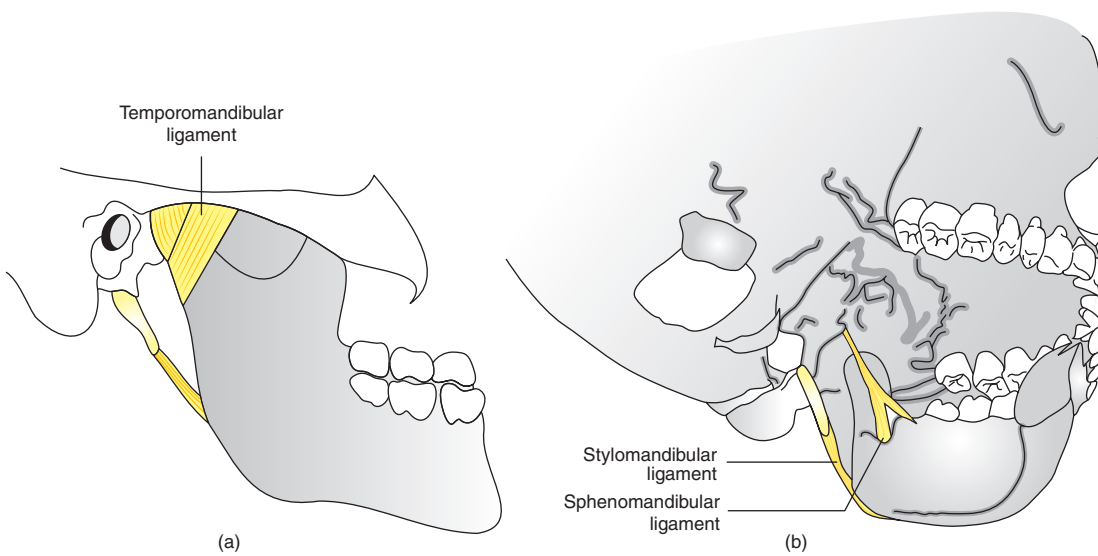


Figure 45.5 (a) Temporomandibular ligament. (b) Ligaments of the temporomandibular joint.

the infratemporal surface of the greater wing of the sphenoid bone and inserts onto the articular disc and fibrous capsule of the TMJ. The lower head originates from the lateral surface of the lateral pterygoid plate and inserts onto the neck of condyle of the mandible.

The primary function of the lateral pterygoid muscle is to pull the coronoid process of the mandible anteriorly, forcing the condylar process out of the mandibular fossa along the articular eminence to protrude the mandible. The upper head influences the position of the articular disc during movement of the TMJ.

Applied Histology

Myofascial Pain Dysfunction (MPD) Syndrome

Pain in the TMJ may be due to various causes such as increased muscle tension and spasm. It is believed that the MPD syndrome is a physical manifestation of psychological stress and that there is no primary disorder of the joint. Pain is secondary to events such as nocturnal jaw clenching and teeth grinding. Treatment is focused on behavioural modification as opposed to joint repair.

MOVEMENTS OF THE JOINT (Fig. 45.6)

1. **Hinge movements:** The opening or closing motions of the mandible around a horizontal axis are known as hinge movements. During the opening of the mouth, the mandible moves down and the condyle moves forward on the undersurface of the disc, exhibiting a hinge movement. When there is wider opening of the mouth, hinge movement is followed by forward gliding of the articular disc. The condyle moves backward during the closing of the mouth.
2. **Translatory movements:** Protrusive or retrusive movements are called translatory or sliding movements. As the mandible moves during protrusion, both condyles leave their fossae and move forward along the articular eminences. When the mandible retrudes, both condyles leave the eminences and move back into their respective fossae. During the forward movement or protrusion of the mandible, the condyle moves with the articular disc over the upper articular surface in a forward direction. The opposite happens in retrusion or reverse direction.

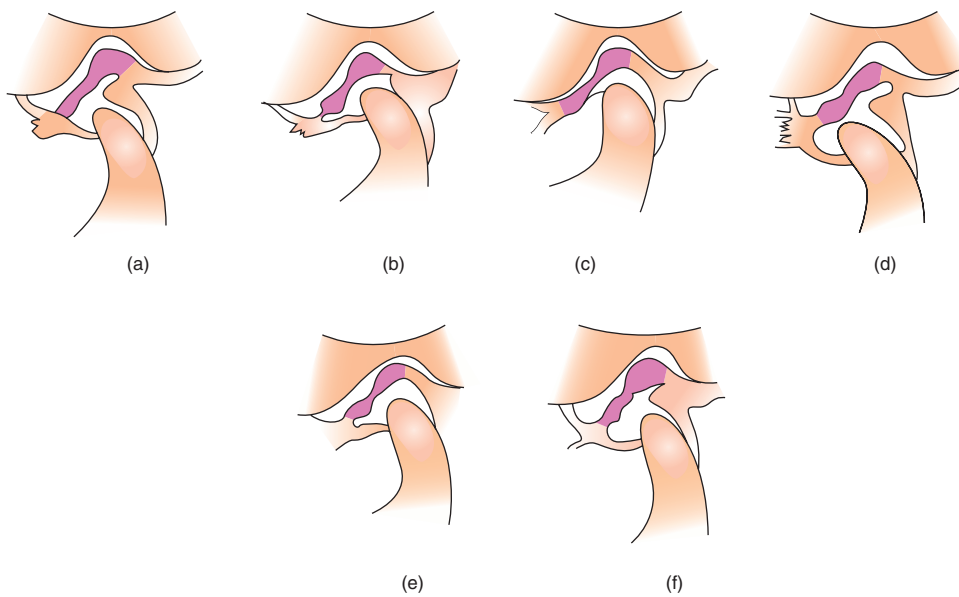


Figure 45.6 Movements of the temporomandibular joint. (a)–(d) Opening movements—condyle moves forward. (e) and (f) Closing movements—condyle moves backwards.

3. **Lateral movements:** The side to which the mandible moves is called the *working side* and the respective condyle is called the *working condyle.* The side that is opposite to the working side is called the *balancing side* and the respective condyle is called the *balancing condyle*.

The movement at the joint happens in two zones: between the upper articular surface and the articular disc and between the disc and the head of the mandible. The upper joint cavity allows gliding movements and the lower joint cavity allows hinge movements.

Applied Histology

Joint Displacement

If the jaw is opened too wide for a long time during yawning or is forced open, there is dislocation of the TMJ in the anterior direction. Displacement of the TMJ can be severely painful.

Clicking of the Temporomandibular Joint

A normal, healthy TMJ is quiet during function. The movement of the jaw during opening and closing is smooth without any sliding to one side or sudden changes in direction. When the muscles of the *TMJ* are overcontracted because of an accident, overclenching or grinding, the ligaments holding the disc can be damaged. This results in the slipping of the disc from its usual position. During the opening movement, the tissue holding the disc towards the back of the joint causes the disc to move on top of the condyle, which results in a clicking or popping sound.

Ankylosis

Ankylosis is immobility of the joint because of bony fusions which might occur due to intrauterine foetal abnormality, forceps delivery, inflammation or malignancies. Ankylosis after birth affects the development of mandible since condylar region possess growth centre.

INNERVATION AND BLOOD SUPPLY

The innervation of the TMJ involves four types of receptors:

1. Ruffini's corpuscles function as static mechanoreceptors which position the mandible.
2. Pacinian's corpuscles are dynamic mechanoreceptors which accelerate movement during reflexes.
3. Golgi tendon organs function as static mechanoreceptors for the protection of ligaments around the joint.
4. Free nerve endings are the pain receptors for the protection of the TMJ itself.

These receptors maintain the proprioception (ability to sense stimuli arising within the body) of the joint. They are innervated by the *auriculotemporal* and *masseteric branches* of the mandibular nerve.

The main source of blood supply is provided by the *superficial temporal artery* and the *maxillary artery,* which are branches of the external carotid artery. Other branches of the external carotid artery—the deep auricular artery, anterior tympanic artery and ascending pharyngeal artery—also contribute to the arterial blood supply of the joint.

ADDITIONAL READING

Biomechanics of the Temporomandibular Joint

The temporomandibular joint has a complex design with provisions for hinge and gliding movement that is capable of inducing significant shear loads onto the fibrocartilage disc during jaw motion. Energy density transfer in the joints determines the biomechanical and biochemical integrity of tissues of the TMJ. Contact kinetics of the TMJ disc cartilage studied in terms of biphasic modelling has elucidated that stress-field translation and further shear strain localization are high in the lateral portion of the disc which is the site prone for disc degeneration. Tractional forces which occur due to the stress field translation contribute to cartilage wear and fatigue particularly with mediolateral translation as the disc is weaker in this aspect. The TMJ disc is responsible for the function of stress distribution and lubrication in the TMJ; mechanical failure may lead to early degenerative changes seen in the TMJ. Tractional forces result due to frictional and plowing forces produced by the deformation of the cartilage matrix as a stress field translates over the surface. Plowing forces cause dynamic compressive and shear strains within the collagen-proteoglycan

matrix which causes movement of hydraulic pressures and fluid movement through the porous matrix. The strain energy which develops as a consequence of the plowing forces is influenced by the magnitude and frequency of the forces applied to the surface of the cartilage, properties of the TMJ disc, such as the anisotropic nature of its yield strength, and propensities for crack propagation and fatigue failure. However, specific mechanisms through which static and dynamic strains in the matrix affect the fibrochondrocytes of the TMJ disc in promotion of repair or failure of the matrix are unknown. The cyclic matrix strain in chondrocyte mechanotransduction has been thought to be one of the mechanisms.

When there is reduction or absence of fluid flow, the hydrostatic pressure gradients which are normally associated with dynamic compression leads to increase in synthesis of cartilage matrix components, such as glycosaminoglycans and collagen, and enzymes which break down the matrix, such as metalloproteinases. Internal strain conditions are controlled by the balance between the anabolic and the catabolic activities of cartilage cells.

Lubricin is Required for the Structural Integrity and Maintenance of TMJ

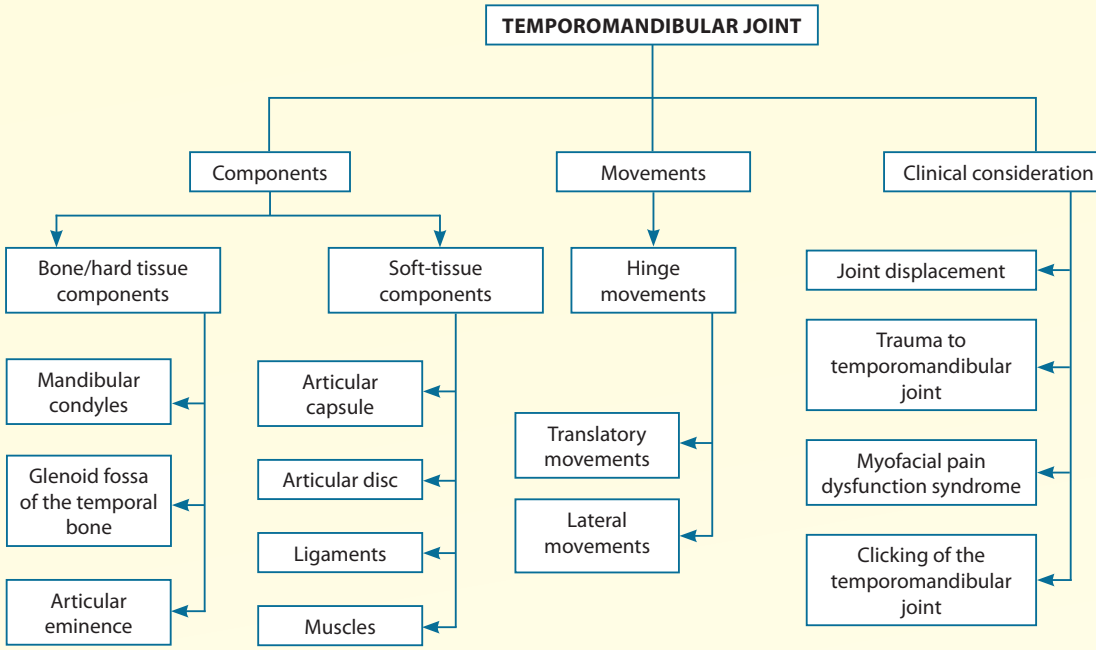
Synovial fluid helps in joint lubrication. The process of lubrication is mediated by the macromolecules present in synovial fluid-hyaluronic acid (HA) and lubricin. Hyaluronic acid increases the viscosity of the synovial fluid and cartilage elasticity. It is synthesized by chondrocytes and synovial cells. Lubricin is a major component of the synovial fluid and plays a vital role in maintenance of TMJ. It is a product of the gene *Proteoglycan-4* (*Prg4*). It is also referred to as superficial zone protein (SZP), megakaryocyte stimulating factor (MSF) precursor or proteoglycan-4 (PRG4). Lubricin is synthesized by synovial or superficial zone cells and is secreted into joint cavities. It protects the articular cartilage surfaces and regulates synovial cell growth. It reduces friction during boundary movement with an extensive mucin-like region rich in O-linked oligosaccharides. Lubricin also prevents cell/protein adhesion, regulates proliferation of synovial cells and protects superficial chondrocytes from death.

SECTION IV

Key Points

1. The temporomandibular joint (TMJ) is referred to as the ginglymoarthrodial joint.
2. The condyle is covered by a thin, fibrous layer called lamina splendens, which consists of poorly vascularized, dense connective tissue.
3. The area of the temporal bone which articulates with the mandibular condyle is called the glenoid fossa.
4. The lateral pterygoid muscle is attached to the lateral pterygoid fovea.
5. The synovial membrane lines the inner surface of the joint capsule. The articulating surfaces and the articulating disc are not covered by the membrane.
6. The articular disc acts as a shock absorber during jaw movements.
7. The TMJ is associated with four ligaments: the temporomandibular ligament, the stylomandibular ligament, the sphenomandibular ligament and the pterygomandibular raphe.
8. During the lateral movement of the mandible, the side to which the mandible moves is called the working side, and the condyle on the working side is called the working condyle. The other side is called the balancing side and the condyle is called the balancing condyle.
9. The nerve supply of TMJ is by the auriculotemporal and masseteric branches of the mandibular nerve.
10. Blood supply of TMJ is provided by the superficial temporal artery and the maxillary artery which are branches of the external carotid artery.

Mind Map



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Multiple Choice Questions

1. Temporomandibular joint is a
   (a) Fibrous joint
   (b) Synovial joint
   (c) Cartilaginous joint
   (d) All of the above
2. The anterior surface of the condyle has a shallow depression called
   (a) Sublingual fovea
   (b) Lateral pterygoid fovea
   (c) Submandibular fovea
3. The layer covering the condyle is called
   (a) Lamina limitans
   (b) Lamina propria
   (c) Lamina splendens
   (d) None of the above
4. The type of collagen present in lamina splendens is
   (a) Type I
   (b) Type II
   (c) Type III
   (d) Type IV
5. Glenoid fossa is present in the
   (a) Squamous part of temporal bone
   (b) Petrous part of temporal bone
   (c) Mastoid part of temporal bone
   (d) Tympanic part of temporal bone
6. The articular disc is made up of the
   (a) Anterior band
   (b) Intermediate band
   (c) Posterior band
   (d) Bilaminar zone
   (e) All of the above
7. The ligaments associated with TMJ are the
   (a) Temporomandibular ligament
   (b) Sphenomandibular ligament
   (c) Stylomandibular ligament
   (d) All of the above
8. The ligament of TMJ which prevents displacement of the joint in the anteroposterior direction is the
   (a) Temporomandibular ligament
   (b) Sphenomandibular ligament
   (c) Stylomandibular ligament
   (d) All of the above
9. The movements exhibited by the mandible are
   (a) Hinge movements
   (b) Translatory movements
   (c) Lateral movements
   (d) All of the above
10. The sensory innervation of TMJ is by the
    (a) Auriculotemporal nerve
    (b) Masseteric nerve
    (c) Both a and c
    (d) None of the above



CHAPTER 46

Maxillary Sinus

Overview

Hollow, air-filled cavities lined by the mucous membrane are called paranasal sinuses. Out of the four pairs of paranasal sinuses—frontal, ethmoidal, maxillary and sphenoidal air sinuses—the maxillary sinus is the largest. The development begins at about 2 months in utero. At birth, the sinus measures 6–8 cm^3 in volume in the anteroposterior direction and is tubular in shape. It grows further to reach the plane of the hard palate by the age of 9 years and becomes ovoid. During the later phase, pneumatization or expansion of the maxillary sinus occurs. The maxillary sinus ostium for drainage are located high on the medial wall and open into the semilunar hiatus present in the middle nasal meatus of the lateral wall of the nose. Histologically, the maxillary sinus is composed of respiratory pseudostratified ciliated columnar epithelium. Specialized mucous-secreting cells called goblet cells are also present in the sinus epithelium. The sub-epithelial connective tissue is also composed of secretory serous and mucous glands along with collagen fibres and neurovascular structures. The maxillary sinus is topographically in close proximity to the maxillary posterior orodental complex and hence any pathology of maxillary posterior teeth can reflect on the maxillary sinus and vice versa also.

INTRODUCTION

The paranasal sinuses are hollow, air-filled cavities lined by mucous membrane. There are four pairs of paranasal sinuses—frontal, ethmoidal, maxillary and sphenoidal air sinuses. The maxillary sinus is the largest of the paranasal sinuses and is pyramidal in shape (**Fig. 46.1**). The maxillary sinus is also called the *antrum* (antrum means cavity or chamber) *of Highmore* after Nathaniel Highmore who described the morphology of maxillary sinus in detail.

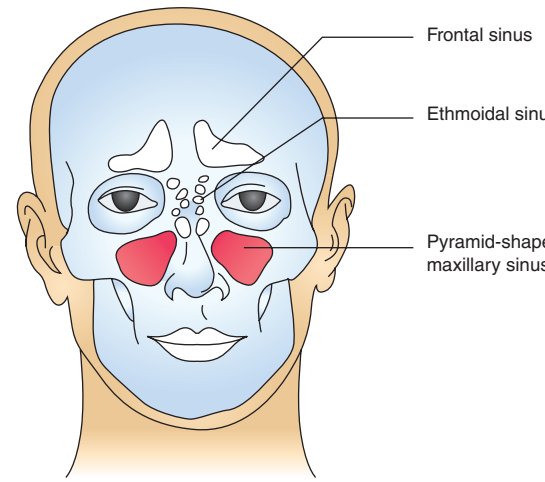


Figure 46.1 Paranasal sinuses.

Knowledge of the maxillary sinus is important in dentistry because of its close proximity to the maxillary posterior teeth.

DEVELOPMENT OF THE MAXILLARY SINUS

The maxillary sinus develops first among the paranasal sinuses. The development begins at about 2 months in utero (IU). The growth of the maxillary sinus is biphasic, i.e. it develops in two phases: from 0 to 3 years and between 7 and 12 years.

At birth, the sinus measures 6–8 cm^3 in volume in the anteroposterior direction and is tubular in shape. The sinus extends laterally by the age of 4 years. It grows further inferiorly to reach the plane of the hard palate by the age of 9 years and becomes ovoid (**Fig. 46.2**).

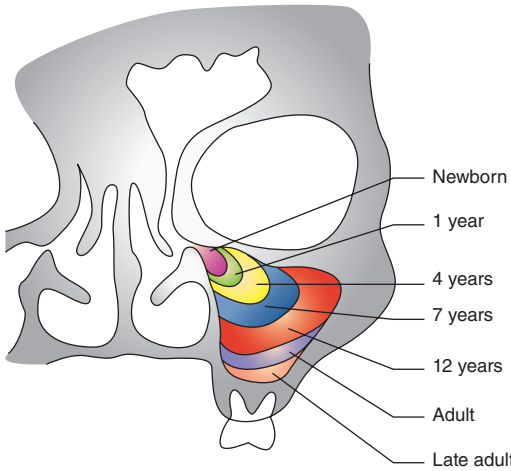


Figure 46.2 Development of the maxillary sinus.

During the later phase, pneumatization or expansion of the maxillary sinus occurs more inferiorly close to the posterior maxillary teeth. Pneumatization can be so extensive as to expose teeth roots, with only a thin layer of soft tissue covering them.

Applied Histology

The process of pneumatization can get suppressed in congenital syphilis because of the infective microorganism (spirochetes) leading to small sinus.

STRUCTURE OF THE MAXILLARY SINUS

The maxillary sinus is present in the maxilla. The adult maxillary sinus is pyramidal in shape and has a volume of approximately 15 cm^3 (34 × 33 × 23 mm). The base of the pyramid is formed by the nasal wall with the apex pointing towards the zygomatic process. The roof is formed by the orbital floor. The floor varies in its level—from birth to 9 years of age, the floor of the sinus is above that of the nasal cavity; after 9 years, the floor is generally at the level of the nasal floor. The floor continues to move in an inferior direction as the maxillary sinus pneumatizes.

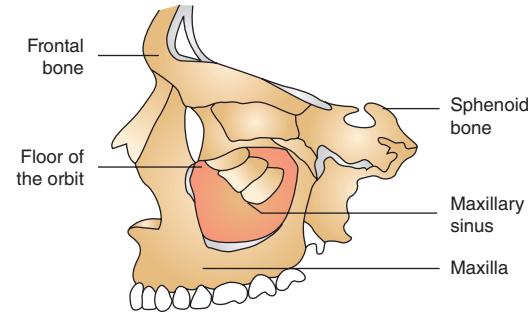


Figure 46.3 Relation of the maxillary sinus with the adjacent structures.

Relations (Fig. 46.3)

1. **Anterior:** Facial surface of the maxilla
2. **Inferior:** Alveolar and zygomatic processes of the maxilla
3. **Superior:** Orbital surface of the maxilla
4. **Posterior:** Infratemporal surface of the maxilla

Maxillary Ostium (Opening/Orifice)

The ostia for drainage are located high on the medial wall and open into the semilunar hiatus (hiatus = sulcus) present in the middle nasal meatus of the lateral wall of the nose. The size of the ostium is usually 2.5 mm.

Applied Histology

The ostia are located at a high level; because of this, the drainage of the contents is difficult when the head is erect (**Fig. 46.4**).

Related Structures

Nasolacrimal Duct

The nasolacrimal duct drains the lacrimal sac. The duct runs from the lacrimal fossa in the orbit, down the posterior aspect of the maxilla and empties into the anterior aspect of the inferior meatus. The duct lies very close to the maxillary ostium.

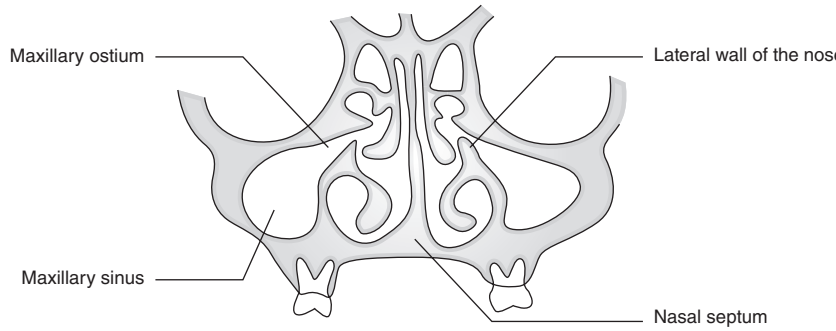


Figure 46.4 Relation of the maxillary sinus with the lateral wall of the nose and the nasal cavity.

Nasal Fontanelles

Nasal fontanelles are the areas of the lateral nasal wall that are devoid of bone, usually covered by mucosa. In some individuals, the anterior or posterior fontanelles may be patent/open resulting in an accessory ostium. They are non-functional ostia that serve to drain the sinus only if the natural ostium is blocked and intrasinus pressure/gravity moves material out of the ostium. Accessory ostia are usually found in the posterior fontanelle.

Applied Histology

Topographical Relationship Between Maxillary Sinus and Orodental Complex

1. Because of its close proximity to the dentition, dental diseases can cause maxillary infection.
2. Extraction of a maxillary posterior tooth can sometimes result in an oroantral communication if the roots are in close proximity to the floor of the sinus.
3. The maxillary sinus is more prone to infections than the other paranasal sinuses because of its location. Maxillary sinusitis is common because of its anatomical location. The drainage orifice lies near the roof of the sinus and hence the maxillary sinus does not drain well, and infection develops more easily.
4. Infections and neoplasms of the maxillary sinus can cause pain in the posterior maxillary teeth.
5. Infections in the maxillary sinus can spread to the cavernous sinus and can be life-threatening.

Vascular Supply

The branches given out at the third part of the maxillary artery—infraorbital, sphenopalatine, greater palatine and posterior alveolar arteries—supply the maxillary sinus. Venous drainage is by the facial vein and pterygoid plexus of veins which communicate with the cavernous sinus through emissary veins.

Lymph drains into the submandibular nodes.

Nerve Supply

1. **Parasympathetic supply:** The greater petrosal nerve (a branch of the facial nerve) is responsible for the mucous secretion.
2. **Sensory innervations:** The branches of the maxillary nerve—the greater palatine nerve and the infraorbital nerve—supply the maxillary sinus.

HISTOLOGY OF THE MAXILLARY SINUS

The histologic features of the maxillary sinus are characterized by the presence of a mucous membrane called the *Schneiderian membrane*, which is a bilaminar membrane with ciliated columnar epithelial cells on the internal (or cavernous) side and periosteum on the osseous side. The mucosa is firmly bound to the periosteum.

Sinus Epithelium

The epithelium is pseudostratified, ciliated and columnar like the respiratory tract. All the cells

lie in contact with the basement membrane, but they do not reach the surface. The cells found in the epithelium are as follows (**Fig. 46.5**):

1. Cells with cilia
2. Cells without cilia
3. Goblet cells
4. Basal cells
5. Transient immune cells, i.e. lymphocytes and mast cells

Ciliated and Non-Ciliated Cells

The cells which reach the free surface are ciliated cells. The ciliated and non-ciliated cells help in creating most of the physical barrier, because they form a tightly connected sheet that lines the nasal cavity.

Applied Histology

The tight junction formed between ciliated and non-ciliated cells effectively keeps foreign materials, pollutants and microorganisms from entering the tissues.

Cilia

The most important feature of the respiratory epithelium is the cilia. Cilia are motile structures projecting in parallel rows from certain epithelial surfaces. They are about 7–10 μm long. Cilia beat with a wave-like synchronous rhythm. They propel surface films of mucus in a consistent direction over the epithelial surface towards the pharynx from where it is expelled.

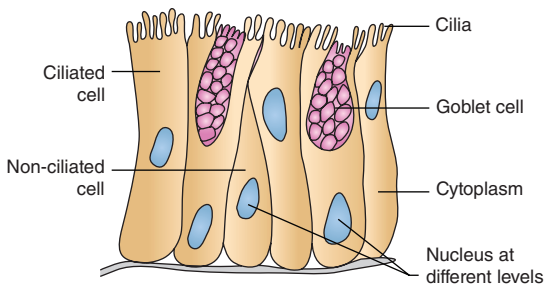


Figure 46.5 Pseudostratified ciliated columnar epithelium.

Applied Histology

The mucociliary clearance removes the microorganisms and irritants that are present in the inspired air and thus aids in preventing respiratory infections.

Goblet Cells

The goblet cells produce mucus. They have a basal portion which has highly developed rough endoplasmic reticulum and nucleus. The Golgi complex is present above these. The secretory glycoproteins are synthesized in the rough endoplasmic reticulum and pass through the Golgi bodies to undergo further glycosylation or modification. Microvilli are present on the apical surface of the goblet cells. The secretory granules which are formed are released from the apical surface by exocytosis (secretion). The secreted mucus produces a mucus blanket.

Applied Histology

The sticky mucus blanket serves as an efficient trapper of dust particles and also moistens the inspired air **(Fig. 46.6)**.

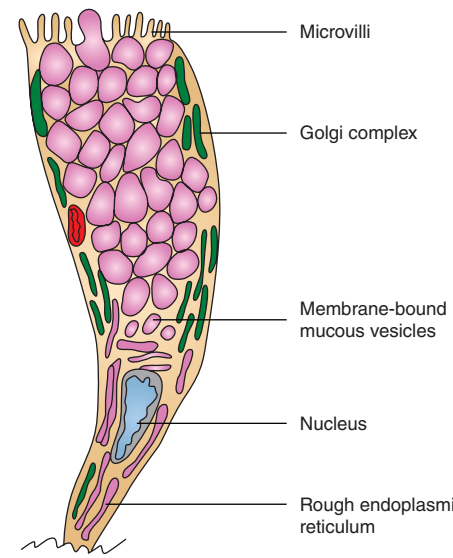


Figure 46.6 Goblet cell.

Immune Function The mucus contains special antibodies and enzymes like the bactericidal lysozyme which prevents viruses and bacteria from sticking to the epithelial lining and helps the white blood cells to recognize them as invaders and kill them.

Basal Cells

The basal cells are progenitor cells/stem cells that divide and grow to replace the other cell types when they grow old or are lost due to a toxic irritant.

Sub-Epithelium

Immune cells such as lymphocytes and mast cells are present in the sub-epithelium which play an important role in defence. Apart from epithelial goblet cell mucous secretion, there are serous and mucous glands present in the sub-epithelial connective tissue which adds up to the sinus secretion. These glands are situated just beneath the epithelial layer and the secretions reach the sinus lumen through the excretory ducts. The glandular secretions are predominantly serous with smaller amount of lipids, proteins, mucous secretion, glycoproteins and mucopolysaccharides. Numerous blood capillaries and non-myelinated nerve fibres are also seen.

FUNCTIONS OF THE MAXILLARY SINUS

1. Warming of inspired air
2. Humidification of dry air
3. The structure and components of the sinus help in creating appropriate resonance in the voice and thus play a major role in speech
4. Pneumatization of the sinus aids in lightening the weight of the skull

ADDITIONAL READING

Thickness of the Schneiderian Membrane and Clinical Implications

The Schneiderian membrane consists of more than 90% of the epithelial cells. The epithelial cells are of the ciliated type and are distributed in a single, columnar, pseudostratified layer. The cilia helps in propelling the mucus towards the ostium. The frequency of the ciliary movements is approximately 60 kHz. The factors influencing the mucous production and clearance of the mucosa can increase the risk of sinusitis. The Schneiderian membrane thickness ranges from 0.3 to 0.8 mm. It is thinnest in the lateral measurements and thicker on the median aspect and mid-sagittal aspect. Increase in mid-sagittal thickness is due to accumulation of mucous secretions in the deepest aspect of the maxillary sinus. Factors such as periodontal diseases thicken the Schneiderian membrane. Schneiderian membrane thickness (SMT) is considered a key anatomic factor which influences sinus membrane perforation and subsequent implant failure. Increased SMT values are considered favourable as they are less prone to perforation during access instrumentation and lifting and could endure stronger compressing force to allow more grafting material insertion (excerpts from Janner et al. 2011 and Monje et al. 2016).

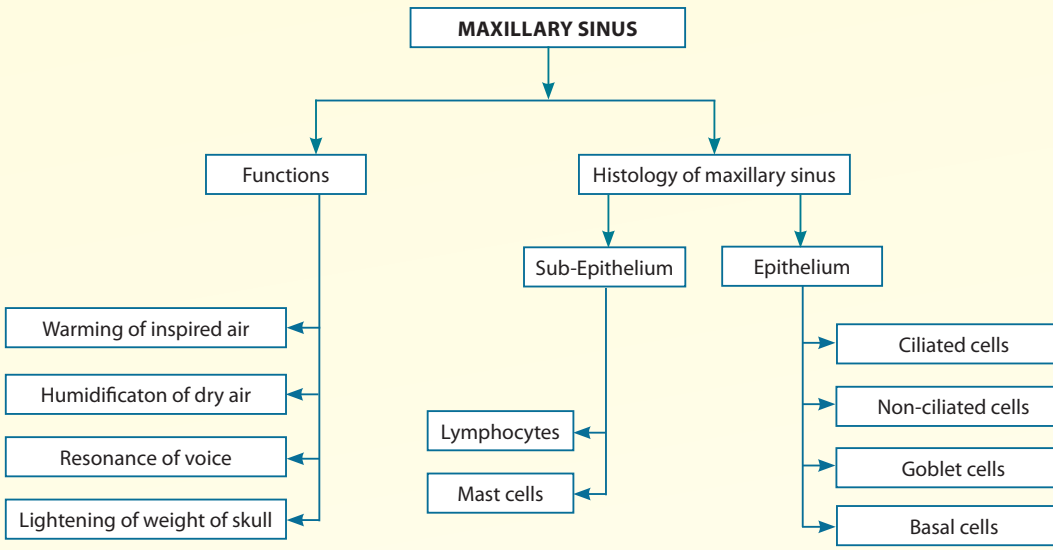
Multipotent Postnatal Stem Cells from the Human Maxillary Sinus Membrane

Sinus lift procedures for implant placement involve the elevation of the maxillary sinus membrane for increasing bone height in the posterior maxilla. The membrane obtained during orthognathic surgery could be used to isolate maxillary sinus membrane stem cells (MSMSCs) through the process of single colony selection and STRO-1 cell sorting. These stem cells are of mesenchymal origin and positive for mesenchymal stem cell (MSC) markers such as STRO-1, CD146, CD29 and CD44; further, under defined culture conditions, MSMSCs were able to form mineral deposits and differentiate into adipocytes and chondrocytes. MSMSCs showed the capacity to generate bone-like tissue and maintained their MSC characteristics after in vivo implantation when transplanted into immunocompromised rodents. Cellular and molecular evidence about MSM stem cells show functional potential in bone regeneration for dental implants (excerpts from Guo et al. 2015).

Key Points

1. The maxillary sinus is the largest of the paranasal sinuses. It is pyramidal in shape.
2. The ostium opens at the hiatus semilunaris present in the middle meatus.
3. The lining membrane of the maxillary sinus is called the Schneiderian membrane.
4. The goblet cells present in the lining secrete mucus.
5. The cilia help to propel the mucus and the dust particles towards the pharynx from where they are expelled.

Mind Map



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Multiple Choice Questions

1. The shape of the maxillary sinus in adults is
   (a) Ovoid
   (b) Tubular
   (c) Pyramidal
   (d) None of the above
2. The development of the maxillary sinus is
   (a) Monophasic
   (b) Biphasic
   (c) Both a and b
   (d) None of the above
3. The roof of the maxillary sinus is formed by the
   (a) Lateral wall of the nose
   (b) Orbital surface
   (c) Oral cavity
   (d) None of the above
4. Pneumatization of the maxillary sinus is
   (a) Expansion of the sinus
   (b) Contraction of the sinus
   (c) Both a and b
   (d) Accidental entrapment of air
5. The maxillary ostium opens at the
   (a) Superior meatus
   (b) Inferior meatus
   (c) Posterior fontanelle
   (d) Middle meatus
6. Accessory ostia are found in the
   (a) Anterior fontanelle
   (b) Superior meatus
   (c) Posterior fontanelle
   (d) Middle meatus
7. The membrane lining the sinus is known as the
   (a) Schneiderian membrane
   (b) Respiratory membrane
   (c) Olfactory membrane
8. The epithelium lining in the sinus is
   (a) Simple columnar
   (b) Simple stratified
   (c) Pseudostratified
   (d) Pseudostratified ciliated columnar
9. The goblet cells are responsible for secreting
   (a) Antibodies
   (b) Enzymes
   (c) Mucus
   (d) All of the above
10. The apical surface of the goblet cells consists of the
    (a) Cilia
    (b) Villi
    (c) Microvilli
    (d) None of the above

CHAPTER 47



Tissue Processing for Microscopic Study

Overview

To view anything under a microscope, it requires specific preparation of the tissue which includes procedures such as fixation, dehydration, clearing, wax impregnation and embedding, sectioning and staining. To begin with, the tissue specimen should be prevented from autolysis so as to appreciate the histologic features as it was in life. This is achieved by the process called fixation. Once this is achieved, the specimen should be made as thin as possible (sectioning) so as to appreciate the microscopic features. Further, the specimen should be able to hold stains for delineation of structures microscopically. For sectioning, the tissue has to be made hard enough and hence wax is utilized to achieve this. But as wax and water are immiscible, the water content from the tissue section is removed by the process called dehydration. Also, the refractive index of the tissue should match with that of the glass slide and this, is achieved by a process called clearing. Followed by this, wax impregnation and embedding is undertaken which renders the tissue specimen sectionable. Once sections are obtained the subsequent procedure is staining. Since the commonly used stains are water based, the sections must be dewaxed and rehydrated for staining purpose. Thus, a tissue specimen is processed and prepared for viewing under the microscope.

INTRODUCTION

Keep a thick piece of any object under a microscope and try observing it through the eyepiece. Are you able to see the details? All you will see is a magnified view of a small surface area that appears dark and not in focus. To study any material microscopically, the material has to be subjected to certain changes. It has to be made very thin so that it can transmit light. It has to be stained so that the various components in it can be differentiated. Preparing a tissue to make it visible under the microscope is called tissue processing. Although there are various methods available depending on the nature of the tissue, this chapter discusses the commonly used procedures in the preparation of oral tissues for microscopic study.

PREPARATION OF ORAL TISSUES

In the study of oral histology, we should consider the preparation of the hard and soft tissues. Enamel, dentin, cementum and bone are the hard tissues in the oral cavity. Hard tissues are calcified structures containing various amounts of calcium and phosphates.

The tissues can be prepared for microscopic study by the following methods:

1. Formalin-fixed paraffin-/celloidin-embedded sections
2. Decalcified, paraffin-embedded sections
3. Ground sections
4. Frozen sections

Formalin-Fixed Paraffin-/ Celloidin-Embedded Sections (Fig. 47.1)

Methods 1 and 2 have some common steps and differ little. The common steps are fixation, dehydration, clearing, impregnation, embedding, sectioning and staining.

Tissue processing can be done manually by transferring the tissue into various chemicals in jars, wax baths, etc., or done mechanically with an instrument known as the *automatic tissue processor* (**Fig. 47.2**).

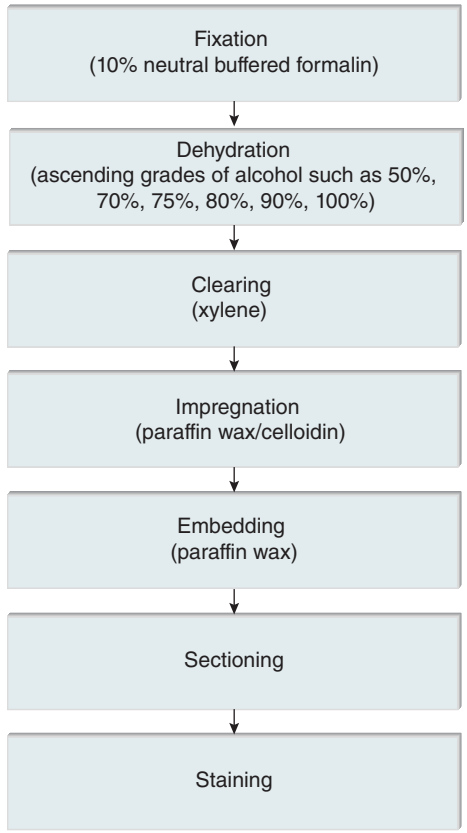


Figure 47.1 Steps involved in formalin-fixed paraffin-/celloidin-embedded sections.

Fixation

As soon as a tissue is obtained, it should be immersed in a liquid which acts as a fixative. *Fixation* is the procedure which preserves the tissue in a state as close to living tissues as possible by avoiding autolysis and putrefaction. During this process, coagulation of proteins occurs due to cross linking of the protein molecules, thus fixing the tissue. Generally, *10% neutral buffered formalin* in a volume of 15 times more than that of the tissue is used as the fixative. Picric acid, glutaraldehyde, alcohol, etc., are some other fixatives used in select situations. Depending on the size of the tissue, the fixation time may vary from 24 hours to 7 days. After fixation, the tissue is washed in running tap water for 10–15 minutes.

Applied Histology

Tissue Shrinkage

Tissue fixed in formalin and embedded in paraffin wax possesses 33% shrinkage. Prolonged fixation in formalin can lead to secondary shrinkage also.

Diffusion of Unfixed Material

If any of the tissue specimen components are unfixed, there might be diffusion and movement

(*Continued*)



Figure 47.2 Automatic tissue processor.

(*Continued*)

of such components within the tissue. This can lead to false localization. Most commonly, glycogen can get diffused leading to an artefact called streaming artefact.

Inadequate or Delayed Fixation

This can lead to alteration in the structure and staining properties of various tissue components. For instance, cells can appear shrunken with loss of details.

Dehydration

This step is done to remove the water content from the tissue. Water is removed from the tissue to allow the penetration of wax to make the tissue hard enough to be sectioned. Once the water is removed, the material used for dehydration occupies its place. For dehydration, *ascending grades of alcohol* such as 50%, 70%, 75%, 80%, 90% and absolute alcohol are used. This achieves gradual and complete dehydration. The tissue is immersed in jars containing various grades of alcohol. The time required in each jar depends on the size of the tissue; generally, 30 minutes to 2 hours in each grade of alcohol may be required.

Clearing

In this step, the tissue is passed through a clearing agent, which makes the tissue appear clear. It is said that the tissue appears clear due to the refractive index, which becomes close to that of glass during this step. This appearance of the tissue allows light to pass through.

Xylene is the most commonly used clearing agent. It removes the alcohol that would have entered into the tissue during dehydration. Xylene is changed twice during the procedure which lasts for 1–2 hours.

Impregnation

The tissue, after clearing, is immersed in a material that supports and hardens the tissue so that it can be cut into thin sections.

Paraffin wax is the routinely used material for this purpose. The specimens which contain good amount of hard tissue, such as a part of maxilla or mandible, need harder embedding material such as *celloidin*.

The tissue is immersed in the molten paraffin wax and kept in the wax bath, which is thermostatically regulated, for a few hours. Here again, two changes of the wax are made. Xylene is miscible with wax and gets slowly replaced with the paraffin wax.

Embedding

After the complete infiltration of the wax, the tissue is removed from the wax bath. It is embedded inside the wax block. For this, Leuckhart's L-shaped metallic pieces (**Fig. 47.3**) with a metal base are used to form the square frame of the desired size,

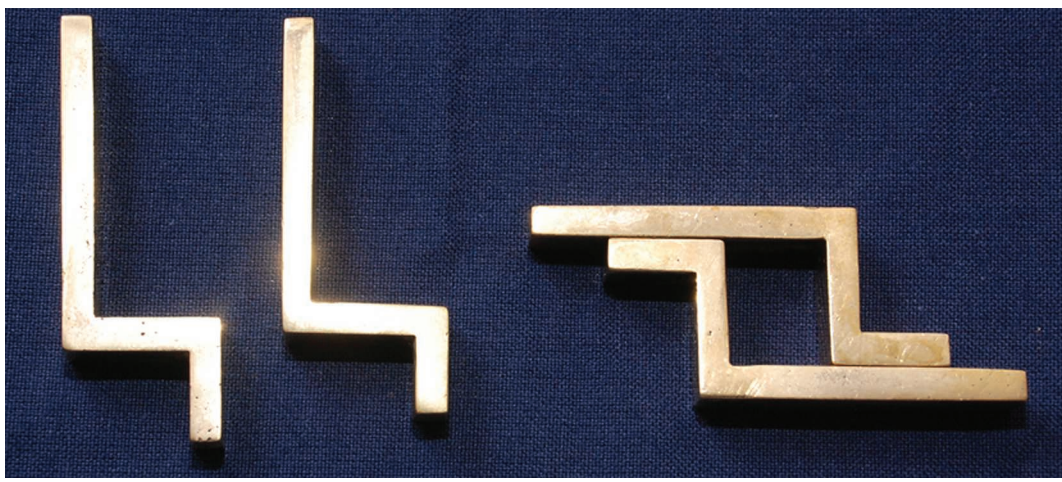


Figure 47.3 Leuckhart's L-shaped pieces.

and the molten wax is poured into it. Immediately, the impregnated tissue is kept in the centre using pre-heated forceps. The wax is allowed to harden.

Automatic embedding stations which regulate the flow of the paraffin wax are also available for this purpose. There are prefixed block frames which give the blocks a uniform size.

While embedding the tissue, one has to take care to orient the specimen in the proper direction. It should be embedded in such a way that both the epithelium and the connective tissue are included in the cutting surface of the block. The cutting surface of the tissue is that which touches the bottom of the metallic plate.

Applied Histology

Curved Specimen

Curving of flimsy small tissue specimens during fixation and processing is very common which can lead to problems during orientation of specimen for embedding. This can be prevented by securing such vulnerable specimens to a rigid surface.

Sectioning

After the preparation of the wax block, it is fastened to a precision instrument called *microtome* (**Fig. 47.4**). Sections as thin as 3–5 μm are cut using this instrument. The tissue becomes advanced after each cut; thus a continuous ribbon of sections is possible.

Various types of microtome knives as well as disposable blades are available for sectioning.

After obtaining the thin section, it is spread on a water bath. Glass slides coated with an *albumin-and-glycerine* mixture in the centre are introduced into the water. The section is lifted gently onto the slide where the albumin coating is present. It is dried for about 15 minutes on a slide warmer. The albumin coagulates and fixes the section onto the glass slide.

Applied Histology

Microtome Knife

Any error with the microtome knives can lead to alternate thin and thick sections or scoring and splitting of sections which can heavily interfere with microscopic interpretation.

Staining

For routine histologic study, *haematoxylin and eosin* stain is used. Haematoxylin stains the nucleus while eosin stains the cytoplasm of the cell (**Fig. 47.5**).

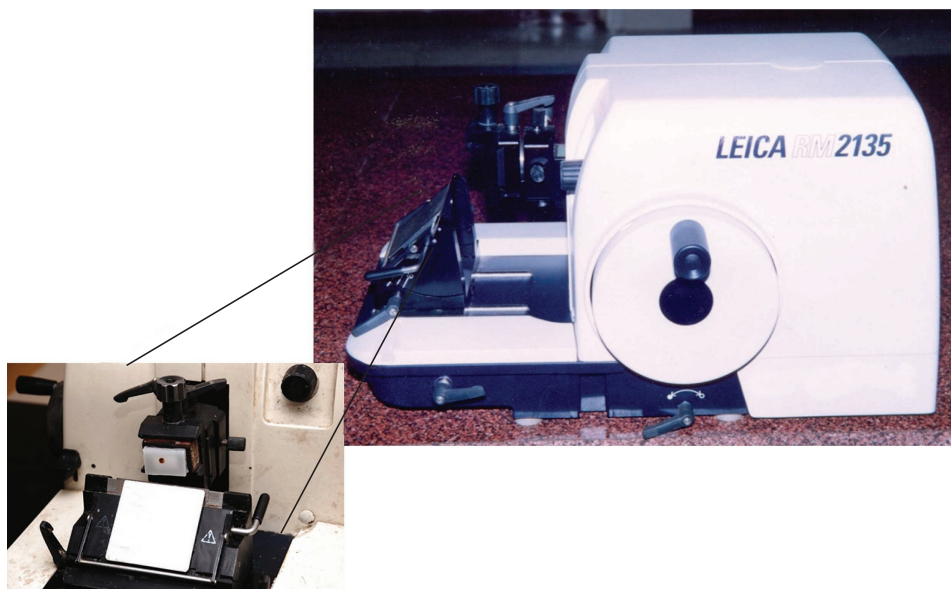


Figure 47.4 Semiautomatic microtome.



Figure 47.5 Haematoxylin and eosin staining sequence.

The staining procedure involves deparaffinization (dewaxing) by placing in xylene for 30 minutes. The slides are then placed in alcohol for 2 minutes and washed in tap water to rehydrate the tissue sections and to take up stain. Haematoxylin staining is done for 4–5 minutes. Then the slides are placed in acid alcohol for 30 seconds. This process is called differentiation and involves removal of excess stain from the tissue section. Washing in tap water is repeated again and counter staining is done with eosin solution for 30 seconds to 1 minute. The slides are again placed in alcohol and xylene. After staining, a drop of a mountant such as the *DPX* (p-xylene-bis-pyridinium bromide) is placed on the section and covered with a coverslip. Now, the slide is ready for microscopy. Various special stains such as periodic acid–Schiff (PAS), phosphotungstic acid–haematoxylin (PTAH), Von Geison and reticulin are used depending on the tissue of interest.

Applied Histology

Stain Particles Incorporation

If the staining chemicals are not thoroughly dissolved in solvent it can lead to precipitation of the stain particles which can appear on the stained sections. This can pose microscopic interpretation difficulties.

Air Bubbles

Air bubbles can get trapped during placement of coverslip which appear as tiny spherical voids under the microscope interfering with appreciation of histologic features.

Decalcified Sections

Hard tissues of the body such as the bone and teeth have to be made soft to be sectioned in a routine microtome. The procedure involved is called decalcification where the calcium is removed from the tissue. This procedure is used to study the dental pulp. During decalcification, enamel is almost completely removed as it is composed of 96% inorganic component. The tissue becomes soft enough to be sent for routine processing and sectioning as described earlier. Hard tissues such as the bone, cementum and dentin can also be studied by subjecting the tissues to controlled decalcification.

After extraction of the tooth, a hole is drilled in the crown, or the apical one-third of the root is cut, to allow the fixative to flow inside. Ten percent neutral buffered formalin is used as the fixative for a minimum of 24 hours.

Then the tooth is kept in the decalcification solution, which removes the inorganic content from it. Strong or weak acids are chosen depending on the tissue to be decalcified, time availability and other such factors. Generally, *5% nitric acid* is used for the decalcification of the tooth. The acid solution is changed everyday and the tooth is tested for the completion of decalcification. The tooth becomes soft and yellowish and allows a pin to enter easily right up to the centre when it is completely decalcified.

After decalcification, the tissue is washed thoroughly in running tap water overnight. It is subjected to routine tissue processing steps such as dehydration, clearing, embedding,

sectioning and staining as discussed in the previous section.

Ground Sections

In addition to decalcification, ground sections are also used to study hard tissues such as bone and teeth. Enamel present in the teeth can be studied only by ground sections as it is lost in the decalcification procedure. In this method, the tooth or bone is directly ground into thin sections without being subjected to the decalcification process so that they can be studied microscopically. This technique is very useful to study the histology of enamel, which is not possible in decalcification, as enamel is lost during decalcification.

After extraction, the tooth is preserved in a liquid medium till further use. *Formalin, saline, distilled water* or *dilute hydrogen peroxide* can be used for this purpose.

There are various techniques to grind the tooth into thin sections. Initially, the tooth is cut longitudinally into two halves using a micromotor and diamond disc. Further thinning of the tooth can be brought about by using a laboratory lathe with coarse and fine abrasive stones or by rubbing the sectioned tooth against Arkansas stone or against Black emery papers of grades 600, 400 or 200. The sections are reduced till they are approximately 50 μm thin. This thin section is lifted using a camel's hair brush and floated on water. The section is carefully lifted onto a glass slide where a drop of mountant is already placed. Another drop of the mountant such as *DPX* or *Canada balsam* is added onto the section and covered with a coverslip. Now the ground section is ready for viewing.

Frozen Sections

Frozen sections are prepared where it is required to view the tissue urgently. After obtaining the tissue, it is frozen using either a freezing microtome or an equipment called *cryostat*. The chamber in the equipment has a temperature as low as –40°C. The tissue is kept inside this chamber. The water within the tissue solidifies and acts as the embedding medium. Sections of thickness 10–15 μm are cut and stained. These sections can be viewed immediately under the microscope.

Applied Histology

In frozen sections, the nucleus are usually bigger in size than the same tissue viewed under microscope after conventional preparation.

ADDITIONAL READING

Natural Alternatives to Fixatives and Stains

A tissue specimen needs to be processed and stained to aid visualization in a microscope. Processing and staining involve use of hazardous chemicals. Exposure to chemicals causes health hazards to the laboratory technicians, pathologists and scientists working in the laboratory.

Natural and biofriendly alternatives such as honey, sugar syrup and jaggery syrup have been found to have the ability to fix tissues. Essential oils extracted from different parts of the plant such as leaves, stems, flowers, bark and roots such as coconut oil, cedarwood oil and bleached palm oil can be used as clearing agents. Naturally occurring staining agents such as carmine, carcade, henna, wing fruit and china rose have been found to be effective. The non-hazardous quality of these natural extracts have opened up new avenues in the field of tissue processing (excerpts from Ramamoorthy et al. 2016).

Optic Imaging of Tissues Without Processing

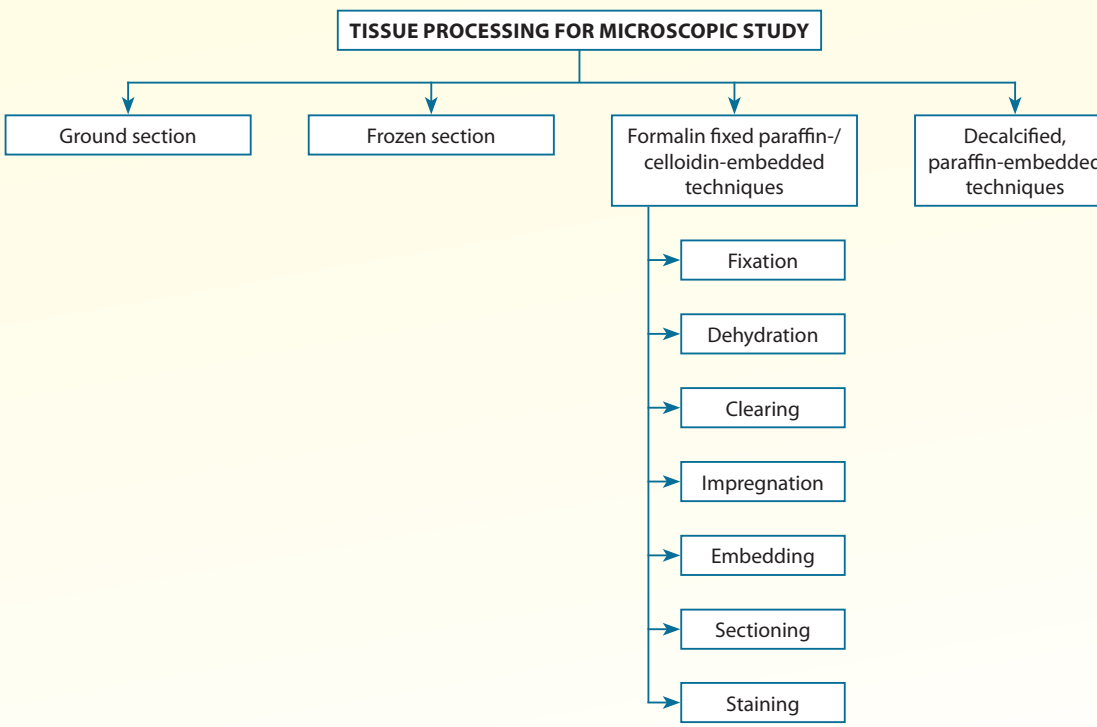
Alternative options of visualizing the structure of living cells and tissues without the need for tissue processing such as fixation or staining are the need of the hour. Light scattering spectroscopic imaging is one such novel optical technology developed to probe the structure of cells and tissues. The mechanism behind this system is to enhance single backscattering from cell components such as nuclei and other organelles and differentiate this component from multiply scattered light. Quantitative assessment of the spectrum of the single backscattering provides quantitative information about cell morphology such as nuclear size, degree of pleomorphism, degree of hyperchromasia, amount of

chromatin, nuclear and cytoplasmic sub-micron texture, etc. Imaging in light scattering spectroscopy converts each pixel to a two-dimensional image. It is represented by a spectrum of backscattered light and a map of histological properties over wide areas of tissue. Alteration of cell and nuclear morphology is commonly seen in pre-cancer and cancer. Optically accessible organs can be directly visualized for changes in the epithelia in such conditions. Fourier transform infrared (FTIR) microspectroscopy is another emerging technique which helps in quantification of the biochemical analysis of tissues and cellular materials (excerpts from Backman 2002 and Zohdi et al. 2015).

Key Points

1. The steps in tissue processing are fixation, dehydration, clearing, impregnation, embedding, sectioning and staining.
2. Ten percent neutral buffered formalin is the most commonly used fixative.
3. The volume of the fixative should be 10–15 times more than that of the tissue to be processed.
4. Dehydration is done by using ascending grades of alcohol.
5. Xylene is used as the clearing agent.
6. Paraffin wax is routinely used as the embedding medium.
7. The instrument used to cut thin sections is called microtome. These sections are 3–5 μm thin.
8. Ground sections are used for the study of bone and enamel. The thickness of these sections is about 50 μm.
9. When the tissue is to be viewed under the microscope for immediate diagnosis, frozen sections are used.

Mind Map



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Multiple Choice Questions

1. Which of the following is the correct order of steps in tissue processing?
   (a) Fixation, embedding, clearing, dehydration
   (b) Fixation, dehydration, clearing, embedding
   (c) Fixation, clearing, embedding, dehydration
   (d) Fixation, dehydration, embedding, clearing
2. The most commonly used fixative is
   (a) 10% neutral buffered formalin
   (b) 20% neutral buffered formalin
   (c) 30% neutral buffered formalin
   (d) 40% neutral buffered formalin
3. Which of the following is a fixative?
   (a) DPX
   (b) Formalin
   (c) Paraffin wax
   (d) Xylene
4. The minimum volume of fixative required is
   (a) 5 times more than the volume of the tissue
   (b) 15 times more than the volume of the tissue
   (c) 45 times more than the volume of the tissue
   (d) 100 times more than the volume of the tissue
5. Which of the following is a clearing agent?
   (a) DPX
   (b) Formalin
   (c) Paraffin wax
   (d) Xylene
6. Which of the following is an embedding medium?
   (a) DPX
   (b) Formalin
   (c) Paraffin wax
   (d) Xylene
7. Which of the following is a mountant?
   (a) DPX
   (b) Formalin
   (c) Paraffin wax
   (d) Xylene
8. The instrument used to obtain thin sections is
   (a) Cryostat
   (b) Microscope
   (c) Microtome
   (d) Tissue floatation bath

9. The thickness of the section obtained in routine tissue processing is
   (a) 3–5 μm
   (b) 13–15 μm
   (c) 23–25 μm
   (d) 33–35 μm
10. Choose the decalcifying agent:
   (a) Alcohol
   (b) Formalin
   (c) Nitric acid
   (d) Xylene
11. The thickness of a ground section is
   (a) 10 μm
   (b) 50 μm
   (c) 100 μm
   (d) 150 μm
12. The instrument used to obtain frozen sections is
   (a) Cryostat
   (b) Microscope
   (c) Microtome
   (d) Tissue floatation bath
13. The thickness of a frozen section is
   (a) 10–15 μm
   (b) 100–150 μm
   (c) 10–15 mm
   (d) 100–150 mm



CHAPTER 48

Histochemistry of Oral Tissues

Overview

The study of qualitative and quantitative assessment of chemicals within cells and tissues is called histochemistry. By using specific chemical tests to identify and pinpoint the location of chemicals within the tissues, it helps in investigating tissue structure and components. Several specialized subdisciplines of histochemistry include histochemical identification of carbohydrates, lipids, nucleic acids, proteins, enzymes, pigments and minerals; each has its own applications. Histochemical identification of carbohydrates include tests such as periodic acid–Schiff (PAS) technique, azure A, alcian blue, toluidine blue and mucicarmine technique. Lipids can be identified using stains such as Sudan III and IV, Oil red O and Sudan black B. ninhydrin-Schiff method, Millon reaction and performic acid–alcian blue method are commonly used in protein identification while Feulgen reaction, methyl green-pyronin technique and acridine orange stains are used in nucleic acids localization. Enzyme histochemistry is a branch of histochemistry wherein various enzymes activities are localized. Histochemical techniques can be applied for determining the activity of enzymes such as acid phosphatase, adenosine triphosphatase (ATPase), esterase, aminopeptidase, cytochrome oxidases, succinate dehydrogenase and glucose-6-phosphate dehydrogenase (G6PD) by which modified activities of those enzymes commonly encountered in various physiological and pathological circumstances can be evaluated.

INTRODUCTION

Histochemistry is the study of qualitative and quantitative assessment of chemicals within cells and tissues. It is a method of investigating tissue structure and components and uses specific chemical tests to identify and pinpoint the location of chemicals within the tissues. Of the several specialized sub-disciplines of histochemistry, each has its own applications. These include histochemical identification of carbohydrates, lipids, nucleic acids, proteins, enzymes, pigments and minerals.

Histochemistry may be considered a modified form of biochemistry. Biochemistry determines the type and quantity of material present in the tissue whereas histochemistry identifies the position and distribution of the materials.

OBJECTIVES

The objectives of histochemistry are as follows:

1. Must produce a coloured final product to make it clearly visible under the microscope
2. Must produce a material that is insoluble so that its position in the tissue can be located accurately
3. Should not allow the material under investigation to separate from its environment and should exactly pinpoint its position in the cell
4. Should be highly sensitive and must accurately detect the presence of material within each cell

STRUCTURE AND COMPOSITION OF ORAL TISSUES

Oral structures are basically composed of connective tissue, epithelial linings and associated glandular structures. It is important to have a basic knowledge of the structure and chemical nature of these tissues to understand the associated biological problems.

Connective Tissue

Connective tissue is one of the major tissue types found throughout the body, the main function of which is to connect together and provide support to other tissues of the body. It is derived from the mesenchyme (mesoderm, which separates the ectoderm and the endoderm).

Connective tissue usually consists of the following portions:

1. Cellular
2. Non-cellular or intercellular substance

The ratio of cells to intercellular substance may vary from one type of connective tissue to another based on its primary function. For example, bone, which provides strength and support, has only a few cells in the dense, rigid intercellular substance, whereas adipose tissue consists primarily of cellular portion.

Connective Tissue Cells

Connective tissue consists of a non-living framework (intercellular substance) in which cells function. The undifferentiated mesenchymal cells are the parent cells of the entire series of connective tissues, from which the different types of cells with different functions develop.

Fibroblasts The fibroblast is the predominant cell type in the connective tissue. It is responsible for the production of collagen fibres and the intercellular substance which binds the fibres together. The fibroblasts accumulate at the site of injury and secrete the intercellular substances. They play a major role in the repair process of the body and hence contribute to the developmental process, wound healing and inflammation.

Connective Tissue Cells of the Teeth Because the oral cavity has dentition, the connective tissue cells of the teeth need to be discussed. These include undifferentiated mesenchymal cells, fibroblasts and odontoblasts:

1. **Undifferentiated mesenchymal cells:** These cells are the primary cells in the pulp tissue. They are abundant in young pulp, but their numbers decrease as age advances. These are totipotent cells which may differentiate into odontoblasts, fibroblasts or macrophages when the need arises.
2. **Fibroblasts:** They are the most numerous cell type in the pulp tissue and are similar to fibroblasts anywhere else in the body. They aid in collagen fibre formation and degradation during the life of the tooth.
3. **Odontoblasts:** They are the second most prominent cells in the pulp. These cells reside adjacent to the predentin with their cell bodies in the pulp and their cell processes (odontoblastic processes) in the dentinal tubules. The number of odontoblasts corresponds to the number of dentinal tubules. Odontoblasts are end cells that have lost the ability to divide. The dead odontoblasts are replaced by cells which differentiate from the cell-rich zone. (For a detailed description, refer to Chapter 37.)

Intercellular Substance

The intercellular substance primarily consists of two components:

1. Amorphous or gel-type ground substance
2. Formed elements or fibrous portion (collagen, reticular and elastic fibres)

The nature of intercellular substance also varies according to its function. It may be extremely hard and dense as in the cortical bone or soft as in the soft tissues. The microscopic appearance is also varied, with some appearing fibrillar in form and some appearing completely homogenous.

Ground Substance This shows a mixture of macromolecules which interact with cells and fibres in the matrix. The ground substance is composed of acid mucopolysaccharides and protein polysaccharide compounds (proteoglycans and glycoproteins):

1. **Proteoglycans:** Proteoglycans are made up of a protein core attached to a large number of glycosaminoglycan (GAG) chains. The unsulphated GAGs such as hyaluronic acid are predominant in the loose connective tissue. Hyaluronic acid is responsible for transport and diffusion of metabolic substances because of its high capacity to bind water. Sulphated GAGs present in proteoglycans may be chondroitin sulphate and keratan sulphate. Chondroitin sulphate, responsible for the supportive and plastic nature of tissue, is predominantly seen in the cartilage. Keratan sulphate is

found in bones and cartilage, where it acts as a cushioning agent to absorb mechanical shock.

2. **Glycoproteins:** A few of the well-known glycoproteins include fibronectin, laminin, chondronectin and osteonectin. In comparison with proteoglycans, these contain fewer associated carbohydrate groups. Fibronectin is secreted by fibroblasts, whereas chondronectin and osteonectin are secreted by chondrocytes and osteoblasts, respectively. Laminin is present in the basement membrane and is produced by epithelial cells. Glycoproteins help in maintaining normal cell morphology and the attachment of cells to the extracellular collagen.

Formed or Fibrous Intercellular Substances

1. **Collagen fibres:** These are the most common fibre type of the intercellular substance and are found in almost all sites of the body. Collagen fibres are present either as individual fibres as in loose areolar tissue or as large bundles of fibres as in tendon, which gives its tensile strength. Four major types of collagen and several minor types of collagen fibres have been characterized. The production of different types is strictly under genetic control and each type varies in its amino acid composition. Collagen is synthesized as pre-procollagen polypeptide chain and later undergoes post-translational changes and results in the characteristic triple helix structure.
2. **Reticular fibres:** These are fine, delicate fibres found connected to coarser and stronger collagenous fibres. They are arranged in a three-dimensional network to provide the bulk of the supporting framework of more cellular organs.
3. **Elastic fibres:** These are produced by fibroblasts and smooth muscle cells present in the walls of blood vessels. The elastic fibre system consists of three different fibres: oxytalan, elaunin and elastin. These three fibres correspond to consecutive stages of normal elastogenesis, where oxytalan are immature fibres, elaunin are developed fibres and elastin are the more mature fibres.

Epithelial Tissues and Their Derivatives

The oral cavity is composed of three different types of epithelium. These include the oral epithelium (lining epithelium), glandular epithelium (salivary glands) and odontogenic epithelium (epithelium concerned with tooth formation). The salivary glands produce mucins. These mucins, along with glycogen, constitute the major portion of the carbohydrates. Mucins have recently been named as *glycoconjugates* and are subdivided into *proteoglycans* and *glycoproteins*. There are different types of mucins, namely the strongly sulphated mucin, weakly sulphated mucin, carboxylated mucin, sulphated sialomucin and neutral mucins. These mucins can be found singly or in combinations in the tissues.

HISTOCHEMICAL TECHNIQUES

Fixation

Human cells and tissues are alive in the body because they are connected to the blood stream, a constant source of oxygen and nutrients. If the blood supply is cut off or if the tissues are removed from the body, they die because of lack of oxygen. In histology, the cells are observed exactly the way they are in the human body. To achieve this, the tissues have to be stabilized immediately after removal from the body. This is done by fixation. Fixation is a process which *attempts to preserve the tissues in a lifelike condition and prevent autolysis of cells*. It is done in optimum conditions such as 40°C temperature, controlled pH of the fixative and optimum volume of the fixative solution.

Aims of Fixation

1. Preserve tissues in as lifelike a manner as possible
2. Once the tissues are removed from the body, prevent their autolysis and putrefaction
3. Ensure that tissues once fixed do not change shape or volume during subsequent staining procedures

Fixatives

A wide variety of materials could be used as fixatives, and the choice of fixative depends on the type of investigation carried out. Fixatives are broadly divided into three main groups: microanatomical, cytological and histochemical.

1. **Microanatomical:** These are used to preserve the anatomy of tissue, with the correct

relationship of the tissue layers with each other intact. The fixatives of this group are as follows:
   (a) Buffered formalin
   (b) Formol calcium
   (c) Alcoholic formaldehyde
   (d) Glutaraldehyde
   (e) Acrolein
   (f) Zenker's fluid
2. **Cytological:** The following fixatives are used when preservation of intracellular structures and inclusions is required:
   (a) Carnoy's fluid
   (b) Clarke's fluid
   (c) Flemming's fluid
   (d) Regaud's fluid
   (e) Muller's fluid
3. **Histochemical:** These fixatives are the choice when histochemical techniques are to be employed (to demonstrate a particular substance). A good histochemical fixative should satisfy the objectives of histochemistry listed in the beginning of the chapter. Examples of histochemical fixatives are as follows:
   (a) Formol saline
   (b) Cold acetone
   (c) Absolute alcohol
   (d) Vapour fixatives (formaldehyde, acetaldehyde and glutaraldehyde in vapour forms)

Specific Histochemical Methods

The histochemical methods of study of oral tissues are broadly categorized into three groups as follows:
1. Glycogen, glycoprotein and proteoglycan methods
2. Protein and lipid methods
3. Enzyme methods

Glycogen, Glycoprotein and Proteoglycan

1. **Periodic acid–Schiff (PAS) technique:** The PAS technique is most frequently used to demonstrate carbohydrate groups. The basement membrane is specifically stained by PAS and hence it is useful in cancer diagnosis to delineate and read basement membrane continuity microscopically.
2. The reaction involves a two-step procedure consisting of the following (**Box 48.1**):
   (a) *Oxidation with periodic acid:* Oxidation of carbohydrates with periodic acid converts the carbohydrates to aldehyde. Periodic acid reacts with the glycol group of the sugar and produces aldehydes.
   (b) *Reaction with Schiff's reagent:* The aldehydes produced react with Schiff's reagent to produce a red/purple-coloured product. Schiff's reagent is sensitive for aldehydes and stains them red/purple colour. Schiff's reagent consists of basic fuchsin (pararosaniline dye) that has been decolourized with sulphurous acid. Once this reagent is mixed with the tissue, there is rearrangement of the chemical groups within the tissues and the final coloured product is produced.

Box 48.1 Periodic Acid–Schiff (PAS) Technique

Periodic acid solution

Periodic acid	1 g
Distilled water	200 mL

Schiff's reagent

Dissolve 1 gram of basic fuchsin in 200 mL of boiling distilled water. Allow the solution to cool to 50°C and add 2 gram potassium metabisulphite while mixing. Allow to cool to room temperature and add 2 mL concentrated hydrochloric acid. Mix, then add 2 grams of activated charcoal and leave overnight in a dark room. Filter and store the solution in a dark container at 4°C.

Procedure

1. Dewax sections and bring to distilled water.
2. Treat with periodic acid for 5–10 minutes.
3. Wash with several changes of distilled water.
4. Treat with Schiff's solution for 15 minutes.
5. Wash in running tap water for 5–10 minutes.
6. Stain with Harris haematoxylin for nuclear staining and differentiate with acid alcohol.
7. Wash in water.
8. Rinse in absolute alcohol.
9. Clear in xylene and mount.

Results

- *Glycogen and other PAS positive substances*: Magenta/bright red (glycogen in diastase-treated sections will not stain)
- *Nuclei*: Blue
- *Other tissue constituents*: Yellow

3. **Demonstration of proteoglycans:** Proteoglycans (mucins) can be demonstrated by various techniques using the following:
   (a) Azure A
   (b) Alcian blue
   (c) Toluidine blue (metachromasia)
   (d) Mucicarmine technique

Applications in Oral Tissues

1. **Hard tissues:** In studies involving the ground substance of teeth and bones, the most frequently used method is the PAS technique, which demonstrates the carbohydrate groups as well as the glycoprotein complexes. Developing bone and dentin stain intensely with the PAS technique, whereas mature bone and dentin exhibit very little activity. Although enamel lamella stains intensely with PAS, enamel matrix is usually non-reactive.
2. **Soft tissues:** The best method to demonstrate glycogen is the PAS technique along with enzyme digestion techniques. Epithelial glycogen is readily demonstrated by the PAS method because it increases during inflammation and repair.

Salivary mucins form a protective covering over the oral mucous membranes. Mucicarmine technique is used to demonstrate mucins and helps in differentiating salivary gland tumours from other tumours. Neutral mucins and weakly sulphated mucins can also be demonstrated by the PAS technique.

Applied Histology

Glycogen, Glycoproteins and Proteoglycans

In a wide variety of conditions, glycogen is significant in the diagnosis of certain tumours. Demonstration of excess glycogen stored in tissues is also important in the diagnosis of glycogen storage disorders, for example Von Gierke disease that results from the deficiency of the glucose-6-phosphatase enzyme. The PAS technique helps in the diagnosis of various conditions. PAS positivity in the basement zone in lupus erythematosus differentiates the condition from lichen planus.

Mucin stains are useful in differentiating a salivary gland tumour from odontogenic tumours and other non-glandular epithelium tumours. Within salivary gland tumours, mucin stains differentiate between mucoepidermoid carcinoma and other salivary gland malignancies as well as between the varying grades of mucoepidermoid carcinoma.

A wide variety of fungi infect humans and most of these contain mucopolysaccharides. The diagnosis and treatment of these infections is based on the demonstration of these organisms in the tissues. The most common opportunistic infection, candidiasis, requires demonstration of candida in the tissues to be treated. Mucin stains are helpful in demonstrating the organism. In the human oral cavity, diagnosis of other infections such as actinomycosis, blastomycosis and histoplasmosis is often possible only with the use of special histochemical stains.

Lipids

Since lipids are usually lost during routine tissue processing, histochemistry of lipids frequently requires the use of *frozen* or *freeze-dried sections,* where the tissues are frozen immediately in a cryostat and sections are made for histochemical evaluation. Total fat content can be evaluated by using fat stains or fat colourant dyes like Sudan dye. These dyes should be used along with an organic solvent for it to penetrate the fat for staining. Various Sudan dyes are used such as Sudan III, Sudan IV, Oil red O and Sudan black B. Phospholipids can be stained by Sudan black B and malachite green aldehyde.

Applications in Oral Tissues

1. **Hard tissues:** Very low amounts of lipids have been demonstrated in the odontoblastic processes and enamel rod sheaths. Phospholipids are also demonstrated in the cell membranes of a developing tooth.
2. **Soft tissues:** Permeability of the oral mucosa may be partly attributed to the lipid content. In this context, the palate shows a greater permeability compared with the skin because of lower proportions of fatty acids and cholesterol.

Applied Histology

Lipids

Histochemical demonstration of lipids is important in differentiating tumours that arise from fat cells (lipoma and liposarcoma) and other tumours.

Proteins

Proteins make up the major constituent of cells and tissues and are basically made up of amino acids linked by peptide bonds. Proteins can occur either alone in tissues or conjugated with other substances to form conjugated proteins (lipoproteins, mucoproteins and nucleoproteins). The demonstration of conjugated proteins is essentially the demonstration of either the lipids or the mucopolysaccharides. The ninhydrin-Schiff method, the Millon reaction and the performic acid–alcian blue method can be used to demonstrate proteins.

Applications in Oral Tissues

1. **Hard tissues:** Protein identification methods such as the ninhydrin-Schiff method are used in the study of dental caries and bone and dentin resorption. Enamel proteins, amelogenins and enamelins can also be identified using the aforementioned methods.
2. **Soft tissues:** Keratinization is one of the important characteristics of oral epithelium. Under normal circumstances, it occurs in certain areas of the epithelium. But in certain pathologic conditions, it occurs anywhere in the mouth. This abnormal keratinization can be demonstrated by appropriate protein stains.

Nucleic Acids

The two nucleic acids are the deoxyribonucleic acid (DNA), found in the nucleus of the cell, and the ribonucleic acid (RNA), which is located in the cytoplasm of cells, mainly the ribosomes. Nucleoproteins refer to the combination of basic proteins with the nucleic acids. For histochemical techniques involving nucleic acids, tissues should be fixed with a rapid fixative which contains both alcoholic and acidic fixative such as Carnoy's solution. Nucleic acids can be demonstrated by the Feulgen reaction, methyl green-pyronin technique and fluorescent methods using acridine orange.

Applications in Oral Tissues

1. **Hard tissues:** Nucleic acid methods have been used to study DNA and RNA synthesis in bone disorders.
2. **Soft tissues:** Nucleic acid synthesis takes place rapidly in actively dividing cells; thus, the basal layers of the epithelium show more intense staining with nuclear stains when compared with the superficial cells of the epithelium.

Enzymes

An enzyme is a substance that initiates or accelerates a chemical reaction; the substances upon which the enzyme acts are referred to as substrates.

The demonstration of enzymes is dependent on the effect they have on the substrate. An insoluble product, referred to as *primary reaction product* (PRP), has to be produced to see the activity of the enzyme on the substrate. Subsequently, this final product, referred to as final reaction product (FRP), has to be coloured to visualize the effect.

Alkaline phosphatases are identified by the *Gomori method*. This method is based on the action of the enzyme (at pH 9) on a substrate containing organic phosphate, in the presence of calcium ions, to form calcium phosphate in situ. Then the tissue of interest is removed and fixed. This tissue is treated with cobalt nitrate which reacts with the calcium phosphate present in the tissue to form cobalt phosphate. This in turn reacts with ammonium sulphide to form cobalt sulphide which is black in colour.

Phosphatase can also be demonstrated by *azo-coupling technique*. In the Gomori method, the calcium phosphate, which is produced in the tissue, may sometimes diffuse to the surrounding tissues and as a result give false localization. To overcome this difficulty, azocoupling techniques are used which give precise microscopic localization of phosphatases. *Glucose-6-phosphatase* enzyme can be demonstrated by Wachstein and Meisel's method.

Other enzymes which have been demonstrated include acid phosphatase, ATPase, esterase, aminopeptidase, cytochrome oxidases and succinate dehydrogenase.

Applications in Oral Tissues

1. **Hard tissues:** Various enzymes have been demonstrated in the hard tissues by histochemical techniques.

   Alkaline phosphatase has been implicated in the synthesis of organic matrix and mineralization and associated with osteogenesis and dentinogenesis. Hence, alkaline phosphatase activity is often used as a cytochemical marker

to differentiate between preosteoblasts and fibroblasts.

(a) Intense acid phosphatase activity is found in osteoclasts and odontoclasts. ATPase location differs with stages of ameloblast lifecycle. In early phases, ATPase is located at basolateral membrane while in mineralization phase it is located at distolateral surface. This change in location is related to enamel mineralization.

2. **Soft tissues:** Alkaline phosphatase activity has been demonstrated in the basement membranes of salivary gland acini and the gingiva. This enzyme has also been implicated in the process of keratinization.

(a) Esterase activity is seen in salivary glands ducts, serous demilunes, taste buds and mast cells. Cytochrome oxidase activity is usually low in normal gingiva which tends to increase in chronic gingivitis. Cytochrome oxidase activity is also noted in the salivary ductal system. Glucose 6 phosphate dehydrogenase enzyme levels are markedly increased dysplastic and malignant cells.

ADDITIONAL READING

Histochemistry Through Enzyme Histochemistry to Immunohistochemistry 'The Path'

The process of histochemistry is to identify chemical components in a specimen. Enzyme histochemistry is used to locate specific enzyme activities in a specimen so as to aid in confirmatory diagnosis. *Immunohistochemistry* is an advancement of histochemistry and the most useful diagnostic tool in the recent era. The immunohistochemistry technique helps in precise identification of tissue antigens such as amino acids, proteins, infectious agents and specific cellular populations through antigen–antibody reactions. The technique comprises

Specimen fixation and tissue processing → antigen retrieval → non-specific site black → endogenous peroxidase black → primary antibody incubation → employment of systems of detection → revealing and counterstaining and slide mounting → interpretation and quantification of the element of interest

Applications and Importance

The immunohistochemical reactions can be used in different situations within research. The most important are as follows:

1. Histogenetic diagnosis of morphologically non-differentiated neoplasias
2. Subtyping of neoplasias (such as lymphomas)
3. Characterization of the primary site of malignancies
4. In research for prognostic factors and therapeutic indications of some diseases
5. Identification of structures, organisms and materials secreted by cells

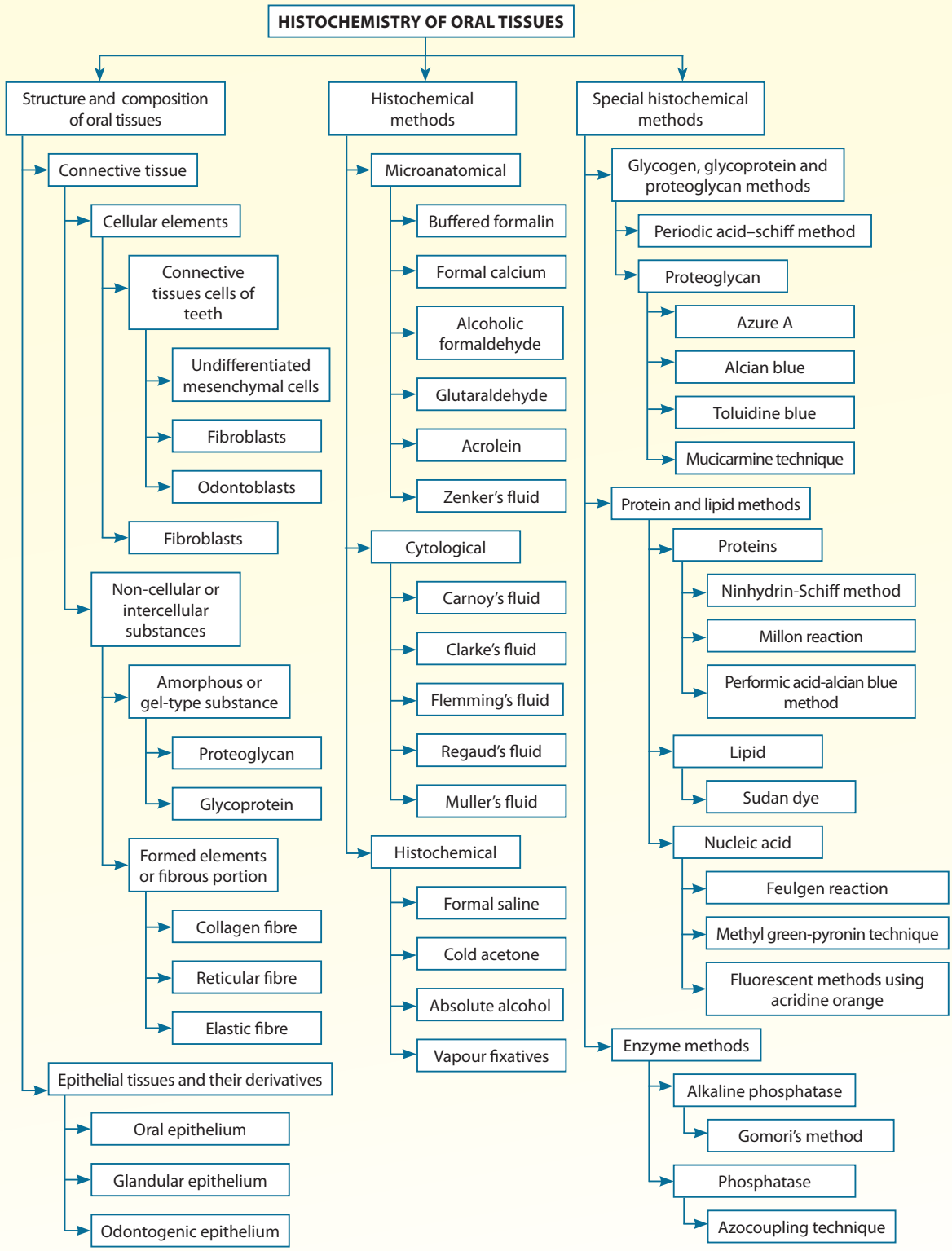
Limitations

1. Technical expertise required to perform the procedure
2. Reaction bias
3. Interpretation bias

Key Points

1. Histochemistry is the study of assessment of chemicals within cells and tissues.
2. Fixation is a process by which there is an attempt to preserve the tissues in a lifelike condition and prevent autolysis of cells.
3. Demonstration of carbohydrate groups is best done by the periodic acid–Schiff (PAS) technique.
4. The PAS technique is a two-step procedure involving (i) oxidation with periodic acid (which converts the glycol group in the carbohydrates to aldehydes) and (ii) treatment with Schiff's reagent which detects the aldehydes.
5. Mucins are elaborated by the salivary gland and demonstration of mucins is useful in differentiating salivary gland pathology from other disorders.

Mind Map


HISTOCHEMISTRY OF ORAL TISSUES
Structure and composition of oral tissues
Histochemical methods
Special histochemical methods
Connective tissue
Cellular elements
Connective tissues cells of teeth
Undifferentiated mesenchymal cells
Fibroblasts
Odontoblasts
Fibroblasts
Non-cellular or intercellular substances
Amorphous or gel-type substance
Proteoglycan
Glycoprotein
Formed elements or fibrous portion
Collagen fibre
Reticular fibre
Elastic fibre
Epithelial tissues and their derivatives
Oral epithelium
Glandular epithelium
Odontogenic epithelium
Microanatomical
Buffered formalin
Formal calcium
Alcoholic formaldehyde
Glutaraldehyde
Acrolein
Zenker's fluid
Cytological
Carnoy's fluid
Clarke's fluid
Flemming's fluid
Regaud's fluid
Muller's fluid
Histochemical
Formal saline
Cold acetone
Absolute alcohol
Vapour fixatives
Glycogen, glycoprotein and proteoglycan methods
Periodic acid–schiff method
Proteoglycan
Azure A
Alcian blue
Toluidine blue
Mucicarmine technique
Protein and lipid methods
Proteins
Ninhydrin-Schiff method
Millon reaction
Performic acid-alcian blue method
Lipid
Sudan dye
Nucleic acid
Feulgen reaction
Methyl green-pyronin technique
Fluorescent methods using acridine orange
Enzyme methods
Alkaline phosphatase
Gomori's method
Phosphatase
Azocoupling technique

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2. Culling CFA. Handbook of Histopathological and Histochemical Techniques. 3rd ed. London: Butterworth & Co; 1974.
3. Kumar GS, editor. Orban's Oral Histology and Embryology. 12th ed. New Delhi: Elsevier India; 2009.
4. Matos LL, Trufelli DC, de Matos MG, da Silva Pinhal MA. Immunohistochemistry as an important tool in biomarkers detection and clinical practice. Biomark Insights. 2010;5:9–20.

Multiple Choice Questions

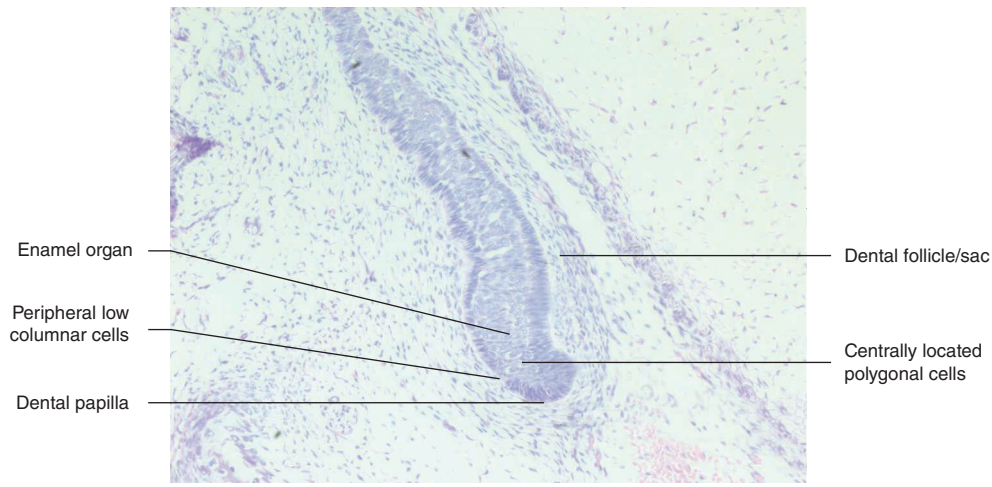
1. Which of the following is not true of histochemistry?
   (a) Must produce a coloured final product
   (b) Should allow the material to separate from its environment
   (c) Should produce a material that is insoluble
   (d) Should be highly sensitive
2. The foundation for any histochemical technique lies in
   (a) Fixation
   (b) Clearing
   (c) Dehydration
   (d) Embedding
3. Which of the following is an aim of fixation?
   (a) Preserve tissues in a lifelike manner
   (b) Prevent autolysis and putrefaction
   (c) Prevent change in shape or volume of tissues
   (d) All of the above
4. The most commonly used fixative is
   (a) 10% neutral buffered formalin
   (b) 20% neutral buffered formalin
   (c) 30% neutral buffered formalin
   (d) 40% neutral buffered formalin
5. The best method to demonstrate carbohydrate group is
   (a) Feulgen reaction
   (b) PAS technique
   (c) Toluidine blue
   (d) Alcian blue
6. Fixation for demonstration of lipids should be done by
   (a) Formaldehyde
   (b) Carnoy's solution
   (c) Freeze drying
   (d) Formol calcium
7. The fixative used for demonstration of nucleic acid is
   (a) Acrolein
   (b) Glutaraldehyde
   (c) Formaldehyde
   (d) Carnoy's solution
8. Demonstration of nucleic acids is done by
   (a) Sudan black B
   (b) Feulgen technique
   (c) PAS technique
   (d) Mucicarmine method

Appendix

Microscopic Slides for Practical Examination

Bud Stage

1. The bud stage is the first stage of tooth development.
2. In this stage, the bud-shaped enamel organ consists of peripherally located low columnar cells and centrally located polygonal cells.
3. Condensed ectomesenchymal tissue present underneath the enamel organ is the dental papilla.
4. Condensed ectomesenchymal tissue surrounding the enamel organ and the dental papilla is the dental follicle/sac.

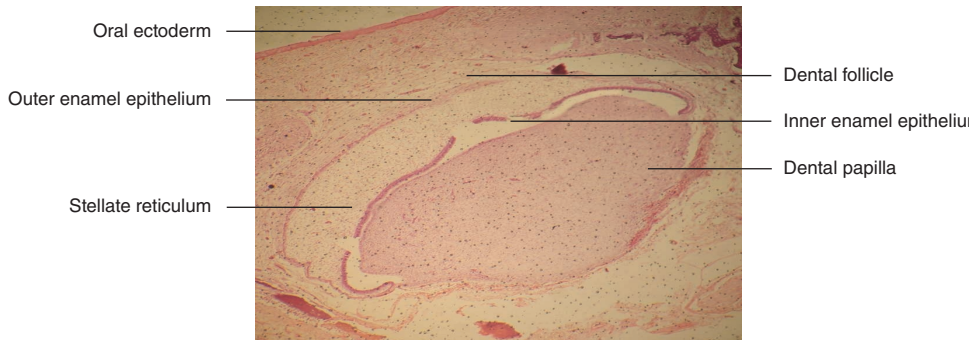


Bud stage (haematoxylin and eosin, 20X)

Cap Stage

1. The cap stage of tooth development results from the unequal growth of the cells of the enamel organ followed by an invagination that develops at the deepest portion of the enamel organ.
2. The peripheral cuboidal cells lining the convexity of the cap are called *outer enamel epithelial cells*.
3. The cells lining the concavity of the cap are low columnar cells called *inner enamel epithelial cells*.

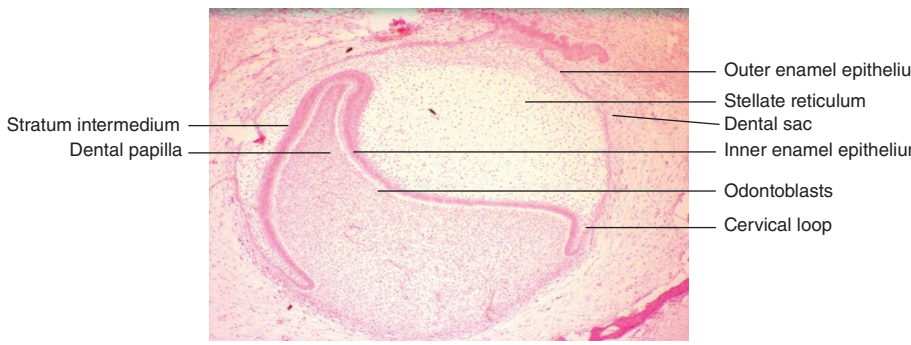
4. The star-shaped cells in between the inner and outer enamel epithelial cells are called *stellate reticulum cells,* which provide cushion-like consistency to the enamel organ and protect the inner enamel epithelial cells from external forces.



Cap stage (haematoxylin and eosin, 4X)

Early Bell Stage

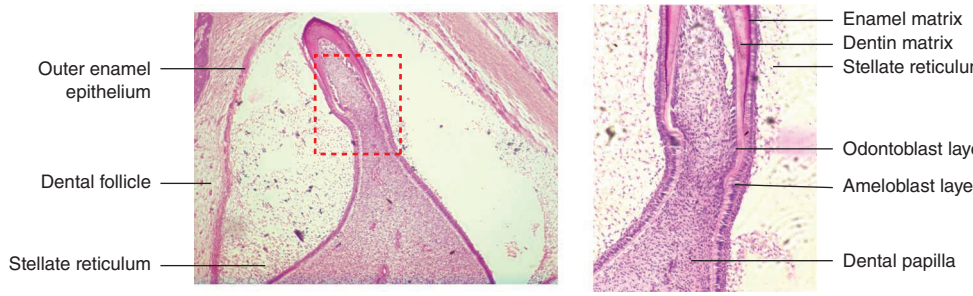
1. The enamel organ assumes the bell shape because of the deepening of the invagination and continued growth of the enamel organ.
2. Four types of epithelial cells are visible during the bell stage of development:
   (a) Inner enamel epithelial cells
   (b) Outer enamel epithelial cells
   (c) Stellate reticulum
   (d) Stratum intermedium
3. The stratum intermedium is made up of two to three rows of flattened cells and is situated between the inner enamel epithelium and stellate reticulum.
4. The junction between the inner and outer enamel epithelium is known as the *cervical loop*.
5. A layer of odontoblasts differentiates from the outermost cells of the dental papilla under the influence of the inner enamel epithelial cells.



Early bell stage (haematoxylin and eosin, 4X)

Advanced Bell Stage

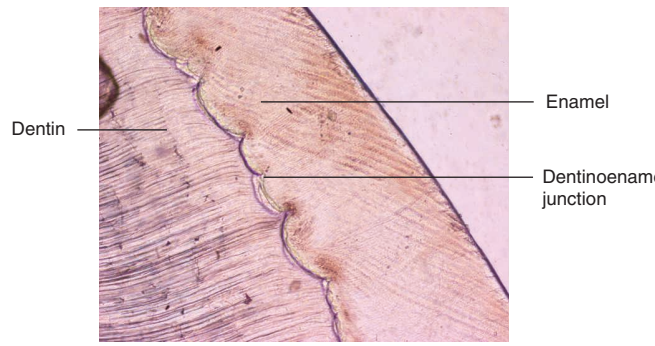
1. The advanced bell stage is characterized by the deposition and mineralization of the first layer of the dentin, followed by the enamel, along the future dentinoenamel junction.
2. In this stage, cells of the stellate reticulum start collapsing before the deposition of the hard tissue.
3. The cells of the outer enamel epithelium assume a flattened, low, cuboidal shape and the surface becomes folded.
4. Mineralization starts at the cuspal tip and proceeds cervically.
5. Hertwig's epithelial root sheath, which initiates root formation, starts as a downward growth from the point of junction of the outer and the inner enamel epithelial cells after dentin and enamel formation reaches the future cementoenamel junction.



Advanced bell stage: (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin, 4X; ii—haematoxylin and eosin, 10X).

Dentinoenamel Junction

1. The dentinoenamel junction (DEJ) is a scalloped border between the dentin and the enamel with the convexity of the scallop directed towards the dentin.
2. Its scalloped nature increases the surface area of contact between the enamel and the dentin and reduces the incidence of cracks developing along the DEJ.
3. The DEJ is less mineralized than the enamel and the dentin.



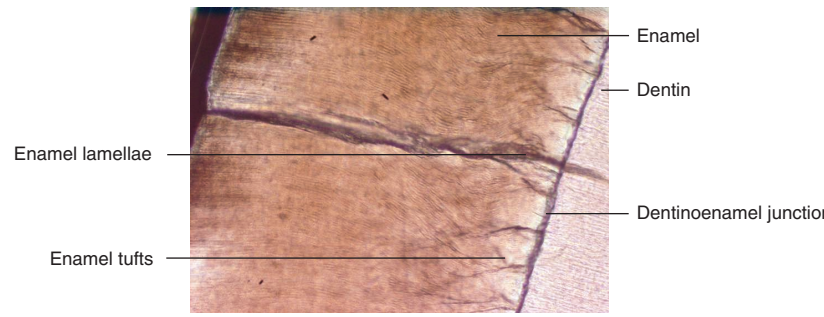
Dentinoenamel junction (ground section, 10X)

Enamel Lamellae

1. Enamel lamellae are hypocalcified leaf-like structures extending from the outer surface of enamel towards the DEJ.
2. These are formed due to stress occurring during enamel formation or due to cracks which develop in the enamel after eruption of teeth.
3. These contain salivary components and organic debris.
4. These are considered weak points in enamel and may allow passage of microorganisms which enter and initiate dental caries.

Enamel Tufts

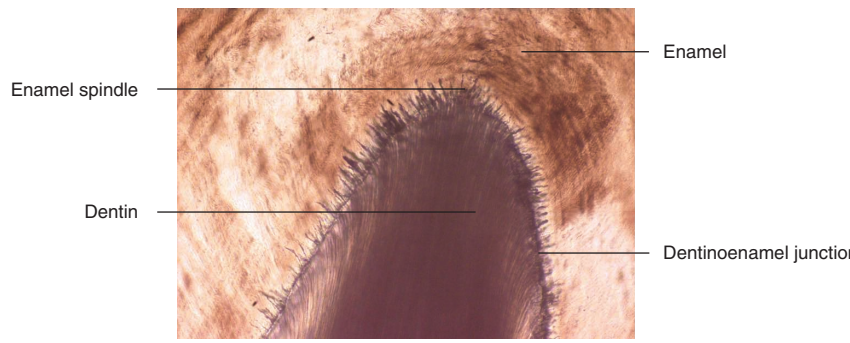
1. Enamel tufts are hypocalcified structures appearing like tufts of grass at the DEJ.
2. They extend up to one-thirds of the thickness of the enamel from the DEJ.
3. These are areas in mature enamel where the highest protein content is present.



Enamel lamellae and enamel tufts (ground section, 10X)

Enamel Spindles

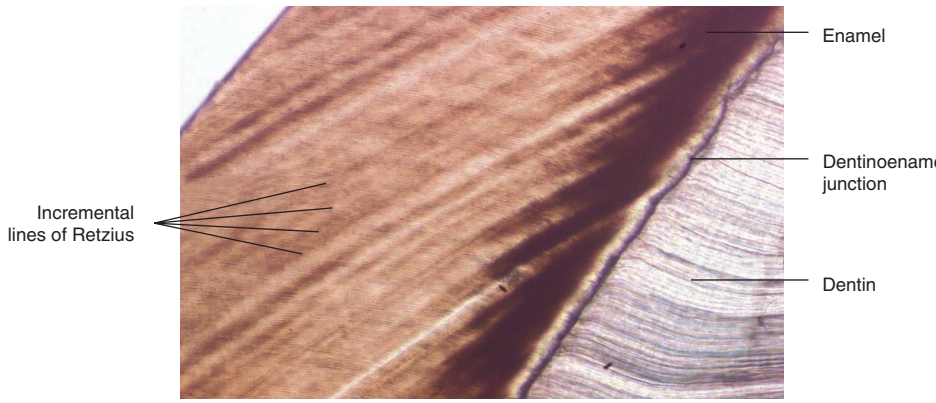
1. Enamel spindles are odontoblastic processes which pass across the DEJ into the enamel and become embedded in the enamel matrix.
2. These appear as dark spindle-shaped structures due to thickening of their ends.
3. These are more abundant in the cuspal region.
4. These are easily identifiable in longitudinal section due to their alignment.



Enamel spindles (ground section, 10X)

Incremental Lines of Retzius

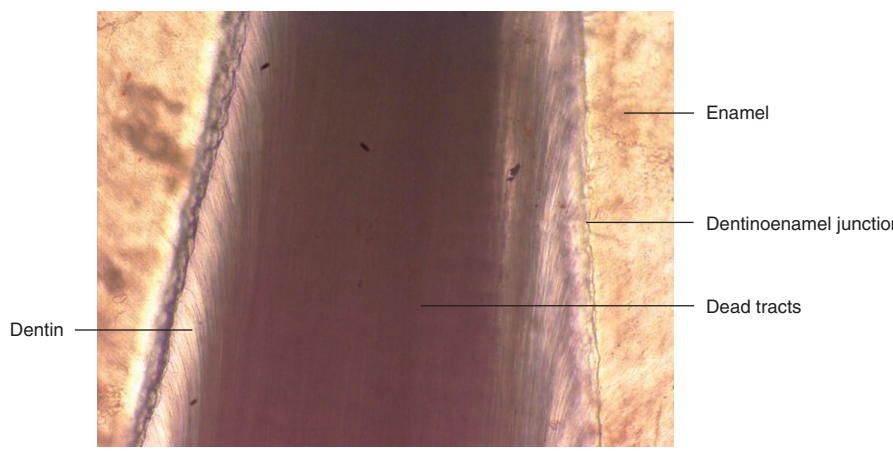
1. The incremental lines of Retzius indicate the incremental or rhythmic deposition of enamel.
2. These are seen as brownish lines that run obliquely across the enamel from DEJ to the outer surface of enamel.
3. The striae are wider apart in the middle portion of the enamel, while they are closer together and more numerous in the cervical enamel due to the slower deposition of enamel.
4. In cross-section, these appear as concentric rings.
5. The lines are less prominent in the enamel formed before birth and more pronounced in the enamel formed after birth.



Incremental lines of Retzius (ground section, 10X)

Dead Tracts

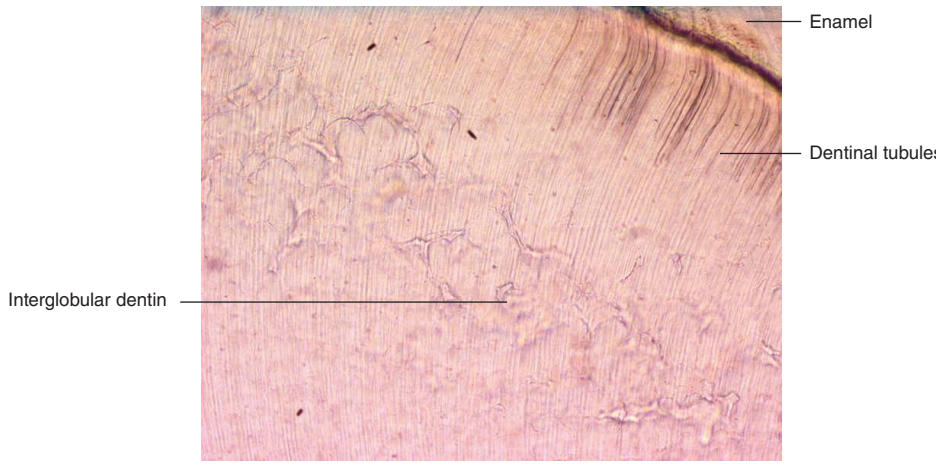
1. Injury resulting in death and subsequent loss of odontoblastic process leads to empty dentinal tubules which become filled with air. Such tubules form dead tracts.
2. In ground sections, these tubules appear dark in transmitted light and white in reflected light.
3. Because of the convergence of the dentinal tubules towards the pulp, dead tracts appear narrow at the pulpal end and broader at the cuspal or incisal ends.



Dead tracts (ground section, 10X)

Interglobular Dentin

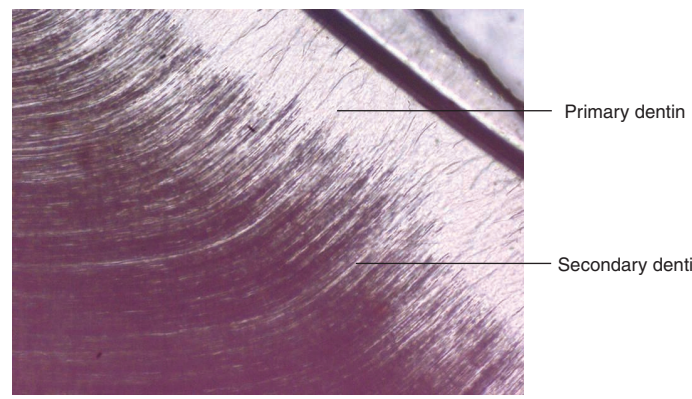
1. Interglobular dentin is a zone of hypocalcification or hypomineralization seen in circumpulpal dentin in the crown and occasionally below the Tomes' granular layer in root dentin.
2. In ground sections, this appears as dark, star-shaped structure under transmitted light.
3. This occurs due to the failure of globules of dentin to fuse into a homogenous mass during calcification.
4. The dentinal tubules pass uninterrupted through interglobular dentin.
5. Peritubular dentin is absent in those portions of the tubules passing through interglobular dentin.



Interglobular dentin (ground section, 10X)

Secondary Dentin

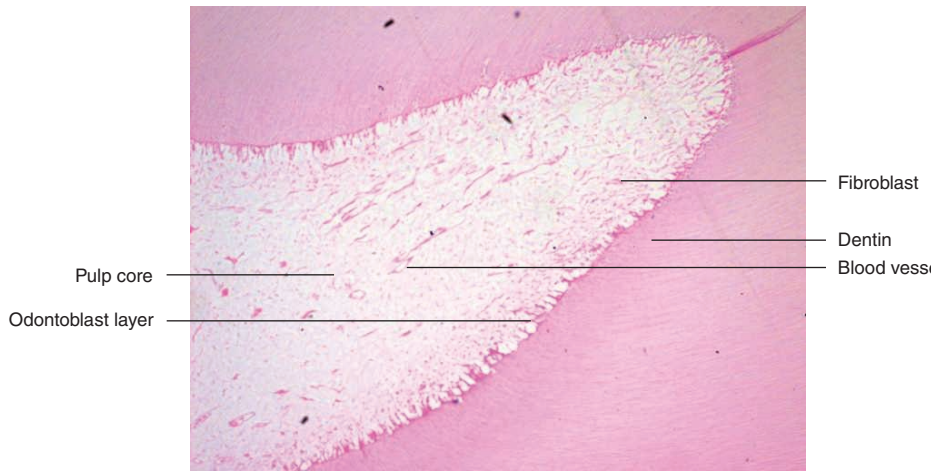
1. Secondary dentin is formed after root completion.
2. It is found bordering the pulp.
3. It contains lesser number of tubules when compared with that of primary dentin.
4. Tubules are more irregular when compared with that of primary dentin.
5. Continuous deposition of secondary dentin on the floor of the pulp leads to smaller pulp chambers and narrower root canals.



Primary and secondary dentin (ground section, 10X)

Pulp

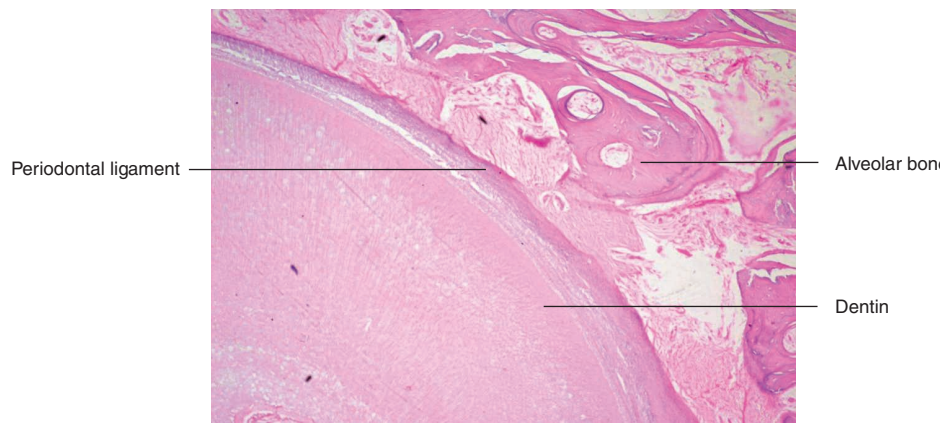
1. The pulp is a specialized connective tissue and a vital portion of the tooth.
2. It is composed of four zones: the peripheral odontogenic region composed of odontoblasts, the cell-free zone or zone of Weil, the cell-rich zone and the pulp core.
3. The cell-rich zone is composed of fibroblasts and undifferentiated mesenchymal cells.
4. The pulp is highly vascularized.



Pulp (haematoxylin and eosin, 4X)

Periodontal Ligament

1. Periodontal ligament is comprised of bundles of collagen fibres attached to the cementum on one side and the alveolar bone on the other side.
2. The portion of periodontal ligament fibres attached to cementum is called *Sharpey's fibres*.
3. The cellular component of the periodontal ligament consist of synthetic cells, resorptive cells, defence cells, undifferentiated mesenchymal cells and epithelial rests of Malassez.
4. This ligament helps anchor the tooth to the socket.



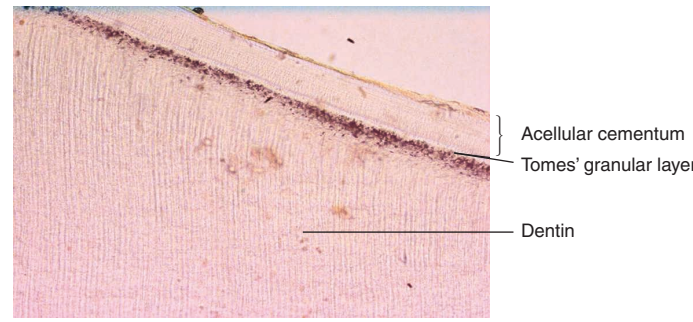
Periodontal ligament (haematoxylin and eosin, 10X)

Tomes' Granular Layer

1. Tomes' granular layer is a granular zone present in root dentin adjacent to the dentinocemental junction visible in ground sections.
2. This layer is formed by the terminal portions of the dentinal tubules in the root dentin which branch profusely, loop and coalesce, thereby giving rise to a granular appearance.
3. This layer increases in thickness from the cementoenamel junction towards the apex.

Acellular Cementum

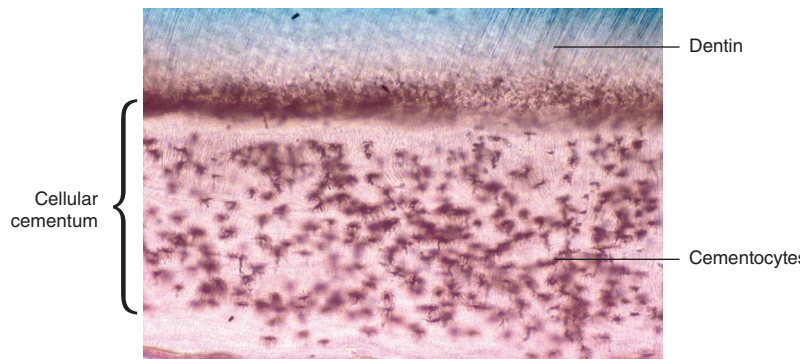
1. Acellular cementum appears as a structureless layer extending from the cementoenamel junction to the middle of the root.
2. Cells are absent since it is deposited at a rapid pace.
3. The incremental lines of Salter are present as dark lines parallel to the root surface.
4. Sharpey's fibres are more numerous in the acellular cementum than in the cellular cementum.



Acellular cementum and Tomes' granular layer (ground section, 10X)

Cellular Cementum

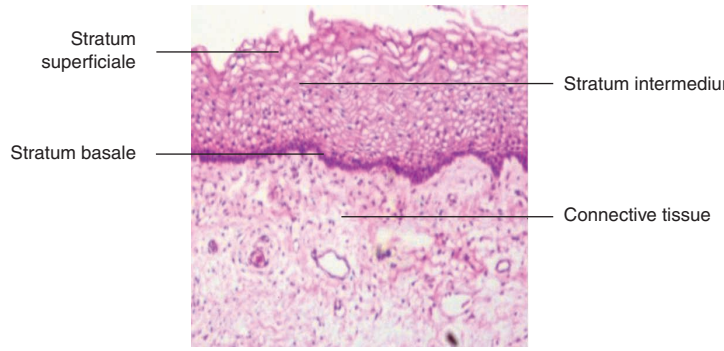
1. Cellular cementum is found in the apical one-third of root.
2. This contains cells called *cementocytes* that are present in spaces called *lacunae*.
3. Cementocytes have several cell processes called *canaliculi* radiating from the cementocyte cell body and directed towards the periodontal ligament from where the cells get nutrition.
4. The incremental lines of Salter are present and are far apart due to the faster deposition of cellular cementum.



Cellular cementum (ground section, 40X)

Non-Keratinized Epithelium

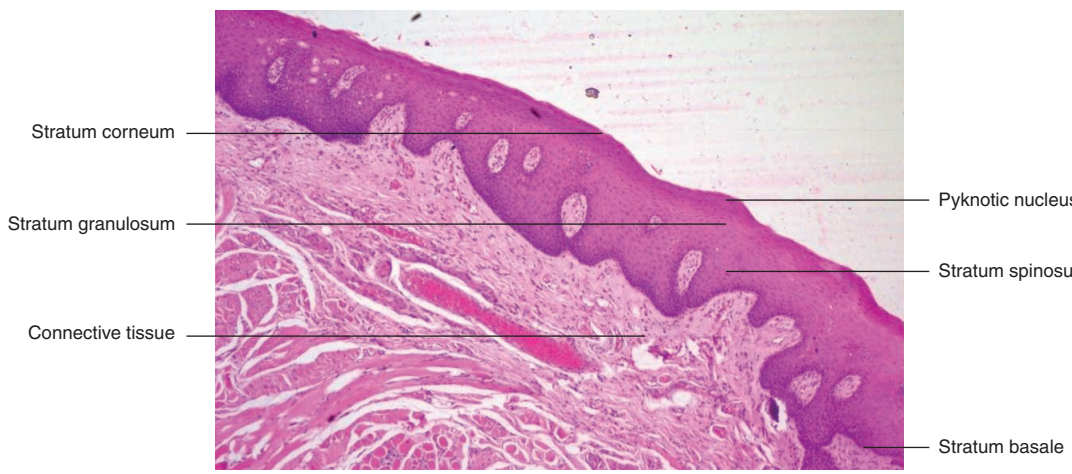
1. The non-keratinized epithelium is stratified squamous in type and has three layers: stratum basale, stratum intermedium and stratum superficiale.
2. The lamina propria is less dense and merges with the submucosa and contains collagen fibres, fibroblasts and blood vessels.



Non-keratinized epithelium (haematoxylin and eosin, 10X)

Keratinized Epithelium

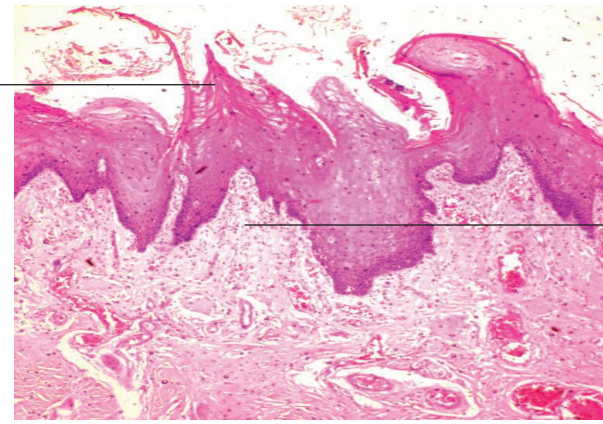
1. Keratinized epithelium has four layers: stratum basale, stratum spinosum, stratum granulosum and stratum corneum.
2. The lamina propria is dense.
3. Long and narrow epithelial rete ridges project into the connective tissue, interdigitating with connective tissue papilla.
4. The stratum corneum layer, in the presence of pyknotic nuclei, is called para-keratinized epithelium and if the nuclei are absent, it is called orthokeratinized epithelium.



Para-keratinized epithelium (haematoxylin and eosin, 10X)

Filiform Papillae

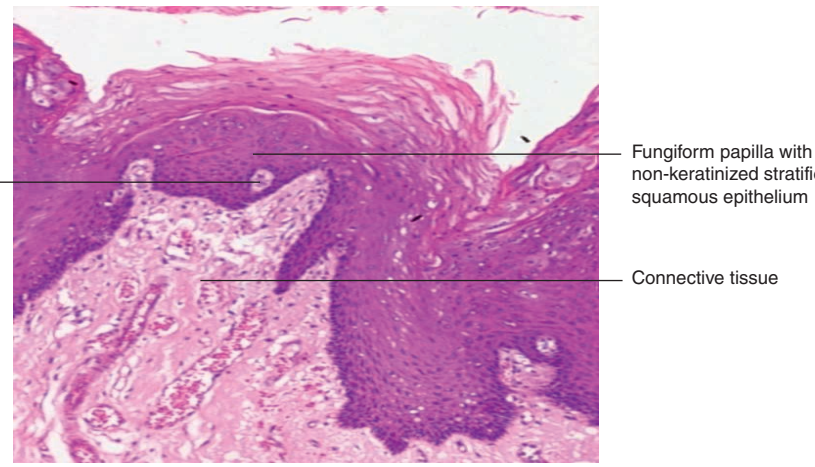
1. Filiform papillae are hair-like projections of the epithelium.
2. These are seen on the dorsal aspect of tongue.
3. These are lined by the keratinized stratified squamous epithelium.
4. These contain a connective tissue core.
5. Taste buds are absent in filiform papillae.



Filiform papilla (haematoxylin and eosin, 10X)

Fungiform Papillae

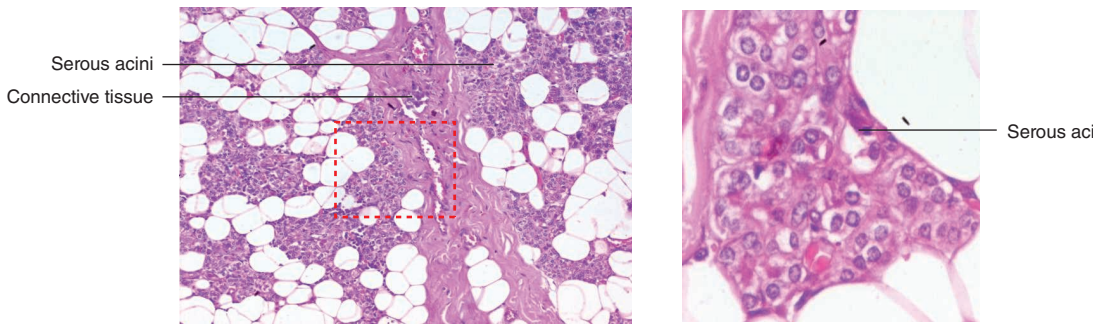
1. Fungiform papillae are mushroom-shaped papillae present between the filiform papillae.
2. These are covered by thin non-keratinized epithelium and have a rich capillary network in the connective tissue.
3. These appear as bright red spots due to the rich capillary network.
4. These may contain one or two taste buds on their dorsal surface.



Fungiform papilla (haematoxylin and eosin, 10X)

Serous Acini

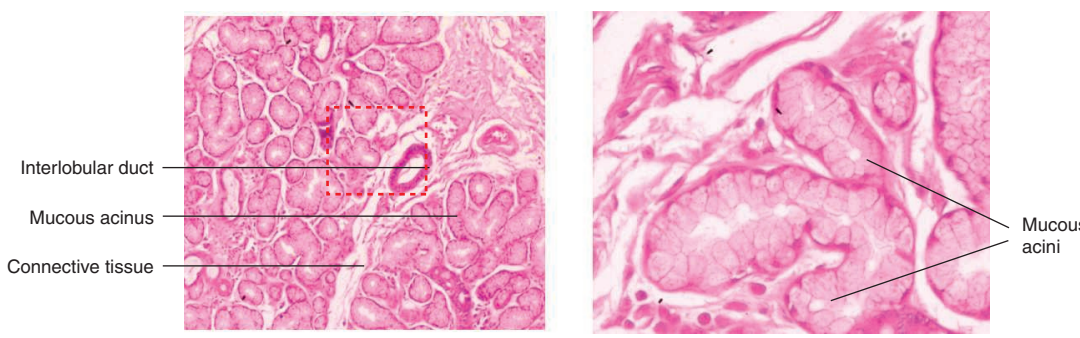
1. Serous acini are pyramidal in shape, with the broad base resting on a thin basal membrane, and have narrow apex bordering the lumen.
2. Their nuclei are spherical in shape and located in the basal region of the cell.
3. The prominent feature is the accumulation of secretory granules in apical cytoplasm.
4. Lumen of the serous acini is smaller than that of mucous acini.



Serous acini: (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin, 10X; ii—haematoxylin and eosin, 40X).

Mucous Acini

1. Mucous acini are columnar or pyramidal in shape, with the base resting on the basement membrane and the apex bordering the larger lumen.
2. Their nuclei are flattened and pressed against the base of cells.
3. Mucous acini are paler because the mucin content does not readily take up stains.
4. Mucous cells are larger and more in number than serous acinar cells.



Mucous acini: (ii) is a magnification of the area outlined in red in (i). (i—haematoxylin and eosin, 10X; haematoxylin and eosin, 40X).

Answers to Multiple Choice Questions

SECTION 1 ORAL ANATOMY

Chapter 1: 1-a, 2-b, 3-c, 4-d, 5-a, 6-b, 7-c, 8-d, 9-a, 10-b.
Chapter 2: 1-a, 2-d, 3-a, 4-a, 5-d, 6-a, 7-a, 8-a, 9-a, 10-b, 11-b, 12-b, 13-b, 14-c, 15-b.
Chapter 3: 1-d, 2-a, 3-a, 4-a, 5-b, 6-d, 7-c, 8-d, 9-a, 10-a, 11-d, 12-c, 13-d, 14-b, 15-a.
Chapter 4: 1-b, 2-a, 3-c, 4-a, 5-c, 6-b, 7-b, 8-a, 9-c, 10-a, 11-b, 12-d, 13-b, 14-a, 15-d.
Chapter 5: 1-a, 2-a, 3-b, 4-d, 5-c, 6-b, 7-b, 8-b, 9-a, 10-b, 11-d, 12-b, 13-a, 14-d, 15-a.
Chapter 6: 1-a, 2-d, 3-c, 4-b, 5-b, 6-a, 7-b, 8-b, 9-d, 10-d, 11-c, 12-a, 13-b, 14-a, 15-c.
Chapter 7: 1-c, 2-a, 3-d, 4-a, 5-c, 6-b, 7-a, 8-a, 9-c, 10-d, 11-a, 12-b, 13-b, 14-d, 15-c.

SECTION 2 TOOTH MORPHOLOGY

Chapter 8: 1-a, 2-b, 3-c, 4-d, 5-c.
Chapter 9: 1-d, 2-c, 3-c, 4-b, 5-a, 6-c, 7-d, 8-a, 9-a, 10-d, 11-a, 12-a, 13-b, 14-e, 15-a.
Chapter 10: 1-d, 2-d, 3-d, 4-c, 5-a, 6-c, 7-c, 8-e, 9-c, 10-d, 11-a, 12-d, 13-c, 14-d, 15-a.
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Glossary

Acidophilic The term that describes the microscopic appearance of cells and tissues, as seen under a microscope, after a histologic section has been stained with an acidic dye.
Afferent Axons that carry impulses towards the central nervous system.
Ageusia Absence of taste sensation.
Ameloblasts Formative cells of enamel.
Anaesthesia The condition of having sensation (including the feeling of pain) blocked or temporarily taken away.
Anastomosis Communication between arterial branches or vessels.
Anchorage Site of delivery from which force is exerted.
Ankylosis The consolidation of bones or their parts to form a single unit.
Anodontia Rare genetic disorder characterised by the congenital absence of all primary or permanent teeth.
Apatite A group of phosphate minerals.
Apoptosis Process of programmed cell death.
Atrophy Partial or complete wasting away of a part of the body.
Attrition The physiologic wearing of tooth as a result of tooth-to-tooth contact.
Autolysis Destruction of a cell through the action of its own enzymes.
Axial Relating to or parallel with the long axis of a tooth.
Axial skeleton Bones that are located close to or along the central axis of the body.
Axon Long, slender projection of a nerve cell, or neuron.

Basophilic The term that describes the microscopic appearance of cells and tissues, as seen under a microscope, after a histologic section has been stained with a basic dye.
Bifurcation The term used for the division of root into two segments.
Biopsy Medical removal of tissue from a living subject to determine the presence or extent of a disease.
Bone marrow Flexible tissue found in the interior of bones.

Calcification The process in which calcium salts build up in soft tissue, causing it to harden.
Canal A long passage within bone which transits blood vessels and nerves.
Cartilage A flexible connective tissue found in many areas in the bodies of humans.
Chronology A record of events in the order of their occurrence.
Ciliated cells Epithelial cells with small, hair-like processes projecting from their outer surfaces.
Cingulum The portion of the teeth occurring on the lingual or palatal aspects that forms a convex protuberance at the cervical third of the anatomical crown.
Cleft An opening, fissure or V-shaped indentation.
Clicking A brief, sharp sound produced during the opening movement of the temporomandibular joint when the muscles are overcontracted because of accident, overclenching or grinding.
Cross-section The intersection of a three-dimensional body with a plane.
Cryostat (*cryo* = cold; *stat* = stationary) A device used to maintain cryogenic temperatures.
Cusp An elevation on the occlusal surface of posterior teeth and canines.

Deglutition Process by which food is passed to the stomach from the oral cavity.
Dendrites Branched projections of a neuron.

Dental pulp The part in the centre of a tooth made up of living connective tissue and cells called odontoblasts.
Dentinal hypersensitivity Sensation felt when the nerves inside the dentin of teeth are exposed to the environment.
Dilaceration Developmental disturbance in the shape of teeth. It refers to an angulation or a sharp bend or curve, in the root or crown of a formed tooth.
Duct A circumscribed channel leading from an exocrine gland or organ.
Dysgeusia Disturbed taste sensation.
Dysphasia Difficulty in swallowing.

Edge Angle formed by merging of two flat surfaces.
Efferent Axons that carry impulses away from the central nervous system.
Electromyography Technique for evaluating and recording the electrical activity produced by skeletal muscles.
Electron microscope Microscope that uses a beam of electrons to illuminate the specimen and produce a magnified image.
Embryogenesis Process by which the embryo forms and develops, until it reaches the stage of the foetus.
Eruption The process of a tooth breaking through the gum tissue to grow into its place in the mouth.
Exocrine A type of ductal glands that secrete their products (including digestive enzymes and some hormone chemical messengers) into ducts that lead directly into the external environment.
Extraosseous Occurring outside a bone or bones.

Fascia A structure of connective tissue that surrounds muscles, groups of muscles, blood vessels and nerves, binding some structures together while permitting others to slide smoothly over each other.
Fixation Chemical process by which biological tissues are preserved.
Foramina Natural openings or perforations through bone that permit transit of blood vessels and nerves.
Forensic odontology Branch of forensic medicine that deals with teeth and the marks left by teeth (used in identifying criminal suspects or the remains of a dead person).
Fossa An irregular hollow or depressed area on the surface of bone.

Ganglia Biological tissue mass, most commonly a mass of nerve cell bodies.
Glycosylation The enzymatic process that attaches glycans to proteins, lipids or other organic molecules.
Gomphosis A joint that binds the teeth to bony sockets.
Grooves Sharply defined narrow and linear depressions formed during tooth development.
Gustation Sense of taste; it is one of the five traditional senses.

Hinge movement The opening or closing motion of the mandible around a horizontal axis.
Histochemistry The branch of science that deals with the chemical composition of the cells and tissues of the body.
Histology The study of the microscopic anatomy of cells and tissues.
Hyperalgesia Increased sensitivity to pain.
Hyperplasia Increase in number of cells or proliferation of cells.
Hypertrophy Increase in the volume of an organ or tissue due to the enlargement of its component cells.
Hypoplasia Underdevelopment or incomplete development of a tissue or organ.

Impacted teeth Teeth which are tightly or firmly wedged in a limited amount of space.
Incisal ridge The portion of crown which makes up the complete incisal portion.
Intraosseous Within a bone; sometimes used to refer to the bone marrow cavity.

Joint A point of articulation between two or more bones, especially such a connection that allows motion.

Ligament A sheet or band of tough, fibrous tissue that connects bones or cartilages at a joint or supports an organ.
Lingual fossa A shallow concavity present between the marginal ridges, below the cingulum.
Lipolysis The breakdown or destruction of fats.

Lymph The fluid that circulates throughout the lymphatic system.
Lymph nodes Small ball- or oval-shaped organs of the immune system distributed widely throughout the body including in the armpit and stomach/gut and linked by lymphatic vessels.

Malignancies The tendency of a medical condition, especially tumours, to become progressively worse and to potentially result in death.
Mamelons Protrusions seen in the incisal ridges of newly erupted permanent incisors.
Mantle dentin First-formed core dentin just near the dentinoenamel junction.
Mastication (or chewing) The process by which food is crushed and ground by teeth.
Melanocytes Melanin pigment–producing non-keratinocytes.
Membrane A layer of material which serves as a selective barrier between two phases.
Merocrine The term used to classify exocrine glands and their secretions, in the study of histology.
Microscope An instrument used to see objects that are too small to be seen with the naked eye.
Microtome Sectioning instrument that allows cutting of extremely thin slices of material known as sections.
Microvilli Tiny, hair-like folds in the plasma membrane that extend from the surface of many absorptive or secretory cells. They are most clearly visible with an electron microscope but may be seen as a 'brush border' under a light microscope.
Morula An embryo at an early stage of embryonic development, consisting of cells in a solid ball.

Natal teeth Teeth that are present at birth.
Neonatal teeth Teeth that emerge through the gingiva during the first month of life.
Neuron An electrically excitable cell that processes and transmits information by electrical and chemical signalling.
Nucleation First aggregation of ions to form a crystal.

Occlusion The manner in which the upper and lower teeth come together when the mouth is closed.
Odontoclasts Cells responsible for the resorption of cementum, dentin and enamel.
Olfaction Sense of smell.
Ossification Process of laying down new bone material by cells called osteoblasts.
Osteoblast Cell responsible for bone formation.
Osteoclast Type of bone cell that removes bone tissue.
Osteodentin Rapidly formed tertiary dentin that contains entrapped odontoblasts and a few dentinal tubules; it thereby superficially resembles bone.
Overbite The extent of vertical overlap of the maxillary central incisors over the mandibular central incisors.

Perfusion Physiologic process of delivery of nutrients to tissues through arterial blood.
Phonation The process by which the vocal folds produce certain sounds through quasi-periodic vibration.
Pits Small, pinpoint depressions located at the junction of developmental grooves.
Placenta An organ that connects the developing foetus to the uterine wall to allow nutrient uptake, waste elimination and gas exchange via the mother's blood supply.
Plaque Biofilm that builds up on teeth.
Pneumatisation The formation of air cells or cavities in tissue.

Quadrant Anatomical segment formed by the division of the maxillary and mandibular arch by an imaginary midline.

Reflex An involuntary and nearly instantaneous movement in response to a stimulus.
Regurgitation Expulsion of material from the mouth, pharynx or oesophagus, usually characterised by the presence of undigested food or blood.
Resonance Intensification of vocal tones during articulation, as by the air cavities of the mouth and nasal passages.
Reteridges Epithelial projections into the connective tissue.
Rickets Softening of bones in children due to deficiency or impaired metabolism of vitamin D, magnesium, phosphorus or calcium.

Ridges Linear, flat elevations on the surface of teeth.
Root canal The space within the root of a tooth.

Secondary dentin Dentin formed by normal pulp function after root end formation is complete.
Shedding Process of exfoliation of deciduous teeth.
Sinuses Air-filled cavities in the bones of the skull, especially ones that communicate with the nostrils.
Stroma The functionally supportive connective tissue framework of a biological cell, tissue, organ, gland or other structure, as distinguished from the tissues performing the special function of the organ or part.
Stuttering Sudden block in speaking of a word or syllable.
Submerged teeth Ankylosed deciduous teeth which are submerged below the plane of occlusion.
Succedaneous teeth Permanent teeth that replace the primary (deciduous) teeth.
Supernumerary teeth Teeth which appear in addition to the regular number of teeth.
Synapse Structure that permits a neuron to pass an electrical or chemical signal to another cell.
Synovial membrane The connective tissue membrane that lines the cavity of a joint and produces the synovial fluid.

Tetany Medical sign consisting of the involuntary contraction of muscles.
Totipotent cell A single cell with the ability to divide and produce all the differentiated cells in an organism.
Triangular ridge Ridge that extends from the cusp tip to the central fossa.
Trismus Inability to normally open the mouth.
Tubercle Small elevation on some portion of the crown produced by an extra formation of enamel.
Turner's hypoplasia Periapical infection of deciduous teeth which can cause enamel hypoplasia of the permanent teeth.

Vestibule Space bounded by lips and cheeks on the exterior and gums and teeth within.
Viscera Internal organs that perform specific functions.

Zygote Initial cell formed when two gamete cells are joined by means of sexual reproduction.

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