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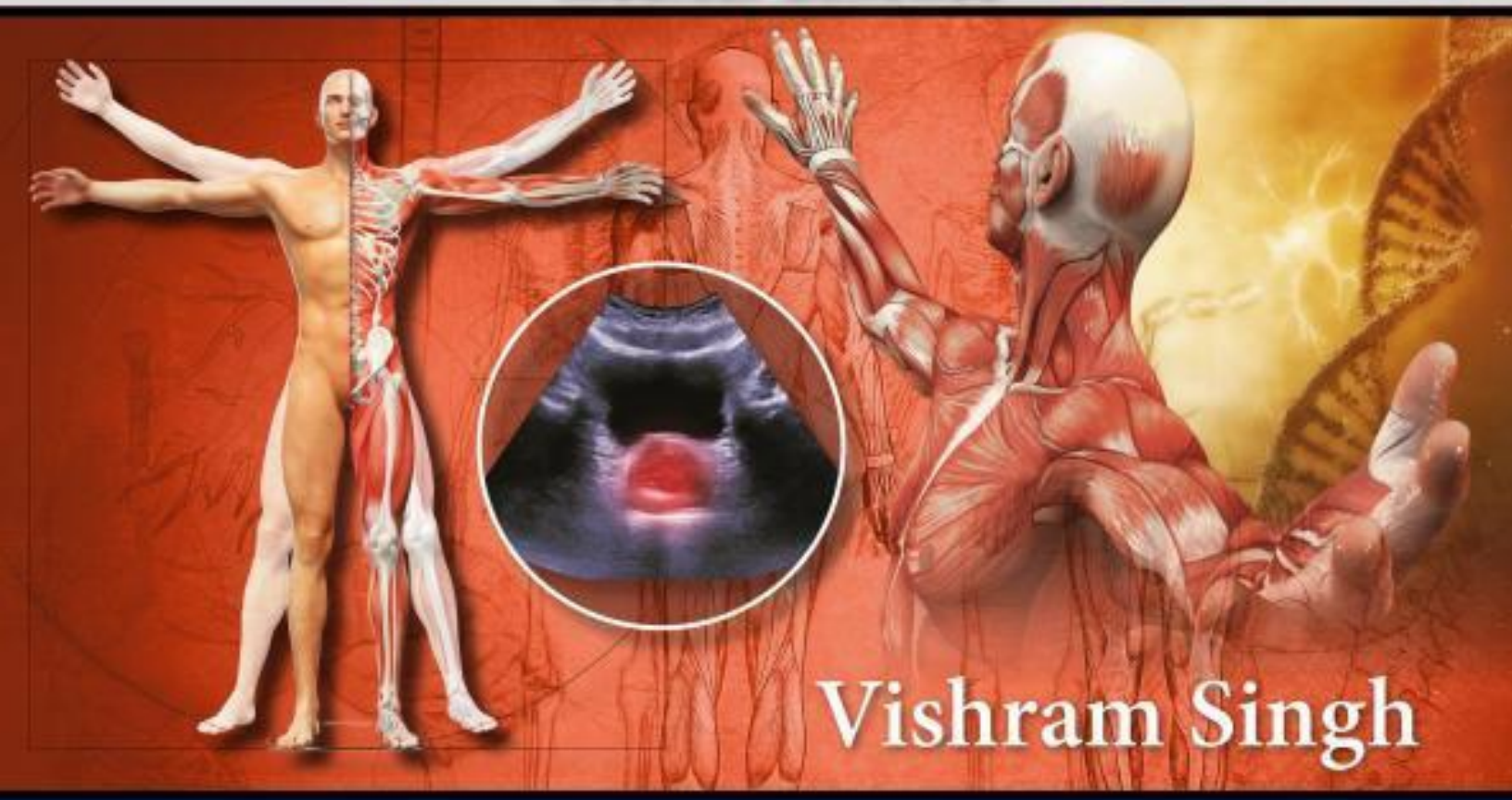
GENERAL ANATOMY

with • Systemic Anatomy • Radiological Anatomy • Medical Genetics



Vishram Singh

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General Anatomy *with* Systemic Anatomy Radiological Anatomy Medical Genetics

FOURTH EDITION

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29. Blood Supply of the Brain
30. Surface Anatomy of Head, Neck and Brain

Multiple Choice Questions

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Dedication

Dedicated to

My Parents
Late Smt Ganga Devi Singh and **Late Shri HR Singh,**
an ever-guiding force in my life

My Elder Sister
Late Smt Susheela Singh
for her help and cooperation during my student life

My Elder Brother
Shri Kaptan Singh
for his sacrifice for me

My Wife
Late Smt Manorama Rani Singh
for her unending support and cooperation of my pursuits

My Students
Past, and Present

Preface to the Fourth Edition

Vishram Singh

This book has been widely used by students and teachers alike since its inception. This edition is extensively revised. The language has been simplified for easy understanding.

This book is unique in the sense that it not only deals with General Anatomy but deals with Systemic Anatomy, Imaging Anatomy and Genetics. Thus, it is four-in-one book. This has been done intensely to cope with reduction in time period for anatomy teaching.

The new text has been added wherever felt necessary. Number of new line diagrams, half-tone figures have been added. Different types of radiographs like CT scans, MRIs, SPECT and PET have been given. The competency codes have been inserted in the Learning Objectives, in the beginning of each chapter also to make learning more aim oriented.

The anatomical and genetic basis of diseases has been given at the appropriate places so that student not only clear their ongoing exams but apply it on patients during their clinical years. I do not claim the absolute originality of the text and figures other than new mode of simplification, presentation and expression.

I whole heartedly welcome the constructive appreciations and criticisms from both students and teachers for further improvement.

"Anatomy forms the basis of medicine and surgery."

Preface to the First Edition

Vishram Singh

There has been a long felt need of a comprehensive book on general anatomy which would systematically explain not only the basic principles of anatomical structures, but also the relationships and functions of these structures within the human body in both healthy and diseased states.

The explosion in knowledge of diseases and the technological advances associated with diagnosis and treatment in the past decade or so has necessitated a radical restructuring of the anatomy curriculum for medical, dental, nursing and paramedical students. As a result, the present-day curriculum of anatomy is more integrated, clinically oriented and system based. This has also created the need for a new textbook refl ecting these changes.

This book is prepared in the light of the recent curriculum changes keeping in view the time allotted for anatomy teaching. Throughout the preparation of this book, the basic theme kept in mind is that anatomical knowledge is required for performing physical examination and diagnostic procedures. Thus, while anatomical details of little clinical relevance have been omitted, clinically oriented topographic anatomy relating to diagnostic and surgical procedures is included. The histological features and developmental aspects have been mentioned wherever they facilitate an appreciation of gross structure/functions of organs and occurrence of congenital anomalies.

In the present-day scenario, there is an alarming increase in problems associated with the spine (vertebral column). Unfortunately, most books do not deal with it as an independent entity. In this book, therefore, a separate chapter has been provided on the vertebral column. Further, important advances have taken place in genetics and radiodiagnosis and it has become imperative for medical students to have an overview of medical genetics and imaging anatomy before going through their clinical courses. For this reason, fundamentals of medical genetics and imaging anatomy are included in this volume.

Most medical colleges and centers follow the regional approach to teach gross anatomy in order to make it surgically relevant. As a result, students often fail to develop the systemic concept to understand medical problems. This volume, therefore, provides an overview of systemic anatomy and lays the foundation for the study of gross anatomy through the regional approach in the subsequent volumes.

The chapters of this volume have been so structured to make the text user friendly, facilitating ready access to the required material and smooth fl ow of knowledge. The chapters are organized in terms of the following components:

- *Chapter Outline:* broadly provides the contents of each chapter.
- *Learning Objectives:* indicate the level of competency a student is supposed to attain.
- *Text:* provides accurate and up-to-date information on the subject, in a visually appealing, interesting and simple manner.
- *Clinical Correlations:* offer clinical facts of practical value and reinforce the importance of theoretical learning in day-to-day clinical situations.
- *N.B.:* presents concepts of high academic value in a simple way.
- *Golden Facts to Remember:* lists important facts needed for appearing in PG entrance examinations, PLAB, USMLE, etc.
- *Multiple Choice Questions:* at the end of each chapter would help the reader assess his understanding and learning.
- *Tables and Flowcharts:* summarize the information and present complex data in a simpler manner.
- *Illustrations:* form the backbone of the book, anatomy being a descriptive science. All illustrations have been carefully drawn–for

conceptual clarity and accuracy. They have been designed to integrate well with the text to maximize learning.

The standard color scheme, applicable to anatomical drawings is used throughout the book. Broadly, the color scheme followed is:

Structures	Color
Arteries	Red
Veins	Blue
Nerves	Yellow
Lymph vessels/Lymph nodes	Violet
Muscles	Pinkish brown
Bone	Creamy yellow
Cartilage	Sky blue

In addition, real life three dimensional radiographs and images are provided to enhance understanding of currently used diagnostic imaging techniques.

General Anatomy is intended to serve as an introduction to human anatomy for students pursuing the first course in anatomy in medical, dental, nursing and allied health institutes.

I hope both teachers and students find this book interesting and useful. I would greatly welcome comments and suggestions from readers for the further improvement of the book.

Acknowledgments

At the outset, I would like to express my gratitude to Prof. (Dr.) A. Halim, my teacher and former Prof. and Head of the Department of Anatomy, King George's Medical University, Lucknow, for creating my interest in anatomy. I learned the art of drawing simple and technically accurate line diagrams from him. May God bless him with long life.

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Competency Map

COMPETENCY CODE	COMPETENCY	CORE (Y/N)	CHAPTER NO.	PAGE NOS.
	ANATOMY			
Topic: Anatomical Terminology				
AN1.1	Demonstrate normal anatomical position, various planes, relation, comparison, laterality & movement in our body.	Y	2	11–21
AN1.2	Describe composition of bone and bone marrow.	Y	6	63–80
Topic: General Features of Bones & Joints				
AN2.1	Describe parts, blood and nerve supply of a long bone.	Y	6	63–80
AN2.2	Enumerate laws of ossification.	N	6	63–80
AN2.3	Enumerate special features of a sesamoid bone.	N	6	67
AN2.4	Describe various types of cartilage with its structure &	Y	6	80–83

	distribution in body.			
AN2.5	Describe various joints with subtypes and examples.	Y	7	85–95
AN2.6	Explain the concept of nerve supply of joints & Hilton's law.	Y	7	95–96
Topic: General Features of Muscle				
AN3.1	Classify muscle tissue according to structure & action.	Y	9	115
AN3.2	Enumerate parts of skeletal muscle and differentiate between A116 tendons and aponeuroses with examples.	Y	9	122
AN3.3	Explain Shunt and spurt muscles.	N	9	129
Topic: General Features of Skin and Fascia				
AN4.1	Describe different types of skin & dermatomes in body.	N	5	50–51
AN4.2	Describe structure & function of skin with its appendages.	Y	5	48–56
AN4.3	Describe superficial fascia along with fat distribution in body.	Y	5	58–60
AN4.4	Describe modifications of deep fascia with its functions.	Y	5	60–61
AN4.5	Explain principles	N	5	51–52

	of skin incisions.			
Topic: General features of the cardiovascular system				
AN5.1	Differentiate between blood vascular and lymphatic system.	Y	11	152–162
AN5.2	Differentiate between pulmonary and systemic circulation.	Y	10	147
AN5.3	List general differences between arteries & veins.	Y	10	144
AN5.4	Explain functional difference between elastic, muscular arteries and arterioles.	Y	10	140
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AN5.6	Describe the concept of anastomoses and collateral circulation with significance of end-arteries.	Y	10	145–146
AN5.7	Explain function of meta-arterioles, precapillary sphincters, arterio-venous anastomoses.	N	10	140–141
AN5.8	Define thrombosis, infarction & aneurysm.	N	10	139–140
AN6.1	List the components and functions of the	N	11	152–154

AN6.2	Describe structure of lymph capillaries & mechanism of lymph circulation.	N	11	154
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Topic: Introduction to the Nervous System				
AN7.1	Describe general plan of nervous system with components of central, peripheral & autonomic nervous systems.	N	12	164–165
AN7.2	List components of nervous tissue and their functions.	Y	12	164–165
AN7.3	Describe parts of a neuron and classify them based on number of neurites, size & function.	Y	12	164–167
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AN7.5	Describe principles of sensory and motor innervation of muscles.	N	12	124–125
AN7.6	Describe concept of loss of innervation of a muscle with its applied anatomy.	Y	12	127–128
AN7.7	Describe various type of synapse.	N	12	170–171
AN7.8	Describe differences	N	12	167

		between sympathetic and spinal ganglia.			

List of Illustrations

between elbow and wrist, **(C)** relationship between neck and shoulder, **(D)** relationship between buttock and knee, **(E)** descriptions commonly used for referring to invagination/evagination, exterior/interior or superficial/deep of body structures.

FIG. 4.7 ■ Types of simple epithelium.
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cartilage and **(B)** conversion of calcified cartilage into bone.
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FIG. 9.11 ■ Myotendinous junction: **(A)** contiguity of muscle fibres with tendon fibres and **(B)** dove-tail type of junction between belly and tendon.

FIG. 9.12 ■ Bursae related to the knee joint. Note that the suprapatellar communicates with the cavity of the knee joint.
FIG. 9.13 ■ Synovial sheath: **(A)** synovial sheath around a tendon passing underneath a fibrous band; **(B)** invagination of the synovial sheath by a tendon and blood vessels reaching the tendon through mesotendons and **(C)** synovial sheath around the long flexor tendons of the fingers.
FIG. 9.14 ■ Motor unit. It consists of a single motor neuron and all the muscle fibres that it innervates. Most muscles have an innervation ratio of one motor neuron per 100–150 muscle fibres. Muscles capable of precise movements have an innervation ratio of 1:10, whereas muscles responsible for gross body movement have an innervation ratio exceeding 1:500.
FIG. 9.15 ■ Neuromuscular junction: **(A)** site where nerve fibre and muscle fibre meet and **(B)** showing presynaptic knob, synaptic cleft and sole plate. The sole plate is the sarcolemma and underlying sarcoplasm.
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FIG. 9.18 ■ Golgi tendon organ reflex. The golgi tendon organ gives rise to afferents which end on an inhibitory interneuron. This reflex inhibits contraction in the same muscle.
FIG. 9.19 ■ Excursion of muscle.
FIG. 9.20 ■ Shunt and spurt muscles.
FIG. 9.21 ■ Diagram to show prime mover and antagonist muscles. For flexion at the elbow biceps brachii muscle acts as the prime mover, whereas the triceps brachii acts as the antagonist. (At the same joint, during extension, the triceps acts as a prime mover and the biceps acts as an antagonist.)
FIG. 9.22 ■ The flexor and extensor muscles of the corpus act as synergists to stabilize the corpus so that the long flexor and extensor of the hand can flex and extend fingers.
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TABLE 17.5 Differences between somatic and germline mutations

Chapter 1: Introduction and history of anatomy

Specific learning objectives

After studying this chapter, the student should be able to:

- Define anatomy and give its subdivisions.
- Discuss why an understanding of human anatomy is essential to the science of medicine.
- Present historical perspectives of the main contributors to the science of human anatomy through life and achievements of Hippocrates, Herophilus, Aristotle, Galen, Leonardo da Vinci and Vesalius.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

Introduction

Anatomy is the science that deals with the structure of the body, from the macroscopic to the microscopic level.

Human anatomy has for long been studied through the dissection of cadavers (preserved dead bodies), which have served as the basis for understanding the structure and functions of the human body. The understanding of the structural organization of the human body is essential

so that a doctor could understand which structure or organ of body part is affected by the disease, which structure is being examined by him and which structure is being cut by him during an operation.

The term anatomy is derived from the Greek word *anatome*, meaning *to cut up*. The term dissection is the Latin equivalent of the Greek term *anatome* and in the past, the word *anatomize* was used more commonly than the word *dissect*.

Earlier, human anatomy was considered to be a descriptive science primarily concerned with identifying and naming body structures, but today the importance of anatomy lies in its functional approach and clinical applications. Therefore, *presently*, human anatomy is a practical applied science that forms the firm foundation of the practice of medicine (i.e., the art of healing).

> *'Anatomy is the basis of medical discourse.'*
>
> —Hippocrates (460-377 BC)

Subdivisions of anatomy

In the past, anatomy was studied mainly by dissection, but nowadays, it is studied in all possible ways and techniques like imaging, microscopy, etc. Different approaches have been adopted to study anatomy. Based on these approaches, anatomy can be divided into the following types:

1. Gross anatomy/topographical anatomy
2. Microscopic anatomy (histology)
3. Surface anatomy
4. Comparative anatomy
5. Physical anthropology
6. Living anatomy
7. Clinical anatomy
8. Radiological anatomy
9. Developmental anatomy/embryology
10. Genetics
11. Experimental anatomy

1. **Gross (topographical) anatomy:** It is a study on cadavers by dissection

and observation of structures by the naked eye. In gross anatomy, the structures are studied either region-wise (**regional anatomy**) or system-wise (**systemic anatomy**).

(a) ***Regional anatomy:*** In this approach, all the structures in a particular region of the body are studied at the same time. The body is dissected region-wise. Since the regional anatomy deals with several systems located in a particular region of the body, this approach to studying anatomy is most useful to the clinicians, particularly the surgeons who need to concentrate mostly on a limited region during surgery. Therefore, the regional approach is the most preferred method of anatomy all over the world.

Conventionally, the body is divided into the following six regions (Fig. 1.1):

1. Head and neck
2. Brain
3. Thorax
4. Abdomen
5. Upper limbs
6. Lower limbs

(b) ***Systemic anatomy:*** In this approach, all the structures forming a particular system are studied together at the same time. A system consists of several related organs which have a common function. The systemic anatomy provides comprehensive knowledge of a particular organ system throughout the body; hence, it is most useful for physicians. In the Indian subcontinent, the gross anatomy is generally taught by a regional approach. Therefore, a brief overview of all the systems is dealt with in the book.

Various systems of the human body (Fig. 1.2) are as follows:

(a) Integumentary system (study of skin and its appendages)
(b) Skeletal system (study of bones)
(c) Articular system/arthrology/syndesmology (study of joints)
(d) Muscular system (study of muscles)
(e) Nervous system (study of neural tissue)
(f) Cardiovascular system (deals with the heart and associated blood vessels)
(g) Lymphatic system (study of lymphoid tissue and lymph vessels)
(h) Endocrine system (study of ductless glands)

(i) Digestive system (study of structures concerned with digestion)
(j) Respiratory system (study of structures concerned with respiration)
(k) Reproductive system (study of structures concerned with reproduction)
(l) Urinary system (study of structures concerned with the formation and disposal of urine from the body)

N.B.

- The term ***locomotor system*** includes osteology, arthrology and myology.
- The term ***splanchnology*** deals with the study of the visceral organs of respiratory, digestive, urinary, reproductive and endocrine systems.

2. **Microscopic anatomy (histology):** It is the study of body structures with the help of a microscope (light microscope or electron microscope). Microscopic anatomy provides structural details of tissues and cells, which otherwise are not visible to the naked eye.
3. **Surface anatomy:** It is the study of the relationship of deeper structures with the skin surface. Some of these structures can be seen whereas others can be palpated on the body surface. These structures are sometimes used as surface (anatomical) landmarks for surface-marking of the much deeper structures with the help of 'skin pencil'.
   The main objective of surface anatomy is visualization in the *mind's eye* of structures that lie beneath the skin. It can be learned using cadavers as well as living individuals. Surface anatomy provides the basis for physical examination and the knowledge is of paramount importance for various surgeries.
4. **Comparative anatomy:** It is the study of changes in the form, structure and function of different parts of the body, that have taken place in the animal kingdom during the course of evolution (phylogeny).
5. **Physical anthropology:** It is the study of the physical characteristics of human beings and their ancestors, and of the variability of these characteristics among and within different racial groups. The knowledge of physical anthropology helps to solve medicolegal problems of the identification of individuals.

6. **Living anatomy:** It is the study of the structures of the bodies of the living human beings by inspection, palpation, percussion, auscultation and with the help of various medical procedures such as bronchoscopy, gastroscopy, cystoscopy, and various imaging techniques.
7. **Clinical anatomy:** It is the use of anatomical knowledge for diagnosis and treatment of various diseases. It also provides the anatomical basis of various diseases.
8. **Radiological anatomy:** It is the radiographic visualization of the structures and their relations with the neighbouring structures inside the body using X-rays. Recently, new imaging techniques such as computerized axial tomography (CAT), magnetic resonance imaging (MRI) and ultrasonography scans are frequently being used to study the deeper structures with greater accuracy and with little or no harmful effects.
9. **Developmental anatomy/embryology:** It is the study of the intrauterine development of an individual, which begins with fertilization and ends with birth. Much can be learned about the structure and function of adults by studying changes that occur during development.
10. **Genetics:** It is the study of the principles of heredity and variation.
    (a) Heredity is the study of similar traits passed from the parents to their offspring; hence, the offsprings resemble like their family members.
    (b) Variation is the study of traits influenced by internal and external forces so that no individual is a replica of the other.
11. **Experimental anatomy:** It is the study of the factors that influence and determine the form, structure and function of different parts of the body by conducting various experiments such as demonstration of sites of valves in the veins by applying a tourniquet and determining the direction of blood flow in the vessel.

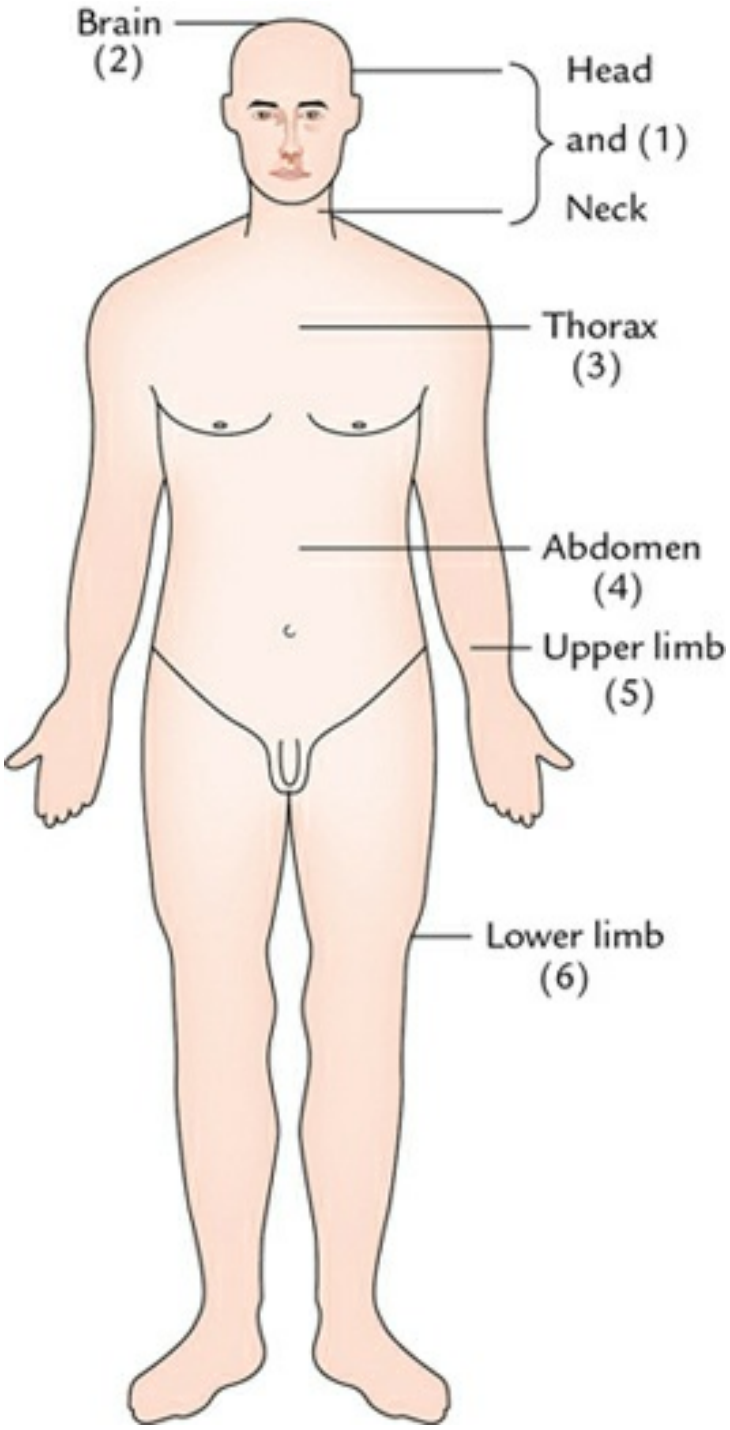
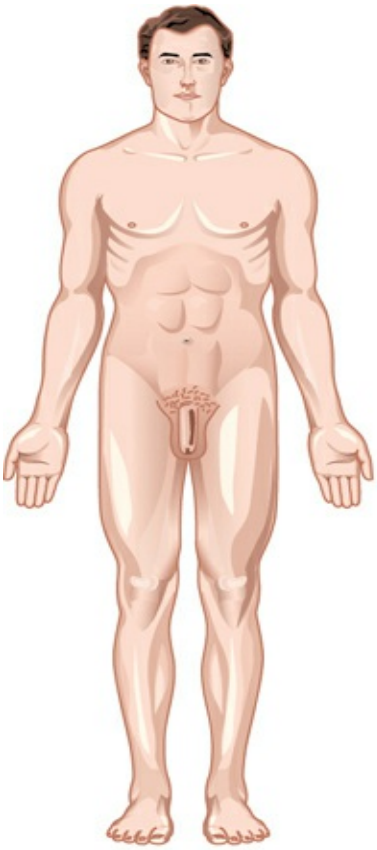
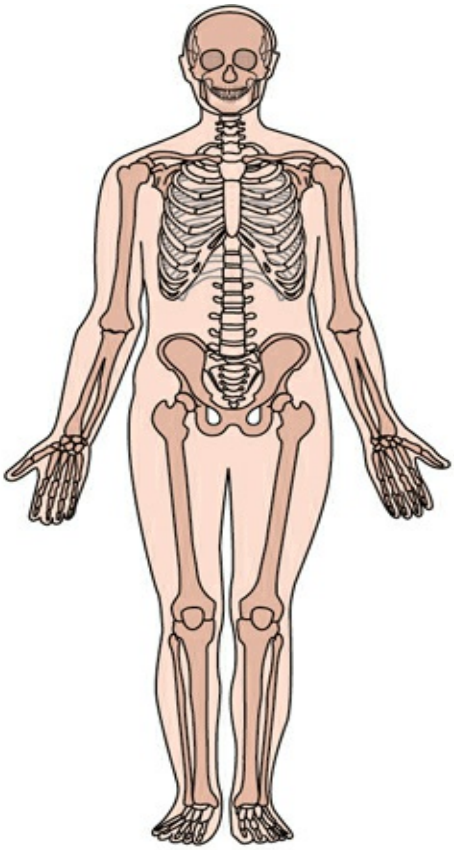


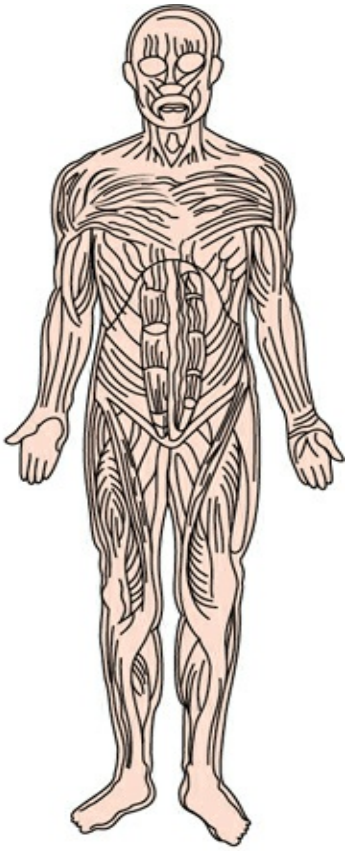
FIG. 1.1 ■ Various regions of the body.



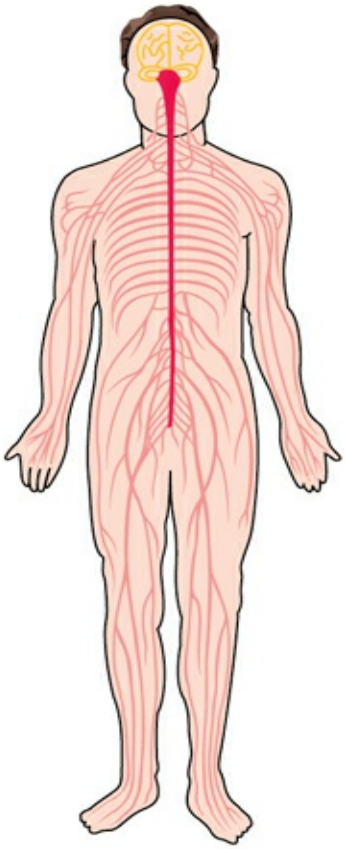
Integumentary system



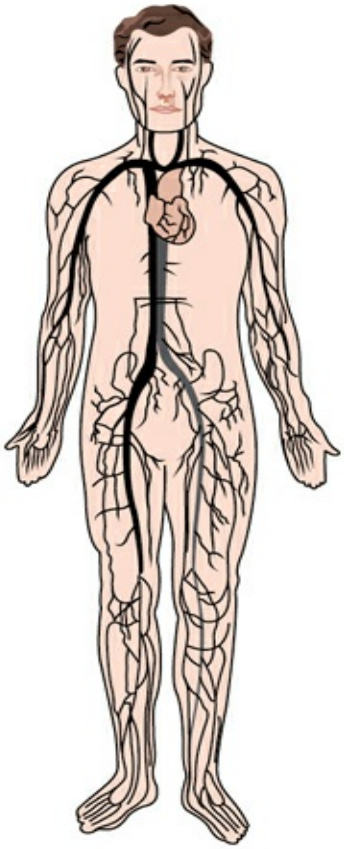
Skeletal/articular system



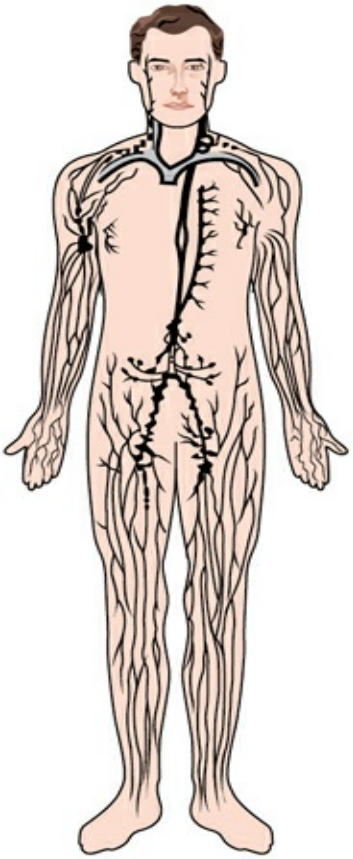
Muscular system



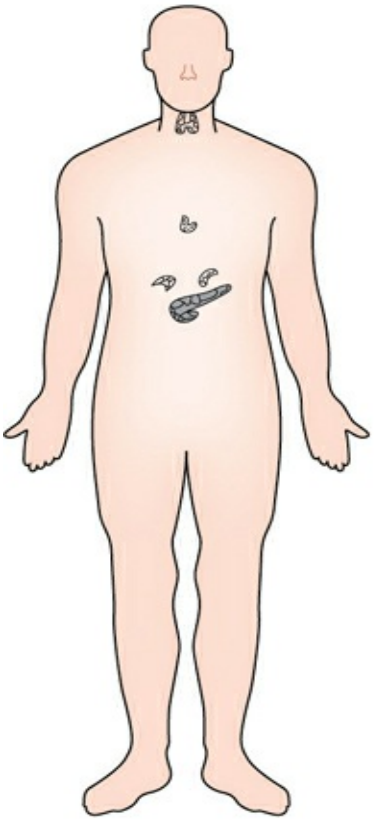
Nervous system



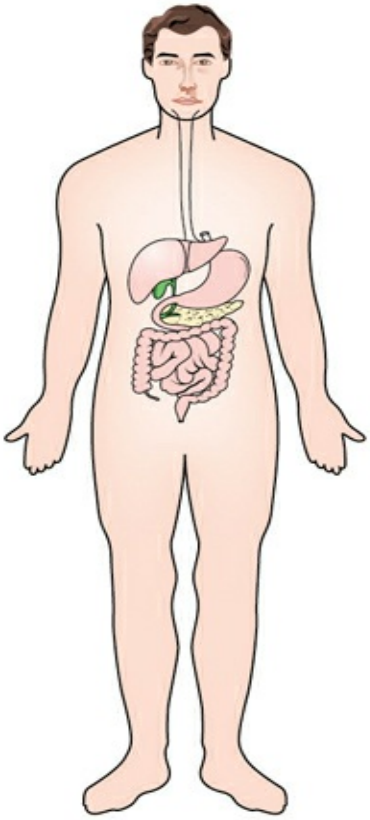
Cardiovascular system



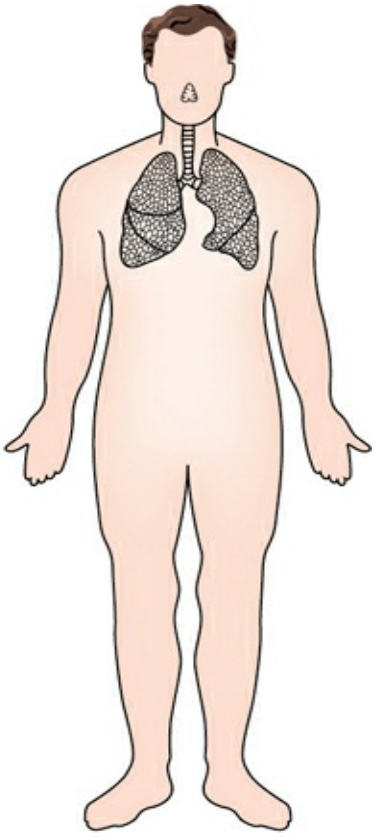
Lymphatic system



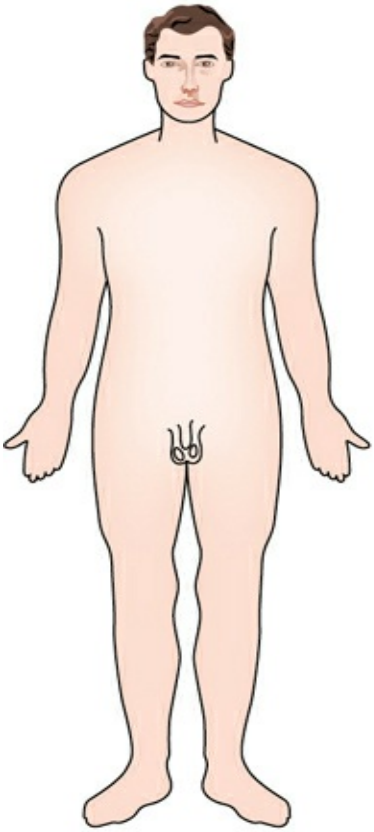
Endocrine system

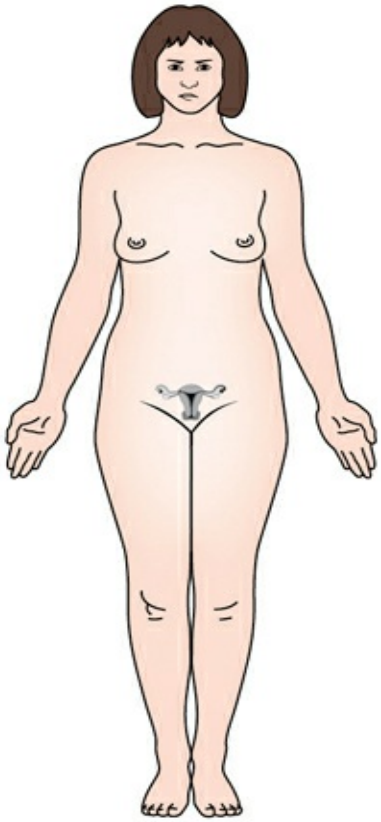


Digestive system

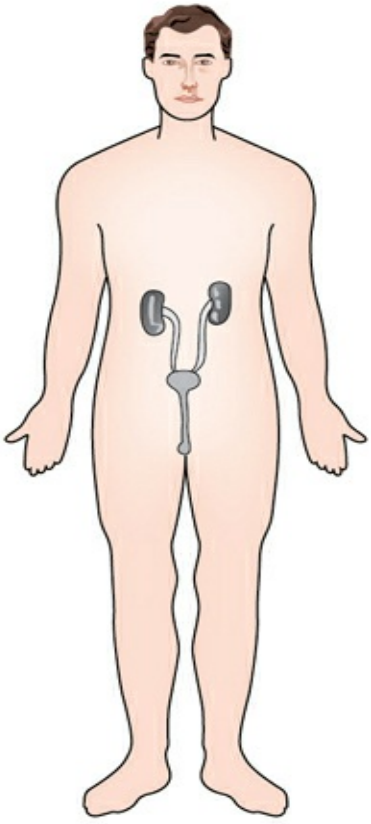


Respiratory system





Male ← **Reproductive system** → Female



Urinary system

FIG. 1.2 ■ Various systems of the body.

History of anatomy

> *'The past is not dead history, it is living material out of which man builds for the future.'*
>
> —Rene Dubos (1901–1982 BC)

The history of human anatomy parallels that of medicine. It has a rich, long, exciting and frequently troubled heritage. People who made significant contributions to the science of human anatomy are listed in Table 1.1.

TABLE 1.1

Contributors to the Science of Anatomy: Historical Perspectives

Contributor	Period	Contribution
Menes	Cir. 3,400 BC	Wrote the first anatomy manual
Sushruta	Cir. 1,000 BC	Recorded weight of tongue and length of the intestine
Hippocrates	Cir. 460-377 BC	Hippocratic oath. Known as the Father of Medicine
Aristotle	384-322 BC	Comparative anatomist, first recorded illustration of anatomy, wrote first-ever account of embryology
Herophilus	Cir. 325 BC	Remarkable work on the nervous system. Recognized brain as the centre of the nervous system and the site of intelligence; known as father of anatomy
Galen	AD 130–216	Most influential writer of all time on medical subjects including anatomy

Leonardo da Vinci	AD 1452–1519	Drew outstanding anatomical sketches.
		Made wax cast of ventricles of the brain
Vesalius	AD 1514–1564	Refuted misconceptions of Galen. Authored *De humani corporis fabrica.* Known as the father of modern anatomy
Harvey	AD 1578–1657	Demonstrated motion of blood in heart and vessels
Leeuwenhoek	AD 1632–1723	Refined microscope. Described cells and tissues
Malpighi	AD 1628–1694	Regarded as the Father of Histology
Robert Hooke	AD 1665	Coined the term 'cell'
Schleiden and Schwann	AD 1838–1839	Formulated Cell Theory
John Hunter	AD 1728–1793	Established Hunterian museums in London. Discovered Hunter's canal
Mendel	AD 1822–1884	Regarded as the Father of Genetics
Röentgen	AD 1895	Discovered X-rays
Henry Gray	AD 1827–1861	Authored the most accepted book on anatomy titled *Gray's Anatomy*
Watson and Crick	AD 1953	Discovered the structure of DNA and won Nobel Prize for this

A brief account of some of the main contributors corresponding to different historical times is as follows:

Early civilization

Sushruta/Suśruta (1000 BC)

He is regarded as the **Father of Surgery**. He lived, taught and practiced his art of medicine on the banks of the Ganges, a holy river, in one of the oldest cities of the world, *Kashi* (now also called Varanasi) in North India. He is the author of the treatise the *Sushruta Samhita*. His contribution to anatomy is (Fig. 1.3):

- Described 300 bones and about 500 muscles in the body.
- Described blood vessels and called them *Dhamnis* and *Siras*.
- Described various organs of the body, namely lungs, rectum, urinary bladder and uterus.
- Described various joints of the body also.

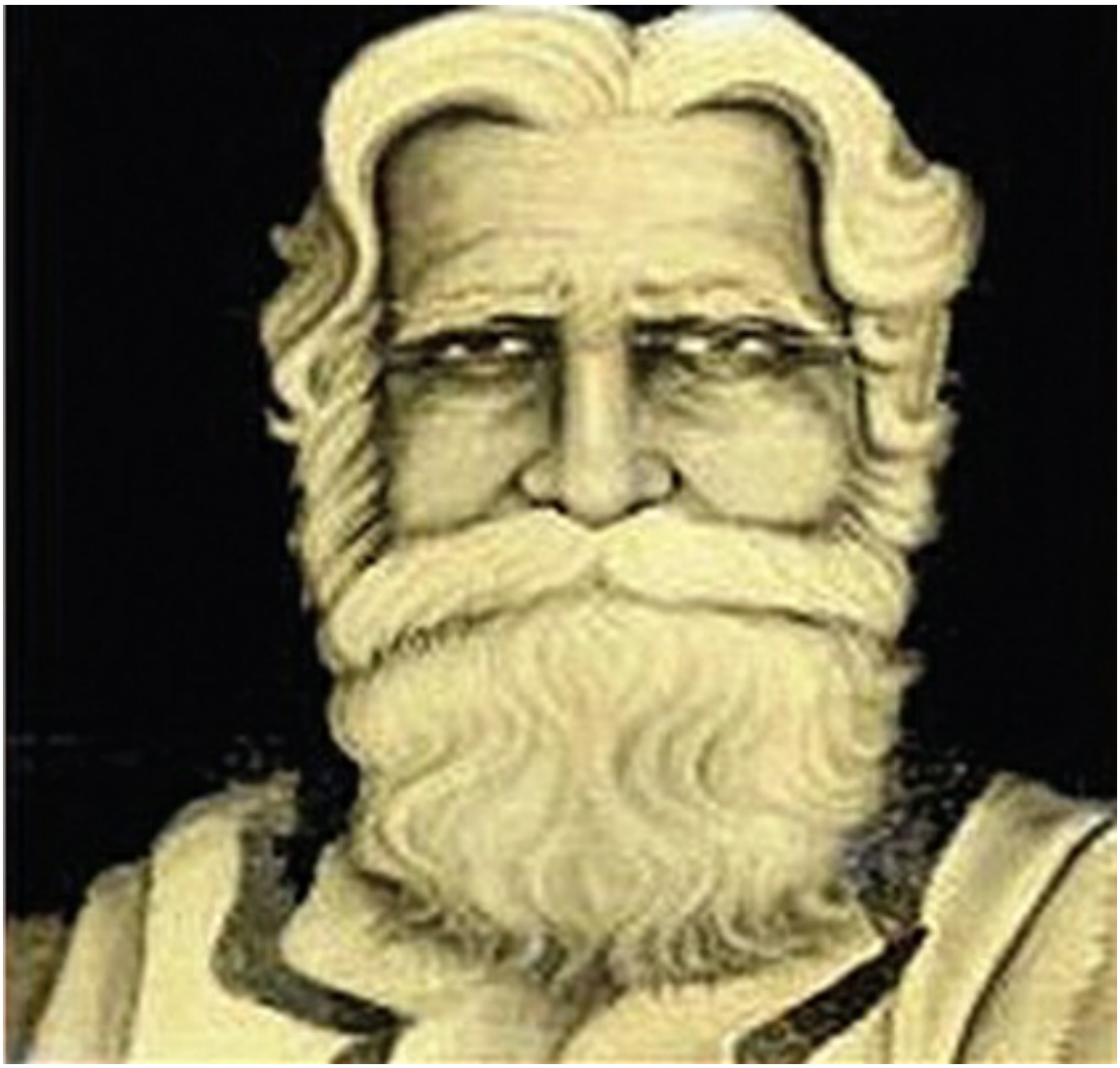


FIG. 1.3 ■ Sushruta.

In his famous treatise '*Sushruta Samhita'*, he called anatomy '***Sharira Sthana'***. This treatise was main source of knowledge about surgery in ancient India.

Grecian period

Hippocrates (460-377 BC)

Hippocrates, a famous Greek physician, is regarded as the **Father of Medicine** because he had established sound principles of medical practice. His name is *memorialized* in the *Hippocratic oath*, which the graduating students take before entering into medical practice (Fig. 1.4).

FIG. 1.4 ■ Hippocrates.

Hippocrates had limited exposure to human dissection, but he was well disciplined in proclaiming his popular theory of body organization, called the ***humoral theory***. According to this theory, the **human body is constituted of four body humours** (i.e. four elements of body fluids) that form the physiologic and pathologic basis of health and disease. These *humours* are **blood, phlegm, yellow bile** and **black bile**. He associated these humours with a particular body organ, namely blood with the liver, yellow bile with the gallbladder, phlegm with the lungs, and black bile with the spleen. A healthy person is thought to have a balance of these four humours. According to Hippocrates, the balance between four body humours can be maintained/restored *by proper diet, hygiene* and *lifestyle.* The concept of humours *has long since been* discarded, though it had dominated medical thought for over 2,000 years. Perhaps the greatest contribution of Hippocrates was that he attributed diseases to natural causes than to the displeasure of Gods. His application of logic and reason to disease was the beginning of present-day scientific medicine. He is most often remembered by the medical fraternity for the **Hippocratic oath.**

This oath embodies a code of ethics that all medical professionals must follow in their practice.

The Hippocratic oath became a standard norm for all medical professionals and continues to be administered to medical students worldwide even today.

Aristotle (384–322 BC)

Aristotle, a great Greek philosopher, was a zoologist, a renowned teacher and an accomplished writer. He made careful examinations of all kinds of animals, including references to humans. He wrote the first-ever account of embryology, in which he described the development of the heart in an embryo. He named the *aorta* and *differentiated the arteries from the veins* (*Fig. 1.5*).

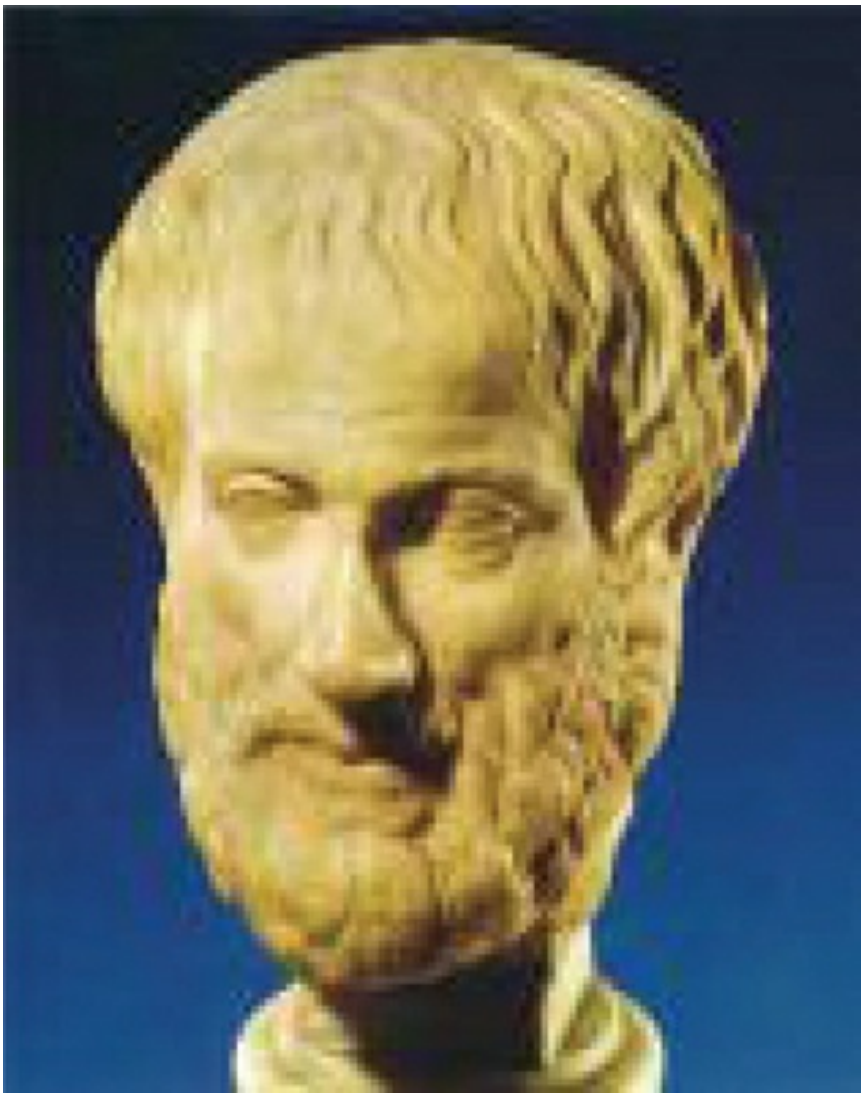


FIG. 1.5 ■ Aristotle.

In spite of his tremendous achievements, Aristotle perpetuated some erroneous views of anatomy. For example, according to him, the heart and not the brain was the seat of intelligence.

He was the first person to use the term *anatome,* a Greek word 'cutting up'.

Herophilus (cir. 325 BC)

Herophilus was a great teacher of anatomy who taught at the School of Medicine in Alexandria, the erstwhile capital of Egypt. Through the vivisections, the study of anatomy flourished in the School of Medicine in Alexandria because of the acceptance of dissections of human cadavers and of living human beings (**vivisections**). These vivisections were performed on condemned criminals with the permission of king 'Ptolemy I Soter (cir. 366–

282 BC)'. The people reasoned that the functions of the human body could be best understood if they were studied in an alive person. A condemned man could repay society through the use of his body for vivisection (dissections of living humans) and dissections of human cadavers, Herophilus provided great descriptions of the skull, eye, various visceral organs and their relationships. He also described the functional relationship of the spinal cord to the brain. Herophilus regarded the brain as the 'seat of intelligence' and described many of its structures such as the cerebrum, cerebellum and the fourth ventricle. He was the first scholar to identify that nerves are either sensory or motor. Two monumental works of Herophilus were titled *On anatomy* and *On the eyes* (Fig. 1.6).

FIG. 1.6 ■ Herophilus.

Roman period

Claudius Galen (cir. AD 130–216)

Galen was perhaps the best physician after Hippocrates. He was the foremost practitioner of the contemporary times in Rome and was called the *Prince of Physicians*. He was certainly the most influential writer of all time on medical subjects. He wrote voluminously and theorized on many medical subjects such as anatomy, physiology, pathology, symptomatology and treatment. Galen's work was mainly based on the data on non-human animals; therefore, it contained many errors. He did, however, provide some accurate anatomical details that are still regarded as classics. For 1,500 years (known as the Galenic age), his writings were taken as an unquestionable authority on anatomy and medical treatment (Fig. 1.7).

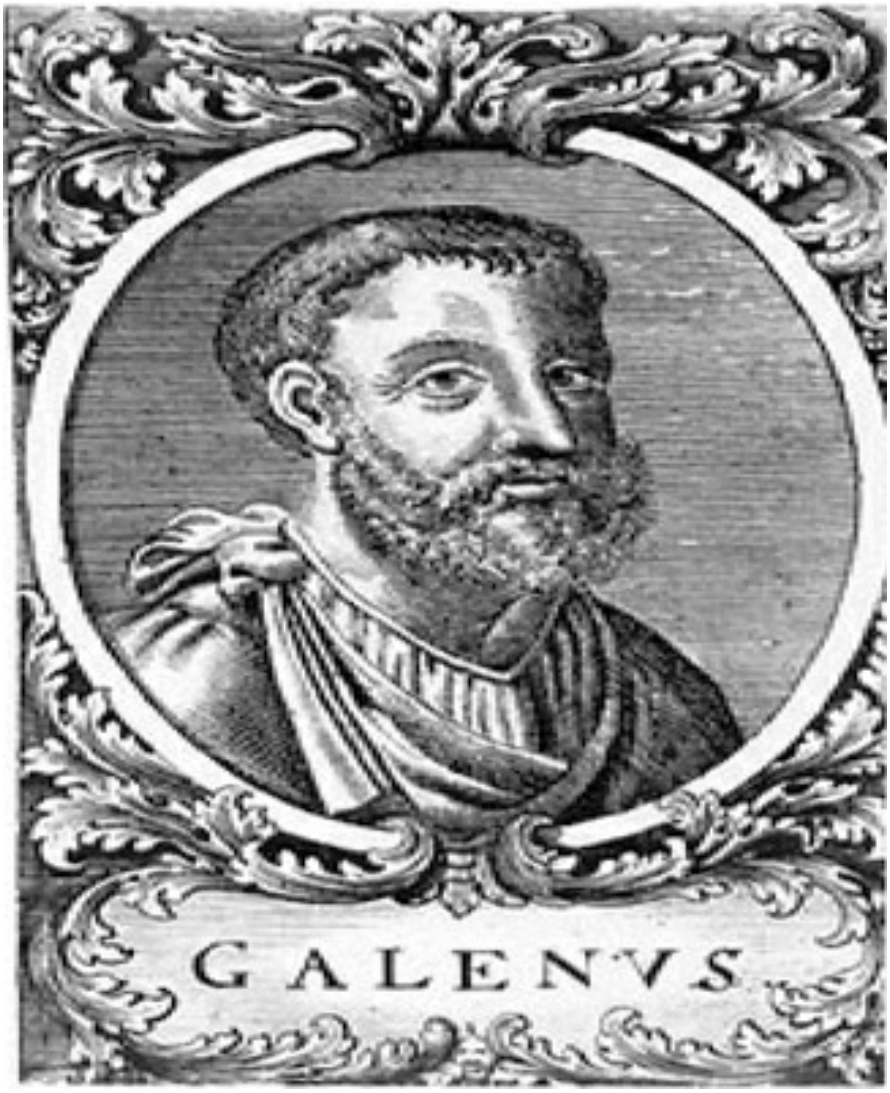


FIG. 1.7 ■ Claudius Galen.

Renaissance period

It is the period when both arts and science were revived. It lasted from the 14th century to the 16th century AD and was a transitional period from the middle ages to the modern age of science. The middle ages were frequently referred to as the **dark ages** because there was no progress in arts and science during this period in Europe. It began with the fall of Rome in AD 476 and lasted for nearly 1,000 years.

Leonardo da Vinci (AD 1452–1519)

He was a great Italian genius who displayed his abilities as a painter, sculptor, architect, musician and anatomist. He is best known for his artistic

works, such as *Mona Lisa* (Fig. 1.8).

FIG. 1.8 ■ Leonardo da Vinci.

As an anatomist, Leonardo da Vinci observed dissections on cadavers very carefully and intended to publish a textbook on anatomy with the Pavian Professor, Marcantonio Della Torre. His plan failed due to the untimely death of Della Torre at the age of 31 years. When Leonardo died, his anatomical sketches were lost, and they remained undiscovered for over four centuries. His 60 notebooks containing nearly 500 diagrams were later published in the year 1898. He was intent on accuracy and his illustrations showed the structural relationships of many organs. The advancement of anatomy would have accelerated by many years if Leonardo's notebooks had been available to the world at the time of his death.

He is considered an originator of cross-sectional anatomy and is the first to describe the moderator band of the right ventricles. He constructed different models of the heart valves to demonstrate their actions.

Sixteenth century

Andreas Vesalius (AD 1514–1564)

The contribution of Andreas Vesalius to the science of human anatomy is immeasurable. Vesalius was born in Brussels to a family of physicians. He was a Professor of anatomy at the University of Padua in Italy. He performed human dissections and initiated the use of live models to determine the surface landmarks for internal structures. His masterpiece anatomical treatise, *De Humani Corporis Fabrica Libri Septem* (*On the Workings of the Human Body*), written in seven volumes at the young age of 28 years revolutionized the teaching of anatomy and remained an authoritative text for two centuries. Various body systems and individual organs were beautifully illustrated and described in the above book. In his book, he boldly challenged hundreds of Galen's erroneous concepts that were taught as facts. Bitter controversies ensued between Vesalius and Galenic anatomists. Vesalius became so incensed by the relentless attacks that he destroyed much of his unpublished work and stopped doing dissections. However, by freeing anatomy from many of Galen's errors, Vesalius laid the foundation on which many subsequent advances in medicine and surgery occurred (Fig. 1.9).

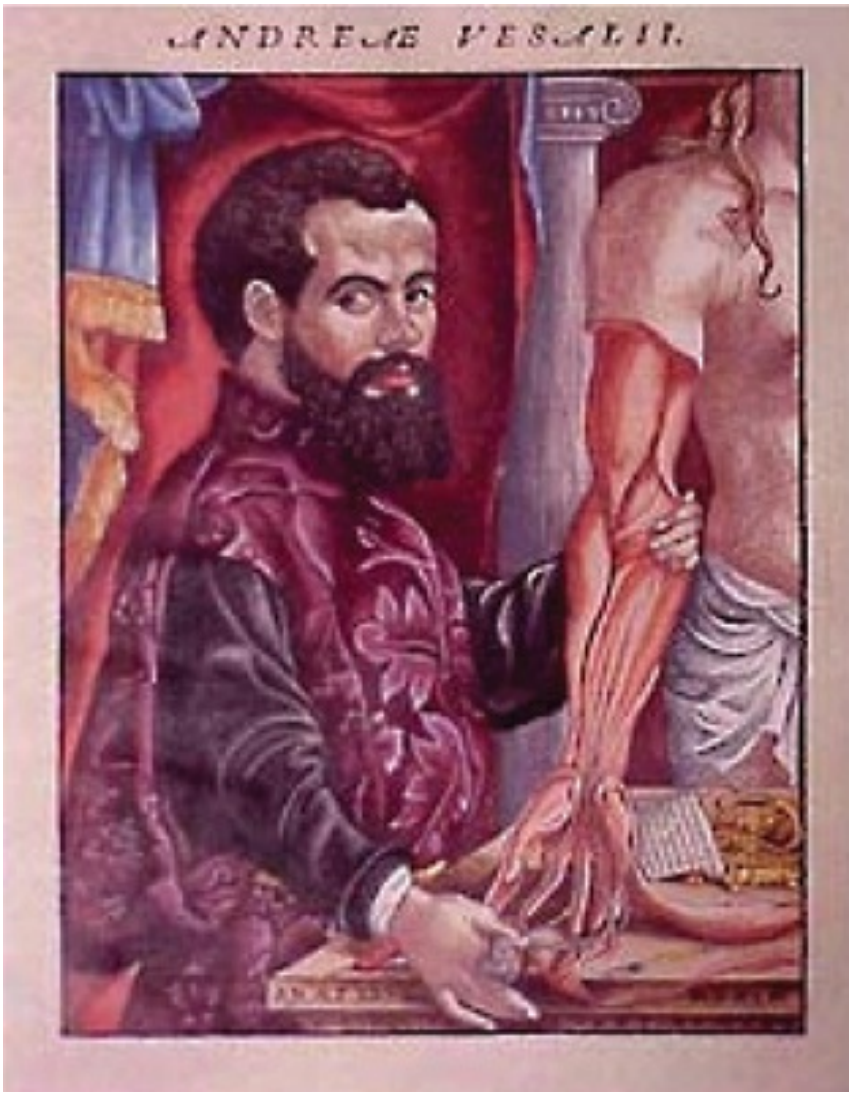


FIG. 1.9 ■ Andreas Vesalius.

Another contribution of Vesalius is that unlike other anatomists of his time (namely, Jacobus Sylvius, Fallopius, Eustachius, etc.), Vesalius chose not to have his name attached to the parts of the body that he described. He remained a teacher of anatomy and a bachelor throughout his life.

Vesalius was the greatest anatomist of his time and is now regarded as the **Father of Modern Anatomy**. He is also called the **Reformer of Anatomy**.

Seventeenth and 18th centuries

During the 17th and 18th centuries, the science of anatomy attained unparalleled acceptance and theatrical status. The human dissections were demonstrated to the public. Two of the most important contributions during this period were:

(a) Explanation of blood flow
(b) Development of microscope.

William Harvey (AD 1578–1657)

In 1628 AD, William Harvey, a British anatomist, conducted experiments *on the motion of the heart and blood in animals* and published the data. His technique of investigation is still regarded as a classic example of the scientific method of conducting research. He established brilliant proof of the continuous circulation of blood within the blood vessels. He demonstrated that blood circulates and does not flow back and forth through the same vessels. Like Vesalius, he was also severely criticized for his deviation from Galenic philosophy.

William Harvey is credited for providing physiological (functional) orientation to anatomy.

Antonie van Leeuwenhoek (AD 1632–1723)

He was a Dutch lens grinder, who improved the microscope tremendously and achieved a magnification of 270 times. The development of the microscope added an entirely new dimension to the study of anatomy. His many contributions include (Fig. 1.10):

(a) Development of techniques for examining tissues
(b) Description of blood cells, spermatozoa, and skeletal muscle.

FIG. 1.10 ■ Antonie van Leeuwenhoek.

Marcello Malpighi (AD 1628–1694)

An Italian anatomist, Malpighi, has been referred to as the **Father of Histology** because he propounded microscopic anatomy and displayed fine details of the body tissues. His name is associated with Malpighian corpuscles of the kidney and Malpighian bodies of the spleen.

John Hunter (AD 1728–1793)

He was not only one of the foremost surgeons of all time but also the most versatile of scientists. He developed the Hunterian museums in London and Glasgow. He was the brother of William Hunter (AD 1682–1771), who was the founder of anatomical theatre in London in the year 1768 AD. The name, John Hunter, is associated with Hunter's canal (adductor canal). It was John Hunter's study of the capillary system of deer which led to his treatment for an aneurysm that is still in use (Fig. 1.11).

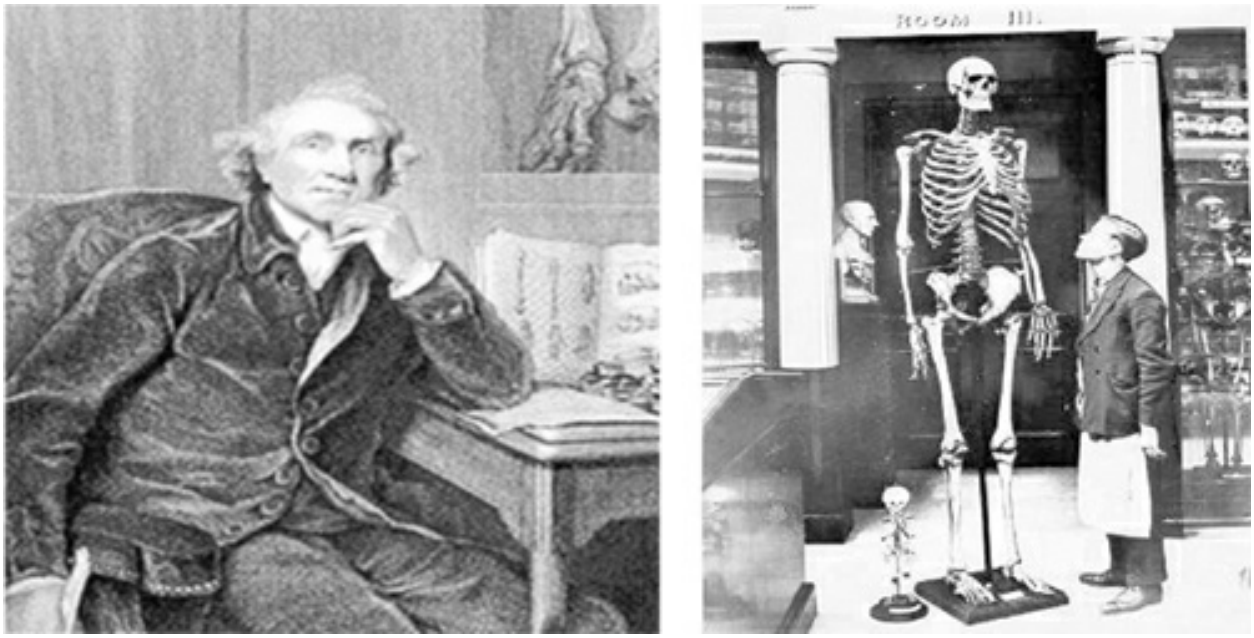


FIG. 1.11 ■ John Hunter.

Wilhelm Conrad Röentgen (1845–1923)

He was a German physicist. He accidentally discovered X-rays in AD 1895 that opened new channels of observations in clinical anatomy that are used in medicine. The X-rays were first used by Röentgen to detect bone fractures and assess the extent of tuberculosis. He was awarded the first Nobel Prize in physics in the year 1901 (Fig. 1.12).

FIG. 1.12 ■ Wilhelm Conrad Röentgen.

N.B.

From 1750 to 1832 AD, the selling of dead bodies flourished immensely in Great Britain and Ireland to interested parties, and people even went to the extent that they resorted to murder for obtaining dead bodies. In 1928, W. Burke and W. Hare were convicted of 16 murders. This led to the enactment of the *Anatomy Act* in London in 1832.

Gregor Johann Mendel (AD 1822–1884)

Mendel performed experiments on plant hybridization. He is known as the **Father of Genetics**.

The other anatomists who made contributions during this period were:

1. **De Graaf:** described ovaries.
2. **Spallanzani:** showed that both the sperm and ovum are necessary for conception.
3. **Francis Glisson:** described the liver, gallbladder, stomach and intestine.
4. **Thomas Willis:** published summary of the nervous system.

Nineteenth century

The major contribution in the 19th century was the formulation of the cell theory and its implications in the understanding of the structure and functioning of the body.

Anatomy became a comparative science during this period. **Dissection was made compulsory for medical students during this period in Edinburgh and Maryland.**

The noted anatomists of this century include:

1. Astley Cooper
2. Georges Cuvier
3. Meckel
4. Henry Gray.

Henry Gray (AD 1827–1861)

Henry Gray, an English anatomist and surgeon, was most popular for his book *Gray's Anatomy*. He was born in Windsor Castle in 1827, London, United Kingdom, and died from smallpox in 1861 in London, the United Kingdom at an early age of 34 years. He was elected fellow of the Royal Society at age 25, a rare distinction to be conferred on a young person (Fig. 1.13).

FIG. 1.13 ■ Henry Gray.

The original *Gray's Anatomy* was written by Henry Gray along with his friend Henry Carter entitled '*Anatomy: Descriptive and Surgical*'. It had 750 pages and 363 figures and was published by John W. Parker and Son, West Strand, in 1858 AD.

Twentieth century

With the advent of the electron microscope, the study of anatomy during this period became specialized and research became more detailed and complex.

The other innovation that gained momentum early in the 20th century was the **simplification and standardization of nomenclature**.

During this century, with the advent of newer imaging techniques such as CT, ultrasonography, MRI, positron emission tomography (PET) scan, etc.

more and more importance is being given to the radiological anatomy.

Twenty-first century

New virtual reality is being used to perform dissection on cyber cadavers. Currently, the visible human project created by National Health Institute (NIH), USA, is an extraordinary digital image library that is highly useful in orienting and associating structures seen in a cadaver in an exact location in a cross-section of the body.

N.B.

As seen in medical curricula, prescribed all over the world, it appears that the main objective of learning anatomy today is to use anatomical knowledge in understanding and solving clinical problems.

Golden Facts to Remember

• **Father of Anatomy**	Herophilus
• **Father of Modern Anatomy**	Vesalius
• **Father of Surgery**	Sushruta
• **Father of Medicine**	Hippocrates
• **Father of Histology**	Marcello Malpighi
• **Father of Genetics**	Gregor Johann Mendel
• **Term *'anatomy'* was coined by**	Aristotle (2300 years back)
• **Who considered the human body as God's most beautiful creation**	Andreas Vesalius
• **First Scientist to dissect the human body**	Herophilus
• **Human vivisections (dissections of the living human body) were allowed in**	School of Medicine in Alexandria (Egypt)
• **Two monumental works of Herophilus *are* entitled**	*On Anatomy* and *Of the Eyes*
• **Light microscope was first invented by**	Robert Hooke
• **Modern light microscope was first designed by**	Abbe

• **Term *'cell'* was first coined by**	Robert Hooke in AD 1665
• **First outstanding work on the motion of the heart and blood in animals was done by**	William Harvey in AD 1628
• **Leonardo da Vinci is best known for**	His artistic work *Mona Lisa*
• **The person who had dissected about 600 living human beings**	Herophilus (cir. 325 BC)
• **Embalming technique was first developed by**	The Egyptians (cir. 3400 BC)
• **People who regarded liver as the source of human emotions**	People of ancient Mesopotamia[a]
• **First recorded anatomical observations made in early Mesopotamia were**	Early Mesopotamia on clay models of sheep's liver over 3000 years ago
• **Best known but least understood contribution of Chinese to anatomy is**	Acupuncture[b]
• **First manual on anatomy was written**	In Egypt about 3400 BC (i.e. even before the pyramids were built)

[a]Mesopotamia was the name given to a long narrow wedge of land between the Tigris and the Euphrates rivers, which is now a large part of present-day Iraq. This area was settled in 4000 BC. Because of the recorded information and culture of the people, Mesopotamia is frequently called the 'Cradle of Civilization'.

[b]Acupuncture has gained acceptance with some medical specialists in the United States as a technique of anaesthesia. The Chinese identified 365 precise meridian sites or vital points that correspond to the number of days in a year. The needles inserted at these sites cure body ailments. The effectiveness of acupuncture has been documented.

Multiple choice questions

1. **The term anatomy is derived from the Greek word *anatome* meaning:**
   (a) To analyze
   (b) To cut up
   (c) To observe death
   (d) To cut anus
2. **What is not true about Hippocrates?**
   (a) He was a famous Greek physician
   (b) He had wide exposure to human dissections

(c) He had attributed diseases to natural causes
(d) He is regarded as the 'Father of Medicine'

3. **The anatomical masterpiece *De Humani Corporis Fabrica* was written by:**
   (a) Galen
   (b) Herophilus
   (c) Leonardo da Vinci
   (d) Vesalius
4. **Who is regarded as the Father of Modern Anatomy?**
   (a) Aristotle
   (b) Herophilus
   (c) Galen
   (d) Vesalius
5. **Who is regarded as the Father of Histology?**
   (a) Leeuwenhoek
   (b) Malpighi
   (c) Schleiden and Schwann
   (d) Watson and Crick
6. **The X-rays were discovered by:**
   (a) Röentgen
   (b) Madam Curie
   (c) Hooke
   (d) Muller
7. **What is not true about Aristotle?**
   (a) He was a pupil of Plato
   (b) He wrote the first known account of embryology
   (c) He thought the heart to be the seat of intelligence
   (d) He had written eight volumes of *De Re Medicina*
8. **A trend towards simplification of anatomical nomenclature began in:**
   (a) 17th century
   (b) 18th century
   (c) 19th century
   (d) 20th century
9. **What is not true about Sushruta:**
   (a) He practised medicine in Kashi
   (b) He is known as the Father of Surgery
   (c) He was a disciple of Charaka
   (d) He called anatomy *Sharira Sthana*

Answers

1. *b*, **2.** *b*, **3.** *d*, **4.** *d*, **5.** *b*, **6.** *a*, **7.** *d*, **8.** *d*, **9.** *c.*

Chapter 2: Anatomical terminology

Specific learning objectives

After studying this chapter, the student should be able to:

- Explain why anatomy is a very precise science.
- Demonstrate the normal anatomical position and describe the anatomical planes of the body. **AN 1.1**
- Recall the terms that are used to describe joint movements. **AN 1.1**
- To know directional terms to describe the relationship, make comparison and show laterality. **AN 1.1**
- Explain why directional terms are relative and must be used in reference to body structure or a body in anatomical position. **AN 1.1**
- Outline the terms used in clinical anatomy.
- Present a brief account of anatomical nomenclature.
- Explain how various anatomical terms are derived.
- Correctly solve the Multiple Choice questions provided at the end of the chapter.

Anatomy is a very precise science because of its universally accepted terminology for describing body parts and their locations.

In order to understand this science, students must master the terms used to describe various anatomical structures and features. A brief analysis of

these terms would not only be an exciting experience but also provide a glimpse into our medical heritage.

The majority of anatomical terms are derived from Greek or Latin, but some of the more recent terms are of German, French and British origin.

Many terms that refer to common plants or animals, namely the word *vermis* means worm; *cochlea* stands for the shell of a snail; *cancer* refers to crab; *uvula* means little grape and even *muscle* is derived from the Latin word *musculus*, which means mouse.

The other anatomical terms are derived from materials and their meanings were used during wars namely, *thyroid* means shield, *Xiphos* means sword, *thorax* means breast plates, *sella* means saddle, *stapes* means the stirrups, *malleus* means anvil and *tympanum* refers to drum.

Furthermore, the students can learn these terms more easily if they understand the meaning of their prefixes and suffixes.

Unfortunately, some of the anatomical terms have been coined in honour of various anatomists, surgeons and physicians, viz. *Poupart's ligament* for inguinal/groin ligament, *Fallopian tube* for uterine tubes etc. Such terms are called *eponyms*. They have no descriptive basis and cannot be associated with anything, and therefore they must be avoided in use or simply be memorized.

Positions of the body

Anatomical position AN1.1

An anatomical position is the reference position of the body.

In this position, a person is considered to be standing erect with eyes looking forward at horizon; the upper limbs hanging by the side of the body with palms facing forwards; the lower limbs positioned straight with feet approximated together and flat on the floor and toes pointing forwards (Fig. 2.1).

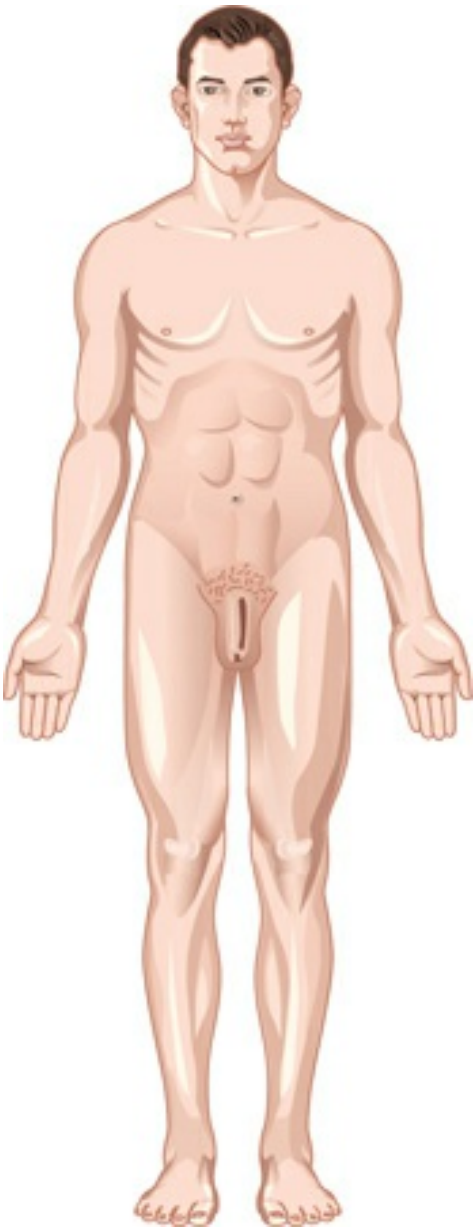


FIG. 2.1 ■ Anatomical position.

In the medical profession, the body parts and their relationships are always described presuming that the body is in an anatomical position, although it may lie or be placed in any position. Although in anatomical position the position of forearms and hands is not a natural one, it does allow for accurate description.

This position is assumed in all anatomical descriptions to ensure accuracy and consistency.

In medicine, all descriptions of the human body are made in anatomical position.

Fundamental position

It is the same as the anatomical position except that the palms of the hand face the sides of the body (Fig. 2.2). This position is often used in discussing the rotation of the upper limbs such as pronation and supination.

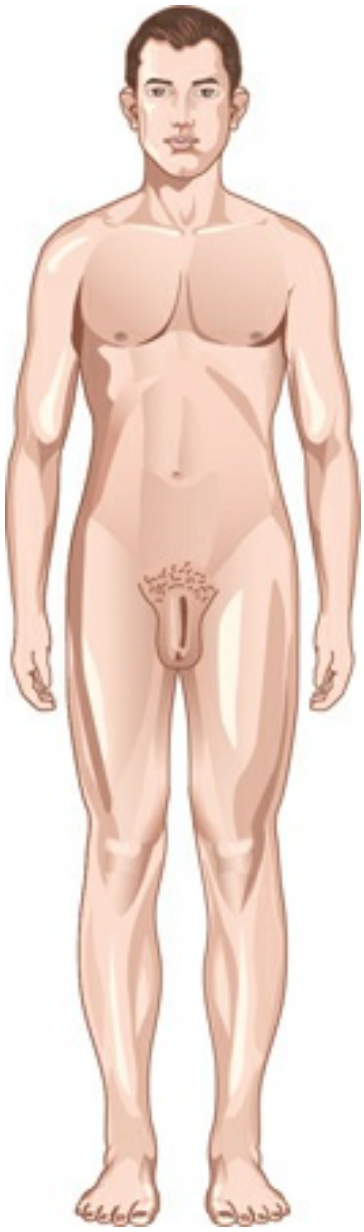


FIG. 2.2 ■ Fundamental position.

Other positions of the body

Some frequently used terms in clinical practice referring to body positions are as follows:

1. **Supine position (recumbent position):** The person lies on the back with his/her face directed upwards (Fig. 2.3).
2. **Prone position:** The person lies on his/her belly (abdomen) with his/her face directed downwards (Fig. 2.4).
3. **Lithotomy position:** The person lies supine with buttocks at the edge of the table. The hips and knees are semi-flexed and the thighs are abducted (Fig. 2.5). This position is used for having adequate exposure to the perineum.

FIG. 2.3 ■ Supine position.

FIG. 2.4 ■ Prone position.

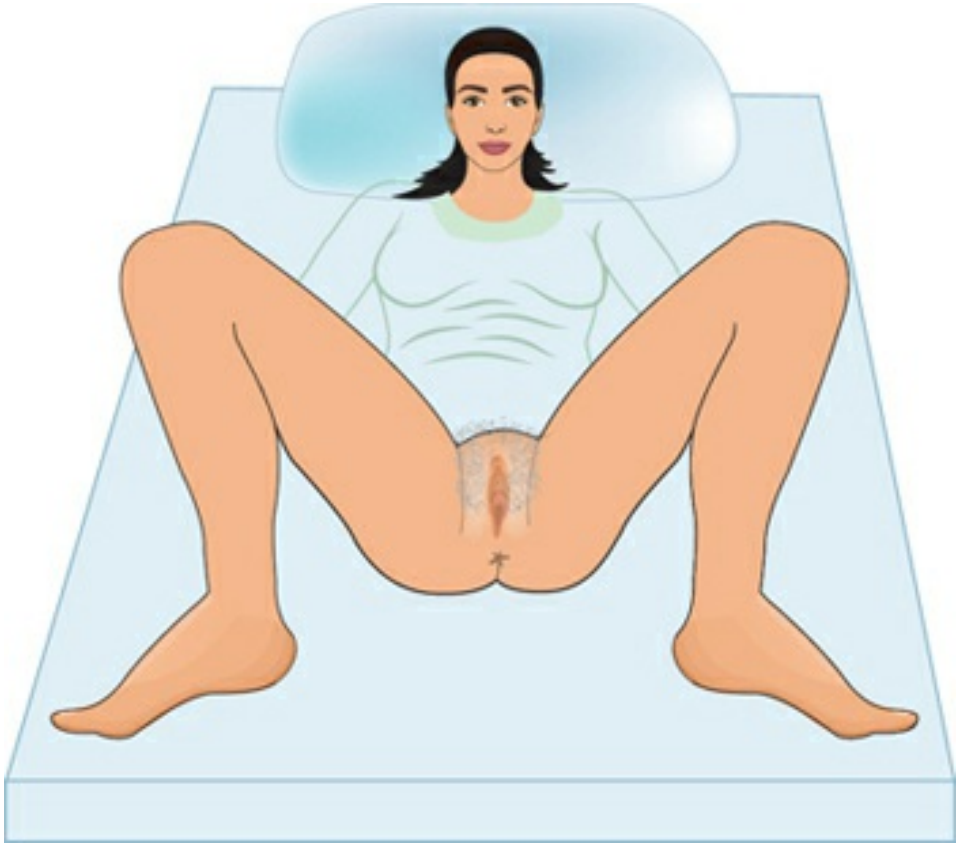


FIG. 2.5 ■ Lithotomy position.

Anatomical planes of the body AN1.1

There are 3 fundamental planes of body (Fig. 2.6). These are:

1. **Midsagittal plane (or median longitudinal plane):** It passes longitudinally through the sagittal suture (midline) and divides the body into equal right and left halves.
   Although showing it clearly on the surface of the body, these halves are generally symmetrical in structure, the same symmetry does not apply to all internal structures.
2. **Sagittal/parasagittal plane:** Any longitudinal plane which passes parallel to the midsagittal plane is termed the sagittal/parasagittal plane. It divides the body into unequal right and left halves.
   Coronal (or frontal) plane: It passes longitudinally at right angles to the median plane and divides the body into the anterior and posterior portions. It corresponds to the coronal suture, hence, termed the coronal plane.
3. **Transverse plane (horizontal or cross-sectional plane):** It passes

parallel to the horizon (ground) at a right angle to the long axis of the body, dividing the body at any level into superior upper and inferior lower portions. It is perpendicular to the median plane.

N.B.

- Any plane other than midsagittal, sagittal, coronal and transverse is termed an ***oblique plane***.
- Whenever the plane passes through the centre of the body, be it sagittal, frontal or transverse, it is referred to as the **cardinal plane** because it divides the body into equal parts.

The point at which the three cardinal planes intersect each other is the **centre of gravity**.

The planes commonly used in clinical practice are drawn in Figure 2.7A, and B.

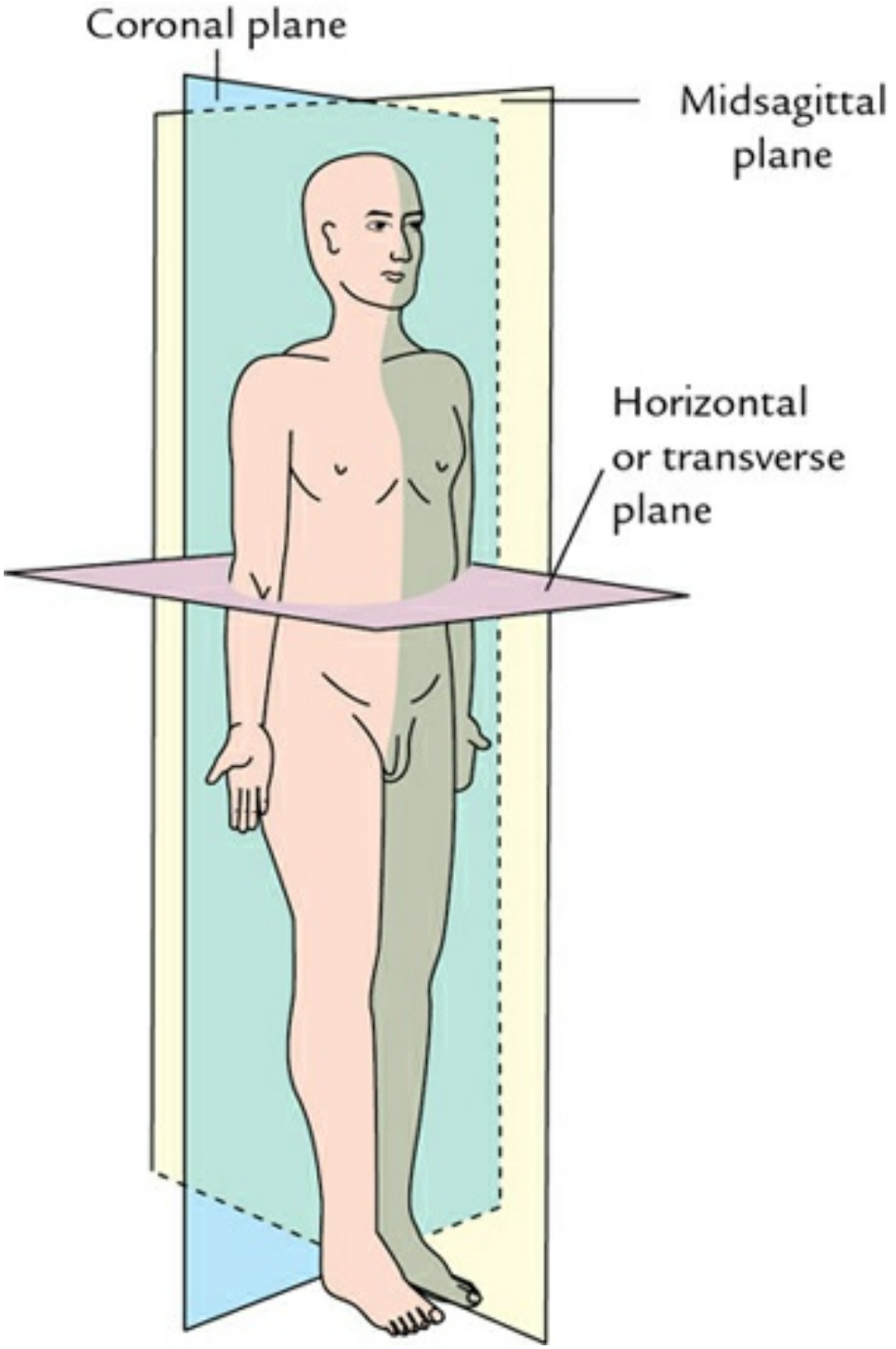
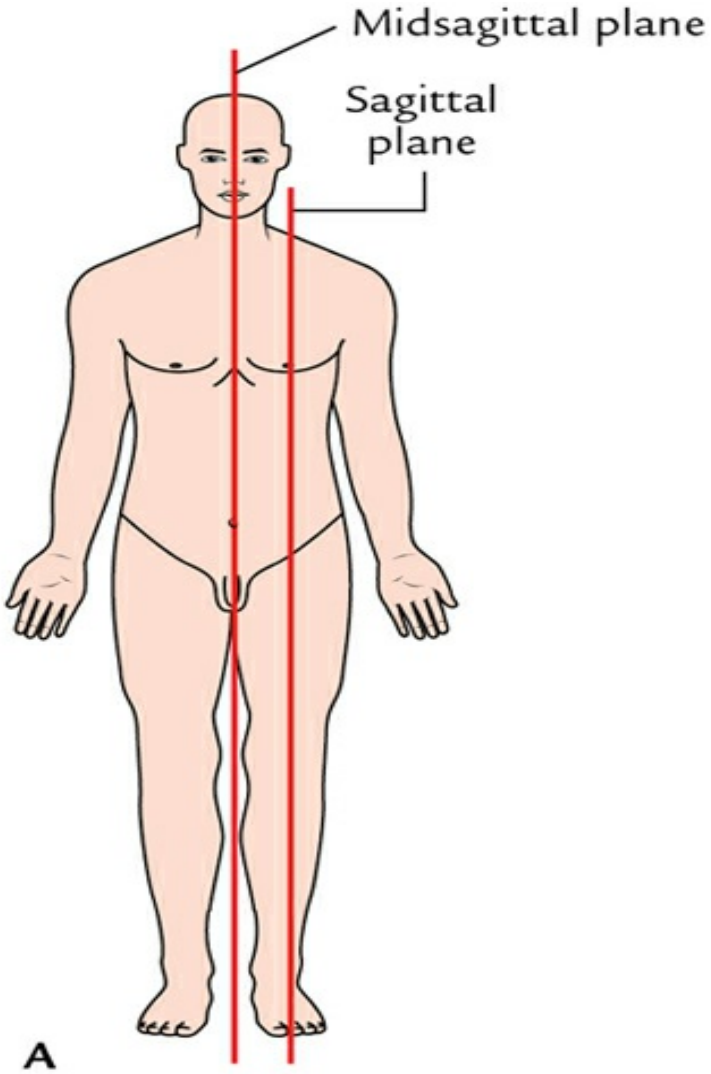


FIG. 2.6 ■ Three fundamental planes of the human body in anatomical position.


Midsagittal plane
Sagittal plane
A

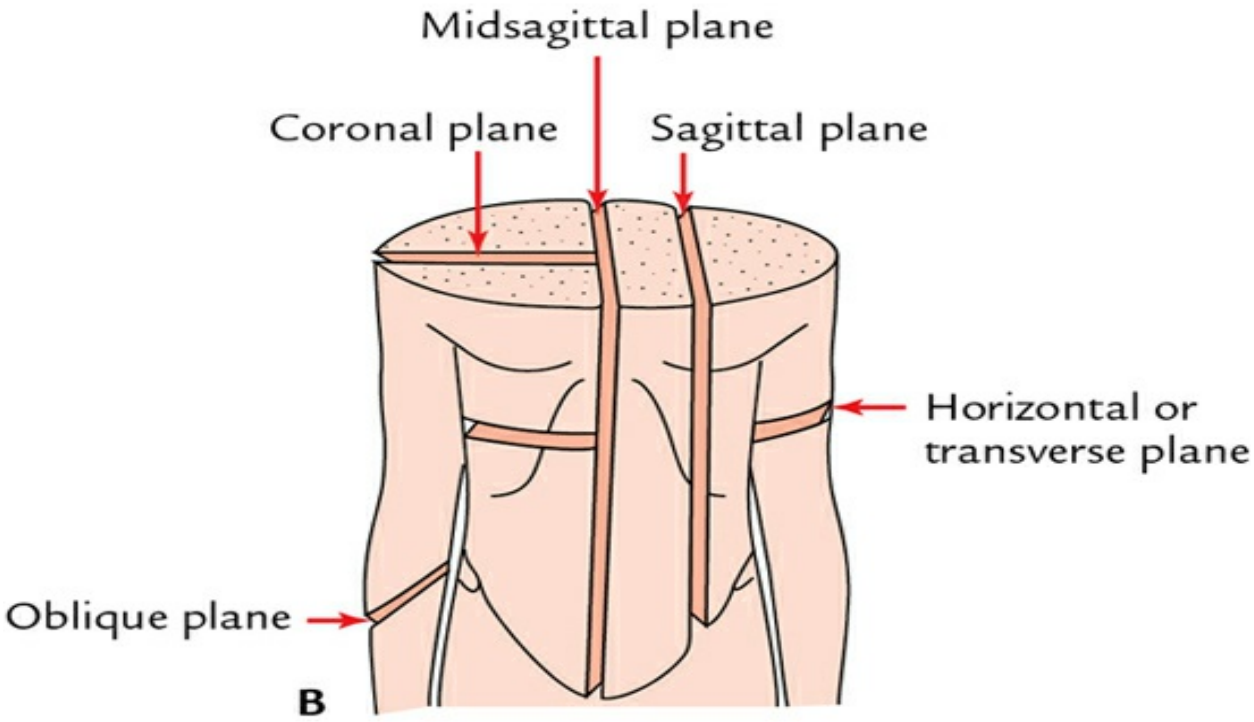

Midsagittal plane
Coronal plane
Sagittal plane
Horizontal or transverse plane
Oblique plane
B

FIG. 2.7 ■ Planes commonly used in clinical practice.

The major anatomical planes of the body are summarized in Table 2.1.

TABLE 2.1

Major anatomical planes of body.

Plane	Features
1. Midsagittal plane (median plane)	A longitudinal (vertical) plane which divides the body into equal right and left halves
2. Sagittal plane	A longitudinal (vertical) plane which divides the body into unequal right and left halves
3. Coronal plane	A longitudinal (vertical plane) which divides the body into anterior (front) and posterior (back) portions. This plane is perpendicular to the longitudinal plane
4. Transverse plane	A horizontal plane which divides the body/part of the body into upper (superior) and lower (inferior) parts

Anatomical terms AN1.1

Descriptive terms

Terms used to describe the relationship between body parts and/or structures relative to each other are as follows (Fig. 2.8 A–D):

1. **Anterior:** Towards the front aspect of the body.
2. **Posterior:** Towards the back aspect of the body.
3. **Superior:** Towards the head.
4. **Inferior:** Towards the feet.
5. **Central:** Towards the centre of the mass of the body.
6. **Peripheral:** Away from the centre of the mass of the body.
7. **Median:** Along the midsagittal (median) plane.
8. **Medial:** Towards the median plane.
9. **Lateral:** Away from the median plane.

10. **Intermediate:** Between medial and lateral.
11. **External:** Close to the surface of the body.
12. **Internal:** Close to the centre of the body.
13. **Superficial and deep:** These terms are used to describe the relative positions of the two structures with respect to the surface of the body.
14. **Ventral:** Towards the belly.
15. **Dorsal:** Towards the back.
16. **Cranial/rostral:** Towards the head.
17. **Caudal:** Towards the tail.

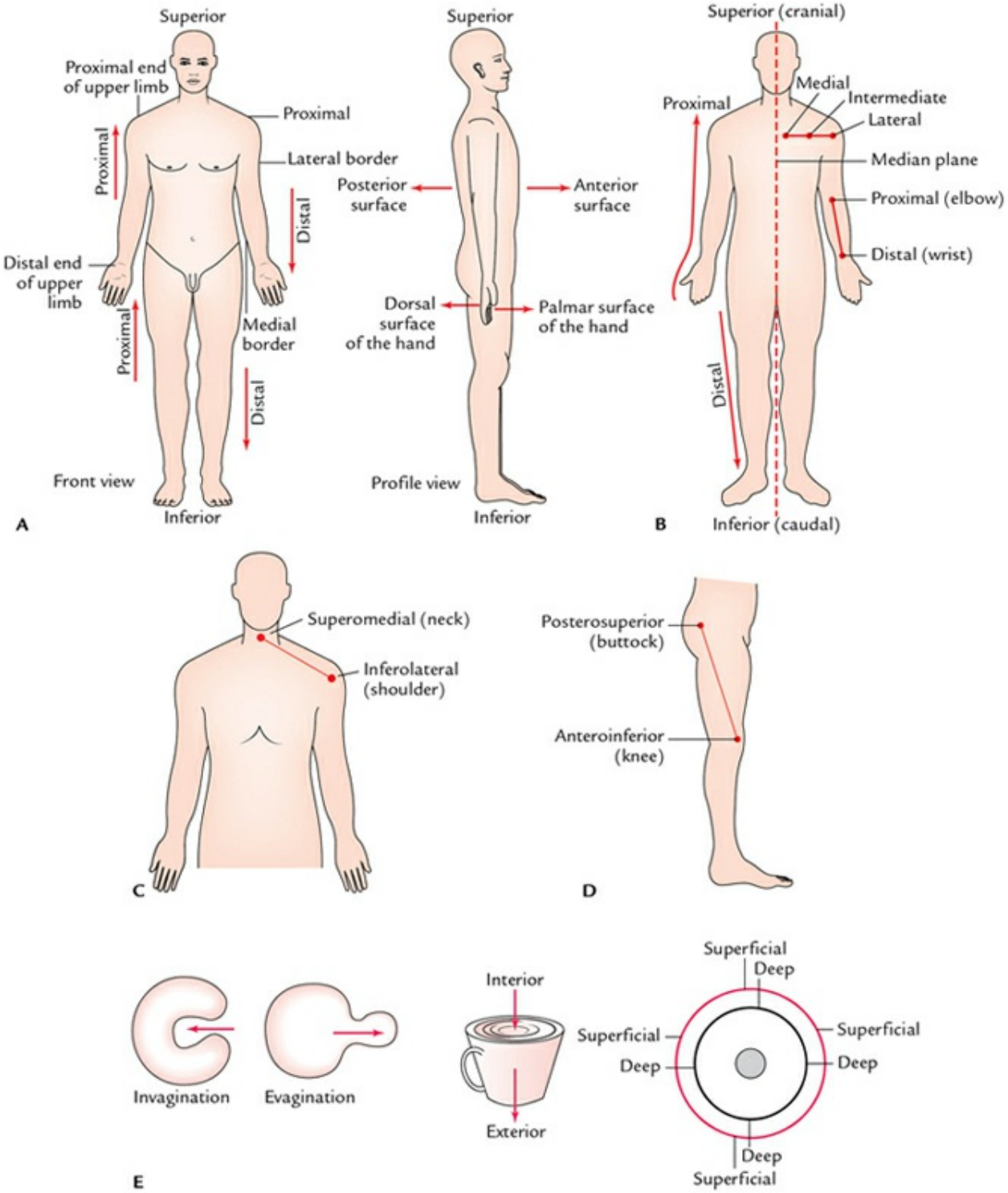


FIG. 2.8 ■ Relative relationship of body parts and/or structures with respect to each other: **(A)** terms referring to the direction of the human body both in front and profile view **(B)** relationship between the location of three different points in the thorax and median plane. It also shows the relationship between elbow and wrist, **(C)** relationship between neck and shoulder, **(D)** relationship between buttock and knee, **(E)** descriptions commonly used for referring to invagination/evagination, exterior/interior or superficial/deep of body structures.

Some other terms (Fig. 2.8E)

1. **Invagination:** Inward protrusion.
2. **Evagination:** Outward protrusion.
3. **Interior:** Inside of a hollow organ.
4. **Superficial:** Towards the surface.
5. **Deep:** Towards the centre.
6. **Ipsilateral:** Same side of the body.
7. **Contralateral:** Opposite side of the body.

Special terms used for limbs

1. **Proximal:** Near the trunk.
2. **Distal:** Away from the trunk.
3. **Radial:** Towards the outer border of the upper limb.
4. **Ulnar:** Towards the inner border of the upper limb.
5. **Tibial:** Towards the inner border of the lower limb.
6. **Fibular:** Towards the outer border of the lower limb.
7. **Preaxial border:** The outer border of the upper limb and the inner border of the lower limb.
8. **Postaxial border:** The inner border of the upper limb and the outer border of the lower limb.
9. **Flexor surface:** The anterior surface of the upper limb and the posterior surface of the lower limb.
10. **Extensor surface:** The posterior surface of the upper limb and the anterior surface of the lower limb.
11. **Palmar or volar surface:** Towards the palm of the hands.
12. **Plantar surface:** Towards the sole of the feet.

Terms used to describe joint movements AN1.1

The movements of the body occur at various joints. These movements are described in relation to the axis and the plane, which are perpendicular to each other. They are described in the following terms:

1. **Flexion** (Fig. 2.9): Movement that takes place in the sagittal plane around a *transverse axis*. It approximates the flexor surfaces of the adjoining parts and thus reduces the angle of the joint. For example, the flexion of the elbow approximates the anterior surface of the forearm with the anterior surface of the arm. The flexion is usually an

anterior movement but occasionally it is a posterior movement. For example, flexion of the knee joint.

N.B.

- In the ankle joint, the flexion occurs when the dorsum of the foot is elevated and this movement is termed *dorsiflexion*. Pressing the foot downward as rising on the toes is called *plantar flexion*.
- *Lateral flexion* is the movement of the trunk in the coronal plane.

2. **Extension** (Fig. 2.9): Movement that approximates the extensor surfaces of the adjoining parts and thus increases the angle of the joint. For example, (a) extension of elbows approximates the extensor surface of the forearm with the extensor surface of the arm. Like flexion, the extension also takes place in the sagittal plane around a transverse axis, (b) extension of the knee approximates the extensor surface of the leg with the extensor surface of the thigh.

N.B.

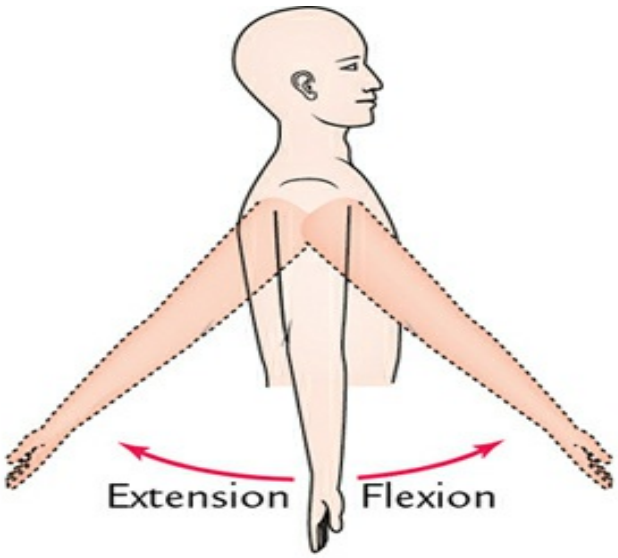
Hyperextension occurs when a part of the body is extended beyond the anatomical position so that the angle of the joint is greater than 180°. For example, when bending the head backwards.

3. **Abduction** (Fig. 2.10)**:** Movement of a limb away from the midline of the body in the coronal plane.
4. **Adduction** (Fig. 2.10): Movement of a limb towards the midline of the body.

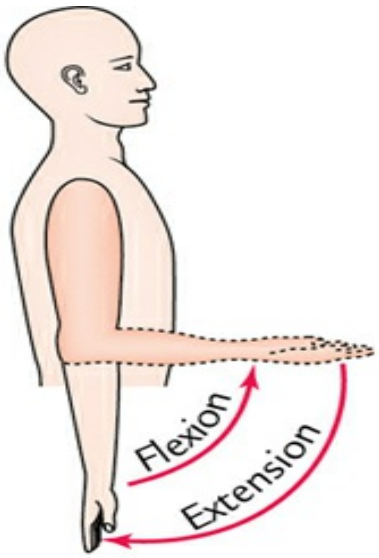
N.B.

- In the case of fingers and toes, the term *abduction* is applied for the spreading of these structures, whereas the term *adduction* is used for approximating these structures (Fig. 2.11).
- In the case of a thumb, the movements are a little complicated (Fig. 2.11) and are described in detail in the *Textbook of Anatomy: Upper limb* (Volume 2).

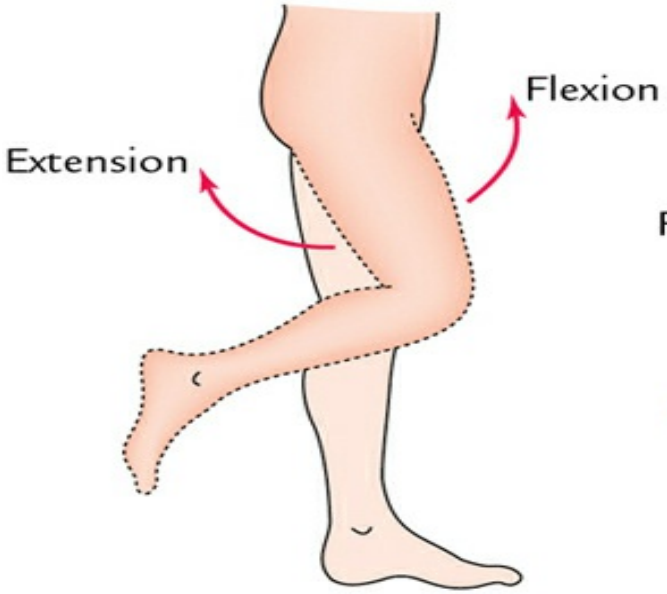
5. **Rotation** (Fig. 2.12)**:** Movements of a part of the body around its long/vertical axis:
   (a) *Medial rotation*: An inward rotation; it results when the anterior surface of the part faces medially.
   (b) *Lateral rotation*: An outward rotation; it results when the anterior surface of the part faces laterally.
6. **Circumduction** (Fig. 2.13)**:** Circular cone-like movement of a body segment, which involves the combination of angular movements in sequence, namely flexion, extension, abduction and adduction. The base of the cone is formed by the distal end of the moving bone. Such type of movement is possible at the biaxial and polyaxial joints, namely wrist, ankle, hip and shoulder joints. During bowling in cricket, there is a circumduction of the upper limb at the shoulder joint where hand-holding a cricket ball moves in a circle (Fig. 2.10).
7. **Supination** (Fig. 2.14)**:** Rotation of the forearm and hand laterally from the mid-prone position around the longitudinal axis so that the palm faces anteriorly.
8. **Pronation** (Fig. 2.14)**:** Rotation of the forearm and hand medially from the mid-prone position around the longitudinal axis so that the palm faces posteriorly.
9. **Inversion** (Fig. 2.15)**:** Movement of the sole in which the sole faces inwards or medially.
10. **Eversion** (Fig. 2.15)**:** Movement in which the sole faces outwards or laterally.
11. **Protraction** (Fig. 2.16A)**:** Movement in which a part of the body moves forward on a plane parallel to the ground. For example, thrusting out the lower jaw (mandible) or thrusting shoulder and arm forward.
12. **Retraction** (Fig 2.16B)**:** Movement in which a part of the body moves backwards on a plane parallel to the ground, that is pulling back the protracted part, namely the mandible.
13. **Elevation:** Movement in which a part of the body is lifted upwards. For example, the elevation of the mandible to close the mouth or elevating the scapula to shrug the shoulder.
14. **Depression:** Movement opposite to elevation.



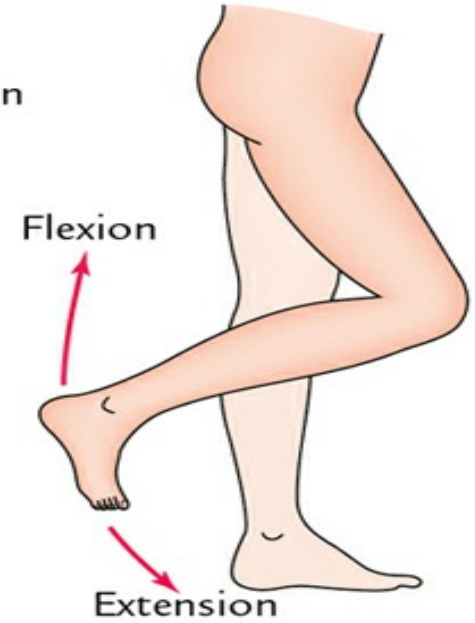
Flexion and extension of shoulder joint



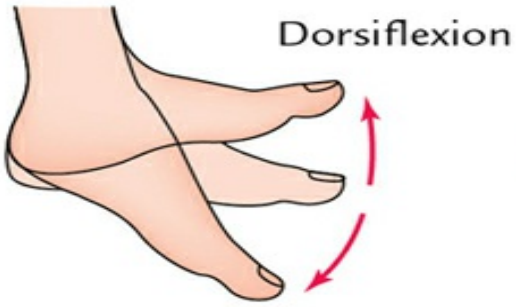
Flexion and extension of elbow joint



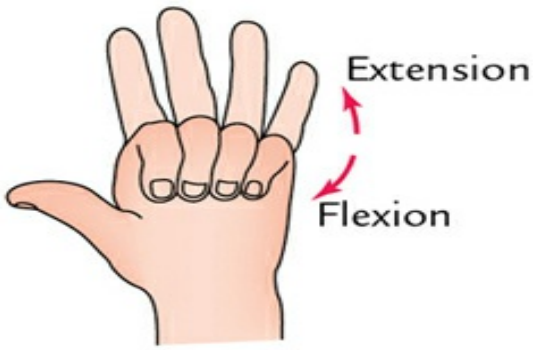
Flexion and extension of hip joint



Flexion and extension of knee joint

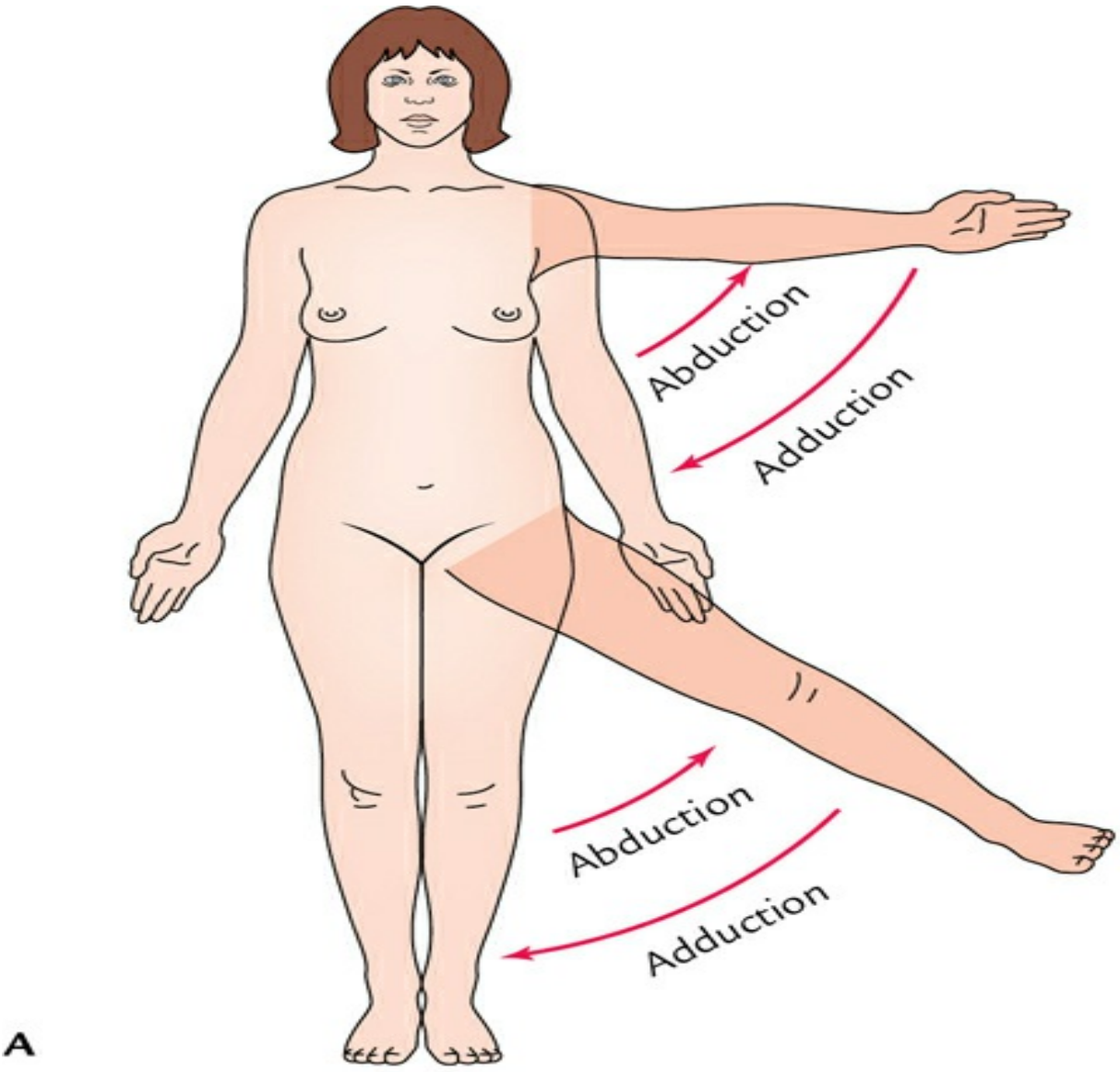


Plantar flexion plantarflexion and dorsiflexion

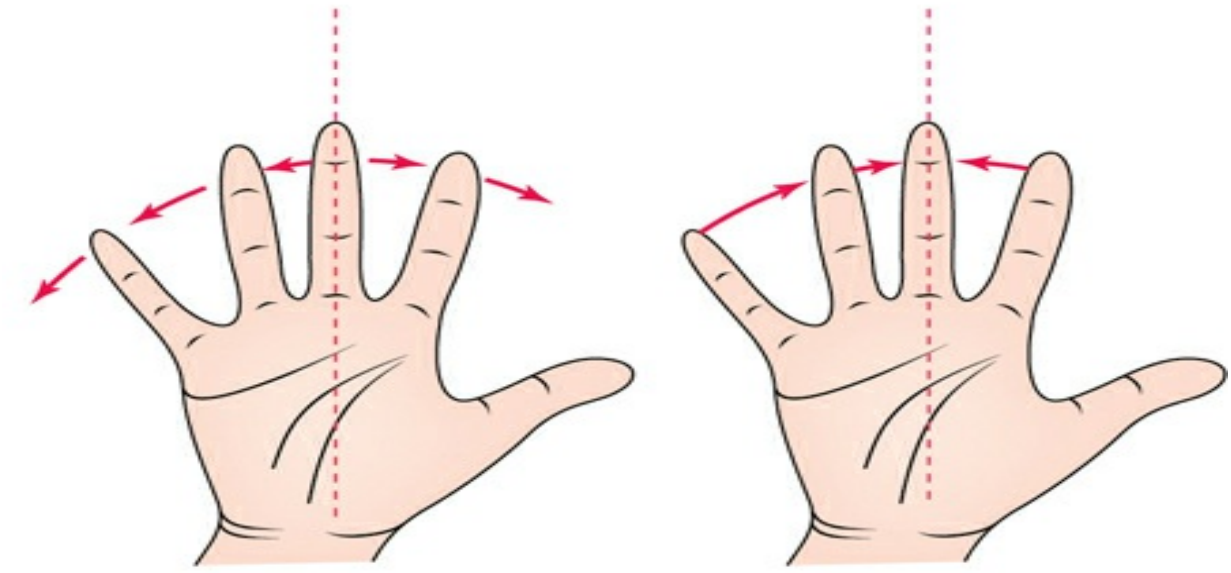


Flexion and extension of fingers

FIG. 2.9 ■ Flexion and extension of joints and fingers.



A



B Adduction of fingers Abduction of fingers

FIG. 2.10 ■ Abduction and adduction of shoulder and hip joints **(A)** and abduction and adduction of fingers **(B)**.

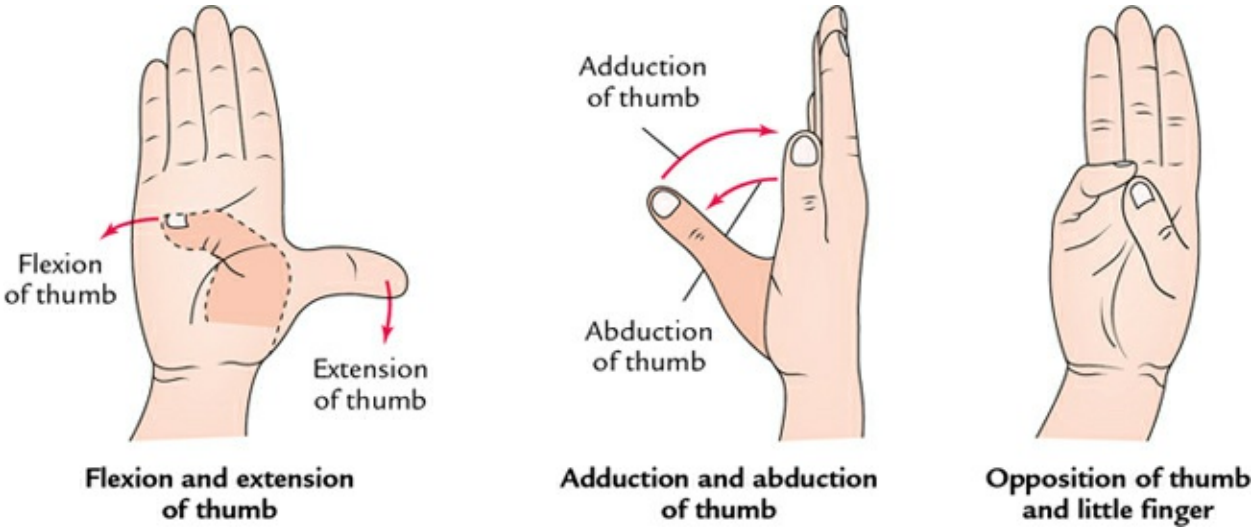


FIG. 2.11 ■ Movements of thumb: Flexion-extension, abduction-adduction and opposition of thumb.

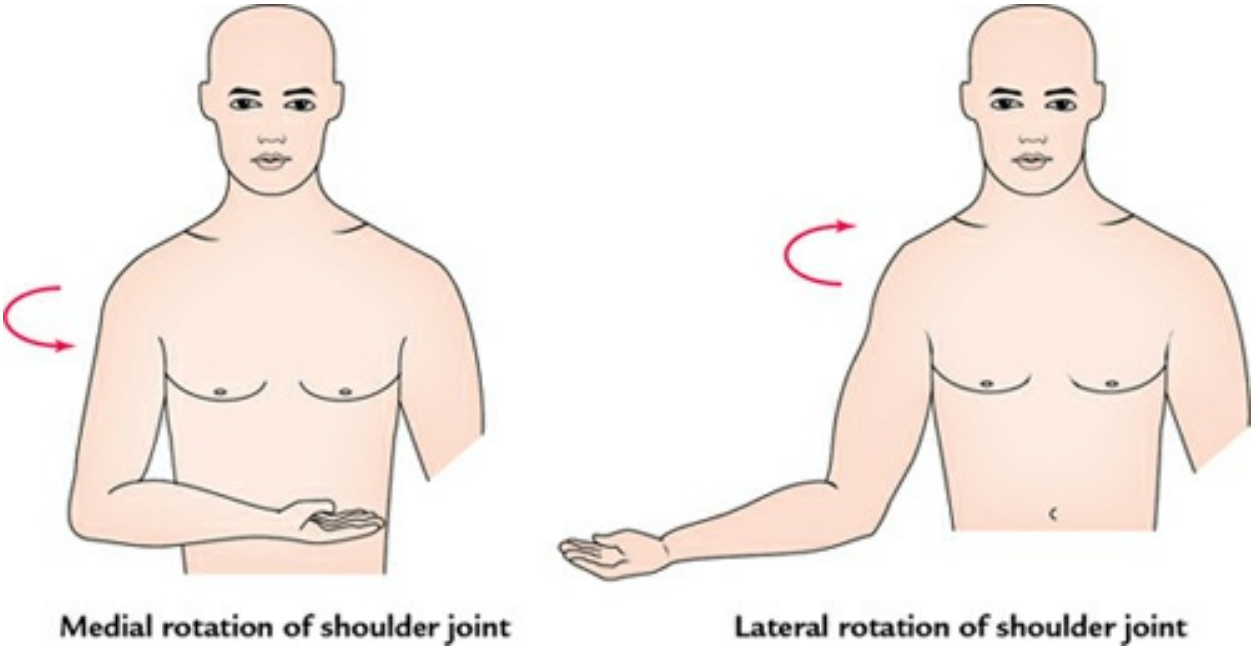


FIG. 2.12 ■ The rotation movement of the shoulder joint.

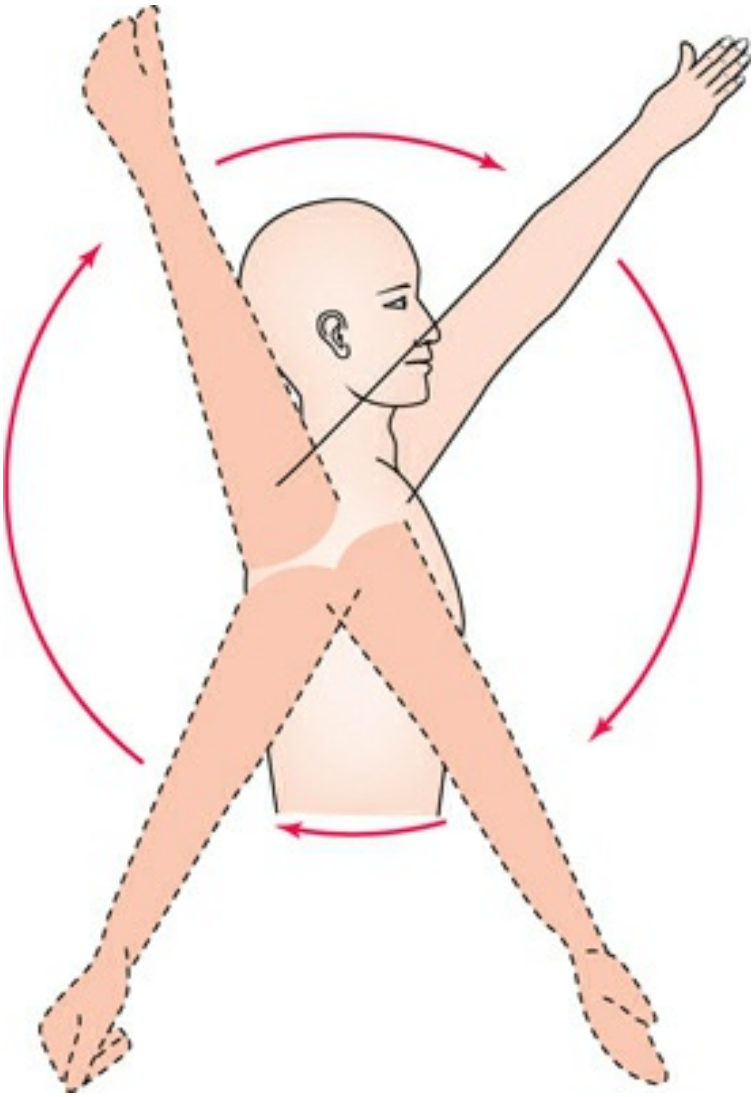


FIG. 2.13 ■ Circumduction of the shoulder joint.

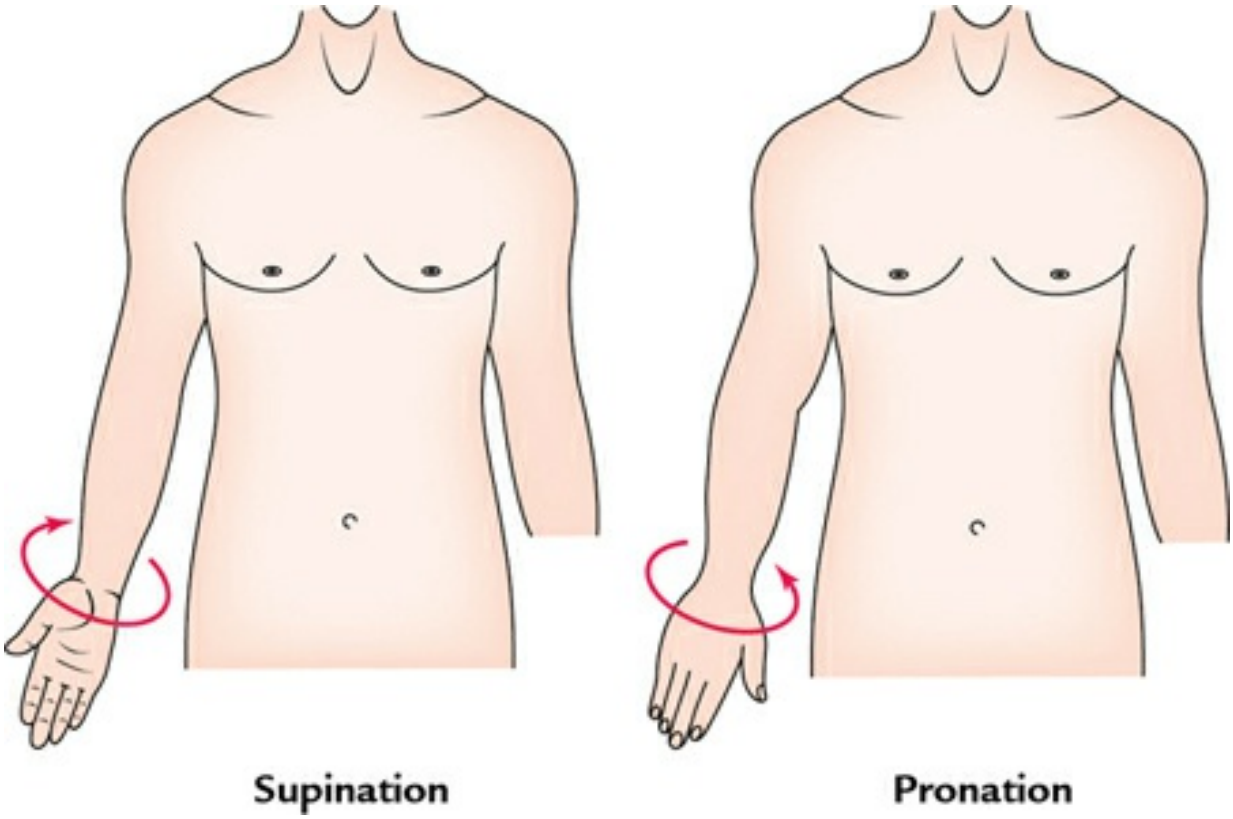


FIG. 2.14 ■ Supination and pronation of the forearm.

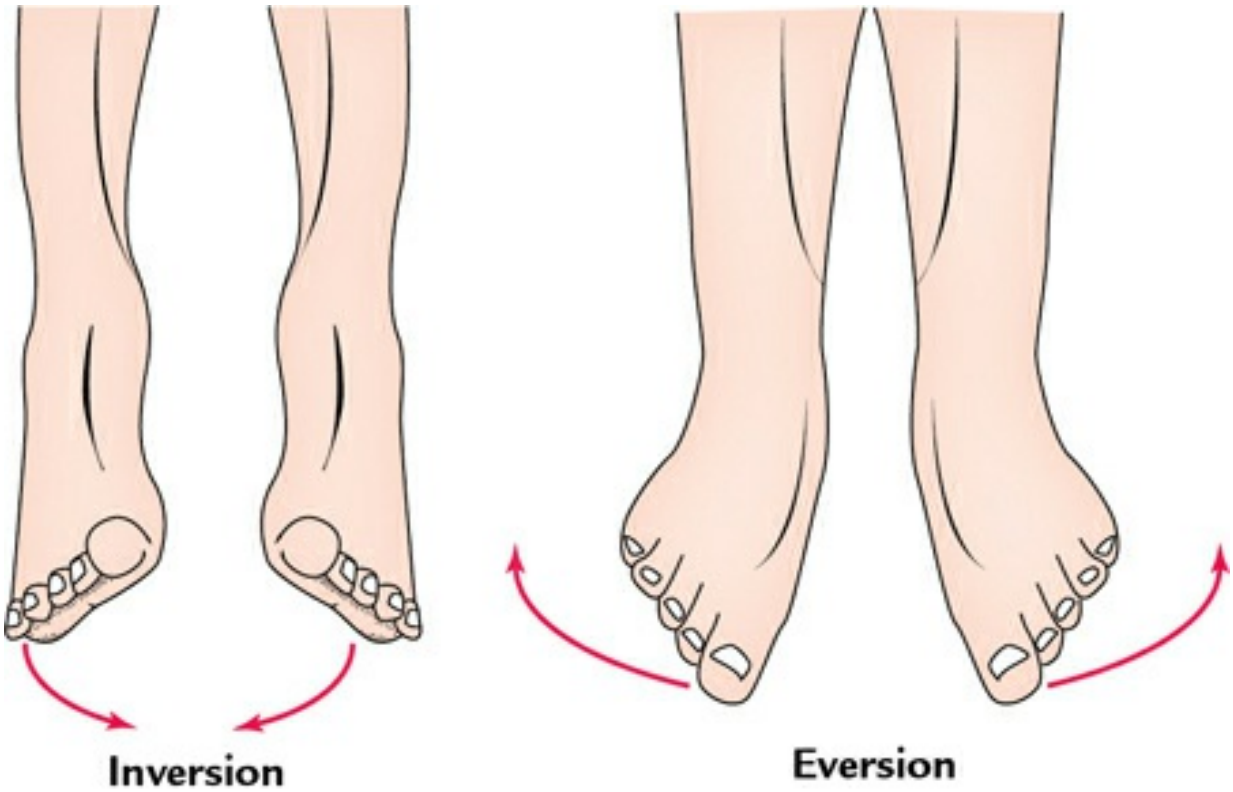


FIG. 2.15 ■ Inversion and eversion of the foot.

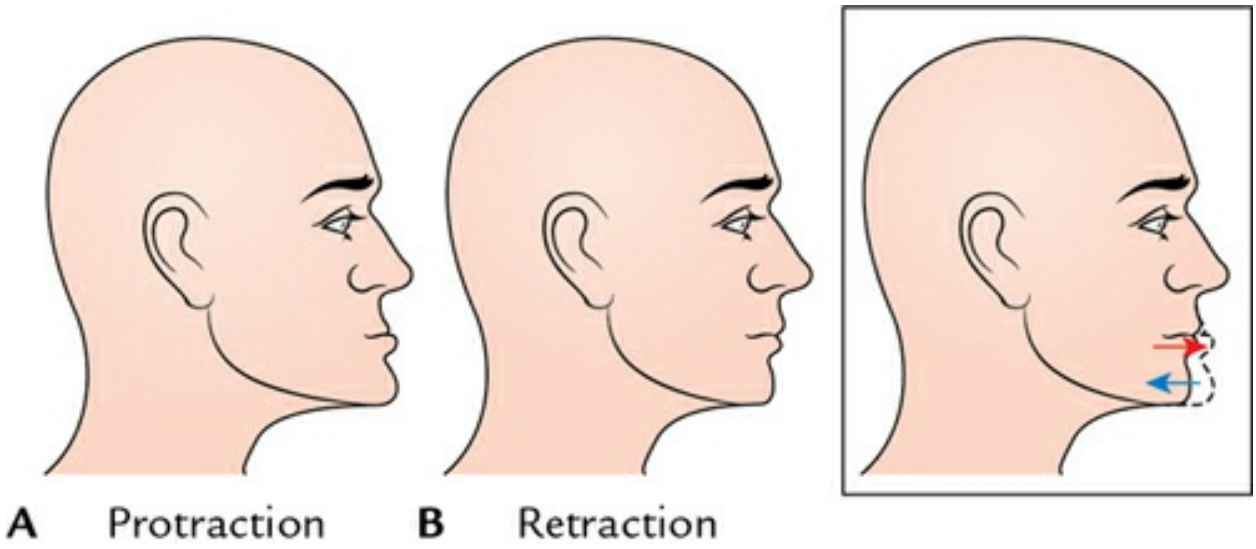


FIG. 2.16 ■ Protraction and retraction of the lower jaw (mandible): **(A)** protraction, **(B)** retraction Figure in the inset on the right side shows both these movements, red arrow shows protraction while blue arrow shows retraction.

Terms used to describe bony features

Depression and openings

1. **Foramen:** A hole, which provides passage to blood vessels and nerves. For example, foramina in the transverse process of cervical vertebrae.
2. **Fossa:** A hollow depression. For example, glenoid fossa of the scapula.
3. **Groove:** A ditch-like groove containing a tendon or blood vessel. For example, the bicipital groove of the humerus.
4. **Meatus:** A canal or tube-like opening in a bone. For example, external auditory meatus.
5. **Sinus:** An air-filled cavity within a bone. For example, paranasal air sinuses (i.e. cavities in the paranasal bones filled with air).
6. **Facet:** A smooth, flat or shallow area. For example, articular facets of ribs.

Projections or processes

1. **Condyle:** Rounded knuckle-like projection, for example, condyles of the

femur.

2. **Eminence:** Projecting a prominent part of a bone, for example, the intercondylar eminence of the tibia.
3. **Head:** Rounded articular projection beyond a narrow neck-like portion of bone, for example, head of the femur, head of the humerus.
4. **Crest:** Sharp ridge or border.
5. **Epicondyle:** Prominence above or on a condyle, for example, medial and lateral epicondyles of the humerus.
6. **Line:** Less prominent ridge, for example, linea aspera of femur.
7. **Spine:** Long thin projection, for example, spines of vertebrae.
8. **Trochanter:** Very large prominence for muscle attachment, for example, trochanters of femur.
9. **Tubercle:** Small rounded projection, for example, greater and lesser tubercles of humerus.
10. **Tuberosity:** Large rounded projection, for example, ischial tuberosity.

Terms used in clinical anatomy

1. **Analgesia:** Loss of pain sensitivity.
2. **Analgesic:** An agent/drug causing loss of sensitivity to pain.
3. **Aplasia:** Failure of development.
4. **Atrophy:** Wasting or shrinking of a cell, tissue or organ.
5. **Anaesthesia:** Loss of sensation.
6. **Benign:** Term used for illness or growth in which outcome is favourable (i.e. it does not endanger life).
7. **Coma:** Loss of consciousness from which the patient cannot be roused (i.e. deep unconsciousness).
8. **Cancer:** In Latin, cancer means a crab. An uncontrollable proliferation of cells that usually destroys and invades adjacent tissues, metastasizes and usually follows a fatal course.
9. **Carcinoma:** Cancerous growth arising from the epithelium (e.g. ectoderm or endoderm).
10. **Convalescence:** Recovery period between the end of a disease and restoration of normal health.
11. **Diagnosis:** Identification or determination of the nature of a disease.
12. **Degeneration:** Physical alteration in a cell, tissue or organ consisting of breaking down into a disorganized or less organised state. A degenerated structure may regenerate or end in necrosis.

13. **Dystrophy:** A degenerative disorder of the structure or organ due to improper nutrition resulting in diminution of size and function.
14. **Embolism:** Occlusion of a vessel by a solid or gaseous matter, which has been transported through the bloodstream, namely detached thrombus (embolus).
15. **Gangrene:** Necrosis (death) of a cell or tissue with liquefaction by bacteria and polymorphs (i.e. putrefaction).
16. **Hemiplegia:** Paralysis of one-half of the body.
17. **Hypertrophy:** Increase in size without any increase in the number of cells.
18. **Haematoma:** Localized accumulation of blood in tissue or space. It is usually composed of clotted blood.
19. **Hyperplasia:** Increase in size of tissue or organ due to an increase in the number of cells.
20. **Hypoplasia:** Underdevelopment of a tissue or organ. It implies fewer than the usual number of cells.
21. **Hyperaesthesia:** Abnormally increased sensibility.
22. **Hyperalgesia:** Excessive sensitivity to painful stimuli.
23. **Inflammation:** Local reaction of tissues to an injury caused by chemical, physical or biological agents. The cardinal features of inflammation include swelling, redness, pain, heat (increased temperature), loss of function and fever.
24. **Infarction**: Necrosis (death) of tissue secondary to sudden loss of blood supply to the affected tissue.
25. **Lesion:** Pathological alteration in the structure or function of a tissue or organ.
26. **Lipoma:** Cluster of fat cells forming a palpable lump. It is a benign growth of mature adipocytes.
27. **Metastasis:** Spread of local disease to distant parts of the body (i.e. spread of disease from one site to another).
28. **Metaplasia:** Abnormal transformation of one differentiated adult tissue form to another type of adult tissue. It represents an adaptive response of tissues to injury.
29. **Malignant:** Illness or growth, which is resistant to treatment and which tends to kill the patient.
30. **Malingering:** Presenting an illness with a conscious effort to deceive. It is common in females.
31. **Monoplegia:** Paralysis of only one limb.

32. **Oedema:** Swelling due to accumulation of fluid in the extracellular space.
33. **Paralysis:** Loss of motor power (function) due to denervation or primary disease of the muscles.
34. **Paraplegia:** Paralysis of both the lower limbs.
35. **Paraesthesia:** Perverted feeling of sensations such as pins and needles, burning, pricking, etc.
36. **Paresis:** Reduction in muscle power.
37. **Prognosis:** Forecasting the course and probable outcome of a disease based on the knowledge of the facts of a particular case.
38. **Pyrexia:** Fever (i.e. increased body temperature).
39. **Signs:** Any manifestation of disease, which is objectively (physical signs) ascertained by a physician.
40. **Symptoms**: Subjective complaints of the patient about his disease or disorder.
41. **Sinus:** A blind track (open at one end) lined by an epithelium.
42. **Syndrome:** A group of signs and symptoms constituting together the picture of a disease.
43. **Sarcoma:** Malignant tumour of connective tissue or mesenchymal cells.
44. **Therapy:** A mode of treatment.
45. **Tumour (neoplasm):** A circumscribed, non-inflammatory abnormal growth (due to uncontrollable proliferation of cells). The benign tumours remain localised, whereas malignant tumours invade neighbouring tissue and spread to other tissues and organs at a distant site, a process called metastasis.
46. **Thrombus:** A semisolid aggregate of blood cells enmeshed in fibrin and clumps of platelets within the blood vessel.
47. **Thrombosis:** Formation of thrombus within a blood vessel.
48. **Ulcer:** A localized breach in the surface continuity of skin or mucous membrane.

Suffixes

a. **itis:** inflammation, for example, tonsillitis (inflammation of the tonsil), appendicitis (inflammation of the appendix).
b. **ectomy:** removal from the body, for example, tonsillectomy (removal of the tonsil), appendicectomy (removal of the appendix).
c. **otomy:** to open and then close a hollow viscus or region, for example,

laparotomy (opening and then closing abdominal cavity), hysterotomy (opening and then closing uterus).

d. **tomy:** an act of cutting, in a surgical operation.
e. **ostomy:** to open a hollow organ and then leave it open for the desired period, for example, tracheostomy (opening of the trachea and then leaving it open), colostomy (opening of the colon and then leaving it open).
f. **oma:** a tumour, for example, lipoma (tumour of fat cells), osteoma (bone tumour), haemangioma (tumour of blood vessels).

Terms used to describe blood vessels

1. **Arteries:** Vessels that carry oxygenated blood away from the heart.
2. **Veins:** Vessels that carry deoxygenated blood towards the heart.
3. **Anastomosis:** Communication between the branches of arteries and tributaries of veins.
4. **End artery:** An artery whose terminal branches do not anastomose with the branches of the arteries supplying the adjacent areas.
5. **Venae comitantes:** Two veins that accompany an artery.
6. **Sinusoid:** Small thin-walled blood vessels (capillaries) with irregular lumen lined by endothelial cells.
7. **Collateral circulation:** Anastomotic alternate pathways (collateral channels) through which the blood can reach the field of distribution of the main artery if it is blocked.
8. **Capillaries:** Microscopic vessels forming a network through which the arterioles (smallest arteries) discharge blood into the smallest tributaries of veins.

Terms used to describe nerves and associated structures

1. **Nerves:** Whitish cords consisting of a large number of exceedingly fine filaments called nerve fibres, bound together in bundles by fibrous tissue.
2. **Plexus:** Braided structure resulting from a network of nerve fibres.
3. **Ganglion:** A group/collection of nerve cells outside the central nervous system.
4. **Nucleus:** Group/collection of nerve cells within the central nervous system.

Terms used to describe fasciae

1. **Superficial fascia:** A mixture of loose areolar and adipose tissue lying deep to the dermis of the skin.
2. **Deep fascia:** Dense inelastic membrane investing structures deep to the superficial fascia. It sends septa between the muscle groups.
3. **Fibrous sheath:** Derived from the deep fascia to form a sheath around the tendons.
4. **Retinaculum:** Thickening of deep fascia that retains the underlying tendons in position.

Terms used to describe muscles

1. **Belly:** Fleshy contractile part of the muscle.
2. **Tendon:** Fibrous noncontractile, cord-like part of the muscle.
3. **Aponeurosis:** Flattened tendon/flat sheet of collagen fibres extending from muscle to its attachment on bone.
4. **Raphe:** Stretchable fibrous band made up of interdigitating fibres of the tendons or aponeurosis.
5. **Origin:** End of muscle, which remains fixed during its contraction.
6. **Insertion:** End of muscle, which moves during its contraction.
7. **Bursa:** Sacs of connective tissue filled with synovial fluid, found where tendon slides over the bone.
8. **Synovial sheath of tendons:** Similar to bursae in the structure; consists of double-layered synovial membrane tubes surrounding the tendons.
9. **Prime movers:** Group of muscles initiating and maintaining a particular movement.
10. **Antagonists:** Group of muscles, which oppose the movement initiated by prime movers.
11. **Synergists:** Muscles, which assist prime movers.
12. **Fixators:** Muscles, which contract isometrically to stabilize the origin of prime movers so that it acts efficiently.

Terms used to describe lymph nodes and lymph vessels

1. **Lymph nodes**: Firm gland-like structures varying in size from a pinhead to a large bean.
2. **Lymph vessels**: Fine-beaded tubes containing clear fluid (lymph),

found in large numbers in tissues adjacent to epithelial surfaces, namely skin, alimentary and respiratory tracts.

Special terms used in dentistry

- **Labial and buccal surfaces**: Surfaces of incisor and canine teeth towards lips are called *labial surfaces*, whereas surfaces of premolar and molar teeth towards the cheek are called *buccal surfaces*.
- **Mesial and distal surfaces**: Surfaces of teeth towards the anterior midline are called *mesial surfaces*, whereas surfaces of teeth away from the anterior midline are called *distal surfaces*.
- **Palatal and lingual surfaces**: Surfaces of upper jaw teeth facing the palate are called **palatal surfaces**, whereas the surfaces of lower jaw teeth facing the tongue are called **lingual surfaces**.
- **Occlusal surfaces**: Biting surfaces of postcanine teeth are termed **occlusal surfaces**.

Note that occlusal surfaces are tuberculate, that is they possess cusps separated by fissures; for details see *Textbook of Anatomy* Vol. III by Dr Vishram Singh.

Anatomical nomenclature

Claudius Galen (AD 130–201) and Andreas Vesalius (AD1514–1564), two great anatomists, wrote books on anatomy in Greek and Latin, respectively. Therefore, most of the anatomical terms have Greek or Latin origin. Initially, anatomical terms used in textbooks and journals were about 30,000 in number. In 1895, the *German Anatomical Society* held a meeting at Basel and approved a list of about 5,000 terms, called **Basle Nomina Anatomica** (BNA). It also laid down six strict rules, which are as follows:

1. Each part shall have only one name.
2. Each term shall be in Latin.
3. Each term shall be as short and simple as possible.
4. The terms shall be merely memory signs.
5. The related terms shall be similar, namely femoral artery, femoral vein and femoral nerve.

6. The adjectives shall be arranged as opposites, namely psoas major, psoas minor, superior oblique and inferior oblique.

In 1933, the Anatomical Society of Great Britain and Ireland held a meeting at Birmingham and revised the BNA. The revised BNA was named **Birmingham Revision** (BR).

BNA was again revised by the German anatomists in 1935 and was called **Jena Nomina Anatomica** (JNA). The **BR** and **JNA** restricted the Greek and Latin words to 5,000 only and allowed the terms of local contemporary language for usage.

In 1950, an International Congress of Anatomists was held at Oxford where it was agreed that further attempts should be made to establish a generally acceptable international nomenclature. In the sixth International Congress of Anatomists held in Paris in 1955, a somewhat conservative revision of BNA was done, incorporating many terms from BR and JNA and it was approved; it is known as **Nomina Anatomica**. The drafts on *Nomina Histologica* and *Nomina Embryologica* were prepared by the subcommittee of the **International Anatomical Nomenclature Committee** (IANC). After a critical revision, the fourth edition of *Nomina Anatomica* containing *Nomina Histologica* and *Nomina Embryologica* was prepared by Roger Warwick in 1977 and published by the Excerpta Medica Foundation. The author of this book, Dr Vishram Singh had the proud privilege of having a long and fruitful discussion with Roger Warwick in the year 1981. Now, IANC is given the responsibility of bringing out the future editions as and when required.

Golden Facts to Remember

• **Majority of anatomical terms are derived from**	Greek or Latin
• **All the terms of the direction that describe the relationship of one body part to another are made in reference to**	Anatomical position
• **A sectional plane that divides the body into anterior and**	Coronal plane

posterior portions	
• A sectional plane that divides the body into right and left portions is called	Sagittal plane
• A sectional plane that divides the body into upper and lower portions is called	Transverse/cross-sectional plane
• Basic procedures used for clinical examination of the body are	*Observation* (visual inspection), *Palpation* (feeling of pressure) *Percussion* (detecting resonating vibrations) *Auscultation* (listening to organ sounds) *Reflex-response testing*
• Anatomical position	The subject stands erect and faces forward with arms at the sides and palm turned forward
• *The fundamental position* is the same as the anatomical position *except* that the	Palms face the sides of the body/forearms are in the mid-prone position
• Adjunct motion	Voluntary independent rotation constituting a degree of freedom
• Conjunct motion	Obligatory coupled rotation which always accompanies some other main movement
• Parts of the body which are not in their natural position in anatomical position	Forearm and hands
• The term *cephalad* refers to a	Head (*cephal* = head)

position or structure close to the	
• Term *caudal* refers to a position or structure closer to the	Feet (*cauda* = tail)
• Movements of supination and pronation of the forearm are equivalent to	Movements of inversion and eversion of the foot, respectively
• Movement unique to human beings	Opposition of thumb
• Term BNA stands for	Basle Nomina Anatomica
• A facial feature unique to human	Prominent chin

Multiple choice questions

1. **Regarding anatomical position, which of the following statements is *not correct*:**
   (a) The body is erect and eyes are directed forward.
   (b) The upper limbs hang by the side of the body and the palms face anteriorly.
   (c) The body is in the foetal position.
   (d) The lower limbs and feet are parallel and toes are directed forward.
2. **Regarding fundamental position, select the *correct statement*:**
   (a) The body is in the foetal position.
   (b) The body is erect and palms face medially.
   (c) The body is erect and palms face anteriorly.
   (d) The arms are extended away from the body.
3. **The sectional plane that divides the body into anterior and posterior portions is:**
   (a) Transverse plane
   (b) Sagittal plane
   (c) Coronal plane
   (d) Oblique plane
4. **Which of the following is not a fundamental plane:**
   (a) Coronal
   (b) Transverse

(c) Vertical
(d) Midsagittal

5. **Select the correct statement:**
   (a) In the supine position the person lies on the back with the face directed upwards
   (b) In the prone position the person lies on his back with the face directed upwards
   (c) In the prone position the person lies on his belly with the face directed to the left side
   (d) In the supine position the person lies on their back with their face directed to the right side
6. **Regarding lithotomy position, all of the following are correct *except*:**
   (a) Person lies supine with buttocks at the edge of the table
   (b) Person lies prone with buttocks at the edge of the table
   (c) Person's hips and knees are semi-flexed
   (d) Person's thighs are abducted and feet are in a strapped position
7. **Regarding movements of hand and feet, which of the following statements is *not correct*:**
   (a) In supination the palm faces anteriorly
   (b) In pronation the palm faces posteriorly
   (c) In inversion the sole faces outwards
   (d) In eversion the sole faces outwards
8. **Regarding movements at a joint, which of the following statements is *not correct*:**
   (a) Flexion approximates the flexor surfaces of the adjoining parts
   (b) Extension approximates the extensor surfaces of the adjoining parts
   (c) In abduction limb moves close to the body
   (d) In adduction limb moves towards the body
9. **Which of the following is also called the frontal plane:**
   (a) Midsagittal
   (b) Sagittal
   (c) Coronal
   (d) Transverse

Answers

1. *c*, **2**. *b*, **3**. *c*, **4**. *c*, **5**. *a*, **6**. *b*, **7**. *c*, **8**. *c*, **9**. *c*

Chapter 3: Architecture and design of the human body

Specific learning objectives

After studying this chapter, the student should be able to:

- Classify humans in the animal kingdom.
- Write the characteristic features of humans.
- State the levels of structural organization of the human body.
- Identify various regions of the human body.
- Outline the body cavities and their contents.
- Discuss the body membranes.
- Notify the disposition of body structures encountered during dissection.
- Correctly solve the Multiple Choice questions provided at the end of the chapter.

The human body is complex like a highly technical and sophisticated machine. Therefore, the knowledge of its organization is essential to comprehend.

Before beginning to study the organization of the human body, one should know the taxonomic position of humans in the Animal Kingdom because we share many characteristics with all living animals. Like all other living

animals, we breathe, eat and digest food, excrete body wastes, locomote and reproduce our own kind. We are subject to disease, injury, pain, ageing, mutations and death. The processes by which our bodies produce, store and utilize energy are also similar to those found in all living organisms. The fundamental patterns of development and growth of many vertebrates are also seen in human development.

In the scheme of classification of animal kingdom established by biologists to organize the structural and evolutionary relationship of living organisms, each category of classification is referred to as a **taxon**. The highest taxon is the Kingdom and the most specific category is species. Human beings are species belonging to the **Animal Kingdom**.

Phylogeny is the origin and evolutionary development of animal species.

Classification of humans in the animal kingdom

Human beings are biological creatures that are classified into eight main taxonomic groupings.

The scientific classification of human beings and the characteristic features of each group are given in Box 3.1.

BOX 3.1

Classification of human beings and characteristic features

Group	Features
Kingdom: Animalia	Eukaryotic cells that lack walls and photosynthetic pigments
Phylum: Chordata	Presence of notochord and pharyngeal pouches
Subphylum: Vertebrata	Presence of vertebral column
Class: Mammalia	Presence of mammary glands and hair
Order: Primata	Presence of a well-developed brain and prehensile hands
Family: Hominidae	Large cerebrum and bipedal locomotion

Genus: *Homo*	Flattened face, prominent chin and nose with inferiorly directed nostrils
Species: *sapiens*	Largest cerebrum

Characteristics of humans

Human beings possess certain anatomical features which separate them from other animals. These are as follows:

1. **A large well-developed brain:** The average adult human brain weighs between 1350 and 1400 g. This gives humans a large brain-to-body weight ratio. The human brain accounts for emotions, thought, reasoning, memory and precisely coordinated movements.
2. **Bipedal locomotion:** Human beings stand and walk on two limbs and the upper limbs swing with movements of the lower limbs.
3. **An opposable thumb:** The human thumb is tremendously versatile. It is opposable to fingers, hence, adapted to grasp the objects.
4. **Well-developed articulated speech:** Human beings have well-developed articulated speech. Hence, they can communicate with each other, which led to the development of their unique culture and language.
5. **Stereoscopic vision:** The human eyes are directed forwards so that when we focus on an object, we view it from two angles. Stereoscopic vision gives us the depth of perception, a three-dimensional image.

N.B.

Human beings differ from other animals in the number and arrangement of vertebrae (*vertebral formula*), the kinds and number of teeth (*dental formula*), the degree of development of facial muscles, etc.

Traits unique to human beings are summarized as under:

- Erect posture
- Intelligence with cognitive function
- Skilled hand with an opposable thumb
- Stereoscopic or binocular vision
- Prominent chin
- Fine co-ordination of muscles for skilled movements

- Well-articulated speech

Organization of the human body

The human body begins with a single cell, growing into a multicellular organism, made up of trillions of cells during this process. It undergoes many levels of the organization. Thus within the body, there are different levels of structural organization. The five main levels of organization (Fig. 3.1) are:

1. **Cellular level:** The cell is the structural and functional unit of life. The human is a multicellular organism composed of 60–100 trillion cells. It is at the cellular level that metabolism, growth, repair, etc. are carried out. The human body contains many distinct types of cells, each of which is specialized to perform specific functions. Examples of specialized cells are: (1) bone cells, (2) muscle cells, (3) fat cells, (4) blood cells and (e) nerve cells. Each of these cell types has a unique structure related to its function.
2. **Tissue level:** The tissue is a group of cells with similar structure and function including extracellular substances between them. The examples are: (1) epithelial tissue, (2) connective tissue, (3) muscle tissue and (4) nervous tissue.
3. **Organ level:** An organ is composed of two or more types of tissues that are integrated to perform a particular function. Examples of organs are: (1) heart, (2) stomach, (3) spleen, (4) eye, (5) skin, etc.
4. **System level:** A body system consists of various organs that have similar or related functions. These are 11 major systems in the body, *namely:* (1) integumentary, (2) skeletal, (3) muscular, (4) nervous, (5) endocrine, (6) cardiovascular, (7) lymphatic, (8) respiratory, (9) digestive, (10) urinary and (11) reproductive systems.
5. **Organism level:** An organism is any living thing considered as a whole whether it is composed of one cell, *namely*, bacteria, or of trillions of cells such as a human being.

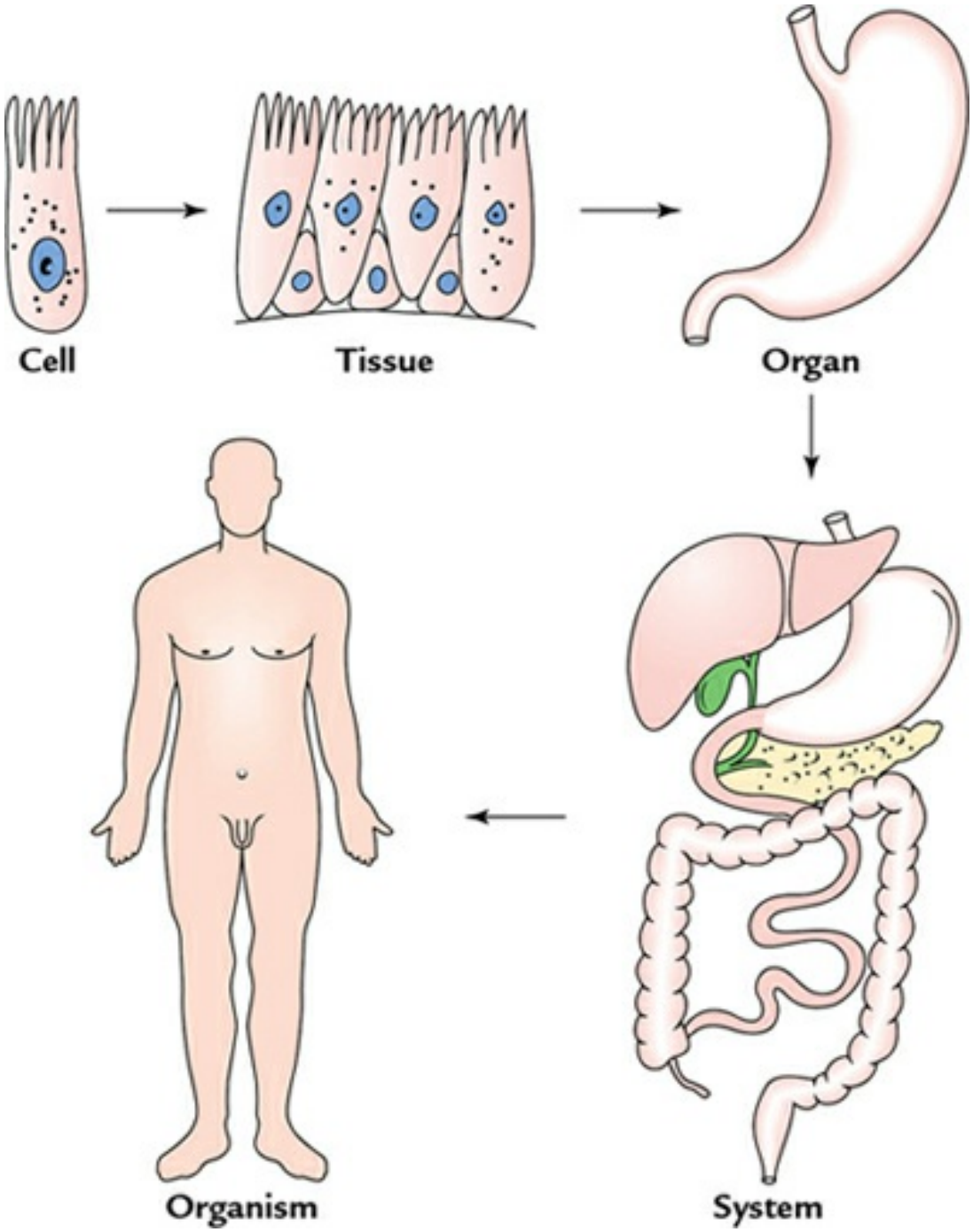


FIG. 3.1 ■ Levels of structural organization of the human body.

The human body is a complex of organ systems that are mutually dependent on each other, interrelated and function together.

Body regions

The human body is divided into several regions (Fig. 3.2). The major body regions are the head, neck, trunk (trunk is frequently divided into thorax and

abdomen), upper extremity and lower extremity:

1. **Head** is the upper globular part of the body. It is divided into two regions (1) the *facial region*, which includes the forehead, eyes, nose and mouth and (2) the *cranial region*, which encloses the brain.
2. **Neck** is the cylindrical region that extends between the trunk and head. The neck supports the head and allows it to move.
3. **Thorax** is the upper part of the trunk and is commonly referred to as the *chest*. The thoracic region includes breasts on its anterior aspect.
4. **Abdomen** is located below the thorax. It presents the *navel* (umbilicus) in its centre anteriorly.
   The lower portion of the abdomen forms the *pelvis*. The inferior aspect of the trunk between the two thighs is called the *perineum*.
5. **Upper limbs** include the shoulder region, arm (brachium), elbow, forearm (antebrachium), wrist, hands and fingers.
6. **Lower limbs** include the gluteal region, thigh, knee, legs, ankle, foot and toes.

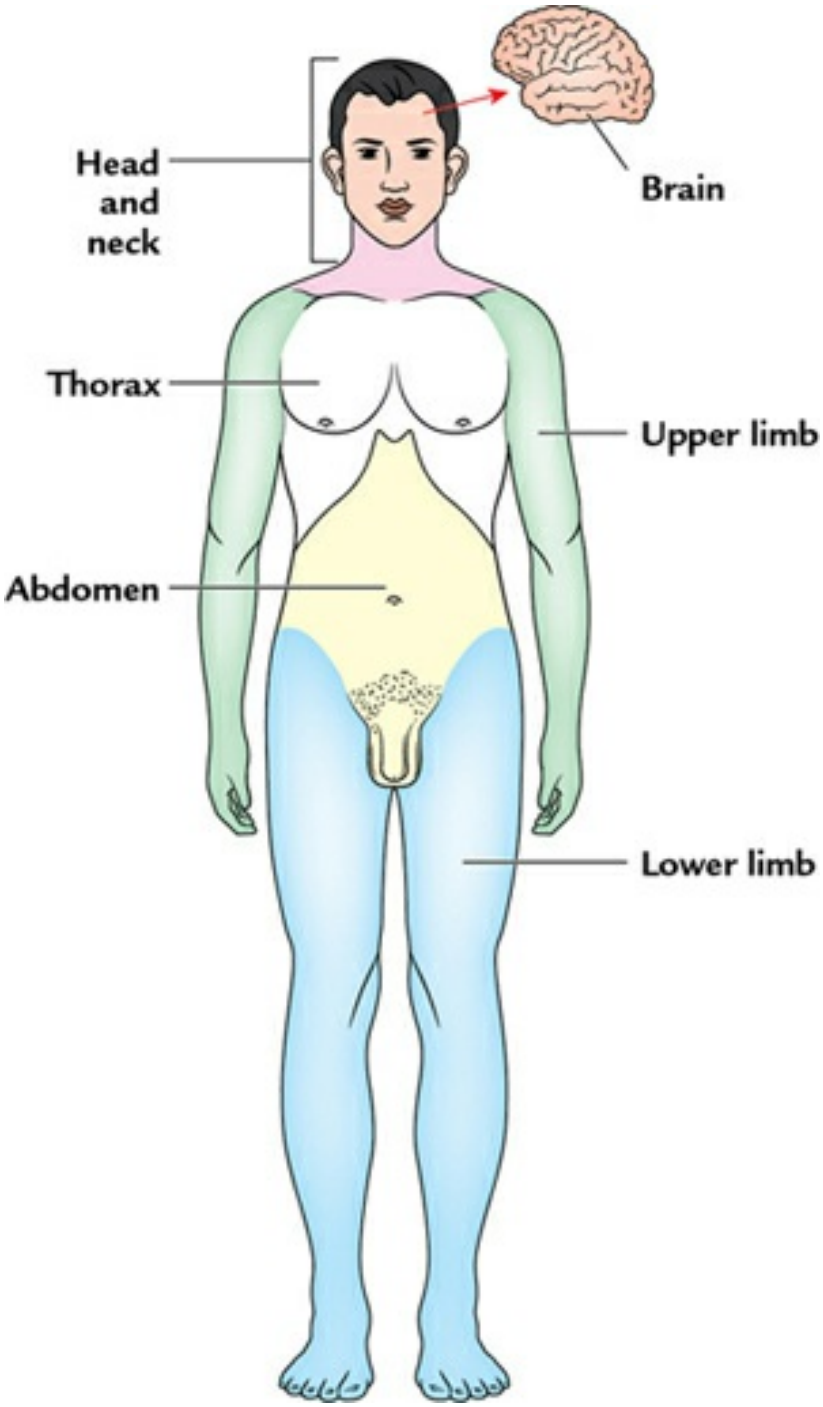


FIG. 3.2 ■ Six major regions/parts of the body as studied in the regional anatomy.

In the classical regional approach of teaching, the head and neck regions are taught together: hence, they together form the **head and neck region**.

Similarly, the **brain** is taught separately and thus, it is also considered a separate region.

Therefore, the regional approach to teaching includes the following **six regions of the body** (Fig. 3.2):

1. Head and neck
2. Brain
3. Thorax
4. Abdomen
5. Upper limb
6. Lower limb.

Body cavities

For functional and protective purposes, the viscera are located within the cavities of the body. The body cavities contain organs and systems that have related functions.

The major cavities of the body (Fig. 3.3) are as follows:

1. **Abdominal cavity:** It is the largest cavity in the body. It is divided into a large upper portion called the **abdominal cavity proper** and a small lower portion called the **pelvic cavity**.

   Abdominal cavity proper: It is oval in shape and is situated in the main part of the trunk. It is bounded *superiorly* by the diaphragm which separates it from the thoracic cavity, *anteriorly* by muscles forming the anterior abdominal wall, *posteriorly* by lumbar vertebrae and muscles forming the posterior abdominal wall, *laterally* by lower ribs and parts of the muscles of the abdominal wall and *inferiorly*, it is continuous with the pelvic cavity.

   The abdominal cavity proper contains organs and glands involved in digestion and absorption of the food:

   (a) Stomach, small intestine and most of the large intestine
   (b) Liver, gallbladder, bile ducts and pancreas
   (c) Spleen
   (d) Kidneys, the upper part of ureters and adrenal glands.

   Pelvic cavity: It is roughly funnel-shaped and extends from the lower end of the abdominal cavity. It is bounded *anteriorly* by pubic bones, *posteriorly* by sacrum and coccyx, *laterally* on either side by innominate (hip) bone, *inferiorly* by muscles of the pelvic floor and *superiorly*, it is continuous with the abdominal cavity.

   The pelvic cavity contains:

   (a) Terminal portion of the large intestine, i.e. sigmoid colon, rectum and anus

(b) Some loops of the small intestine
(c) Urinary bladder
(d) Uterus
(e) Uterine tubes
(f) Ovaries
(g) Prostate
(h) Seminal vesicles.

2. **Thoracic cavity:** This is situated in the upper part of the trunk. It is bounded *anteriorly* by the sternum and costal cartilages of the ribs, *laterally* by 12 pairs of ribs and intercostal muscles, *posteriorly* by thoracic vertebrae and intervertebral discs between the bodies of the vertebrae.

   The thoracic cavity contains:
   – Trachea (lower part only), bronchi and lungs
   – Heart, aorta, superior and inferior vena cava
   – Thymus and thoracic duct
   – Oesophagus.

3. **Cranial cavity:** It is the cavity within the skull and is therefore bounded by the bones of the skull as follows: *anteriorly* by the frontal bone, *posteriorly* by occipital bone, *laterally* on each side by temporal bone, *superiorly* by parietal bones and *inferiorly* by sphenoid, ethmoid and parts of frontal, temporal and occipital bones. The cranial cavity contains:
   – Brain

4. **Vertebral canal:** It is located within the vertebral column. It contains:
   – Spinal cord

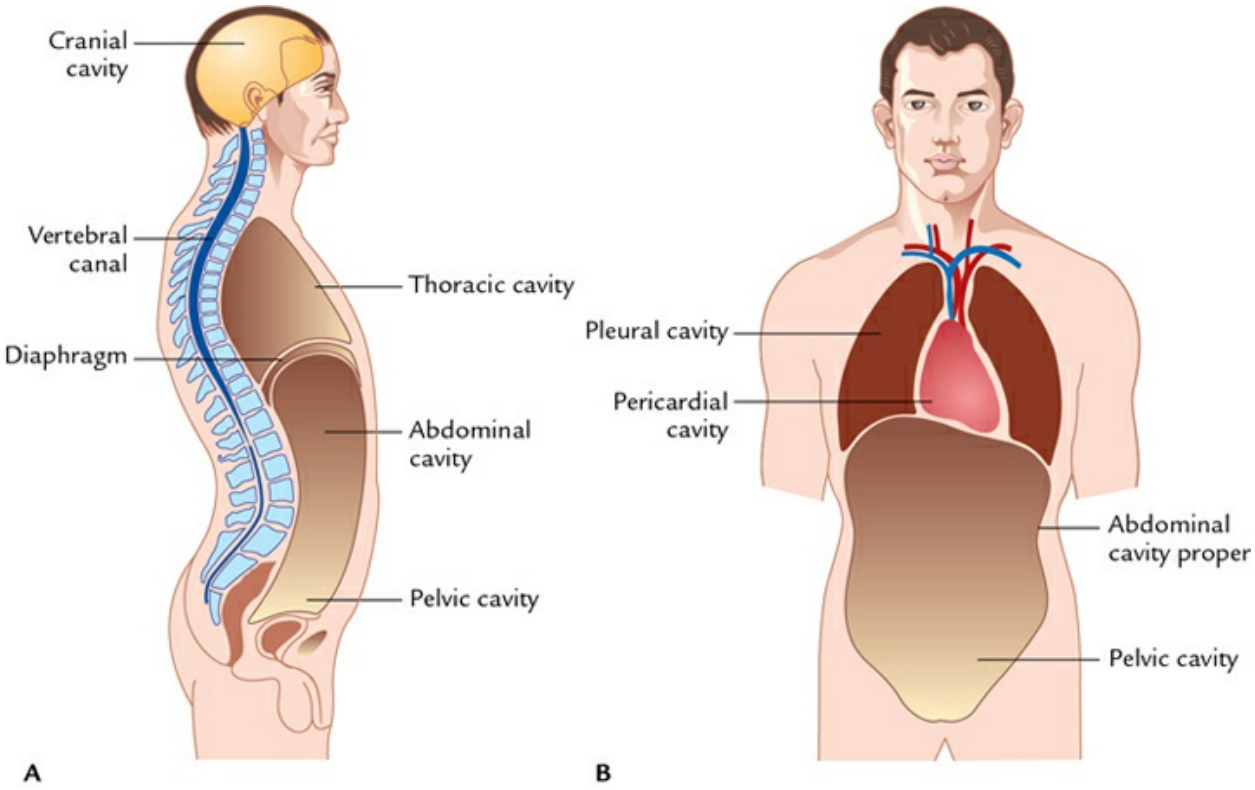
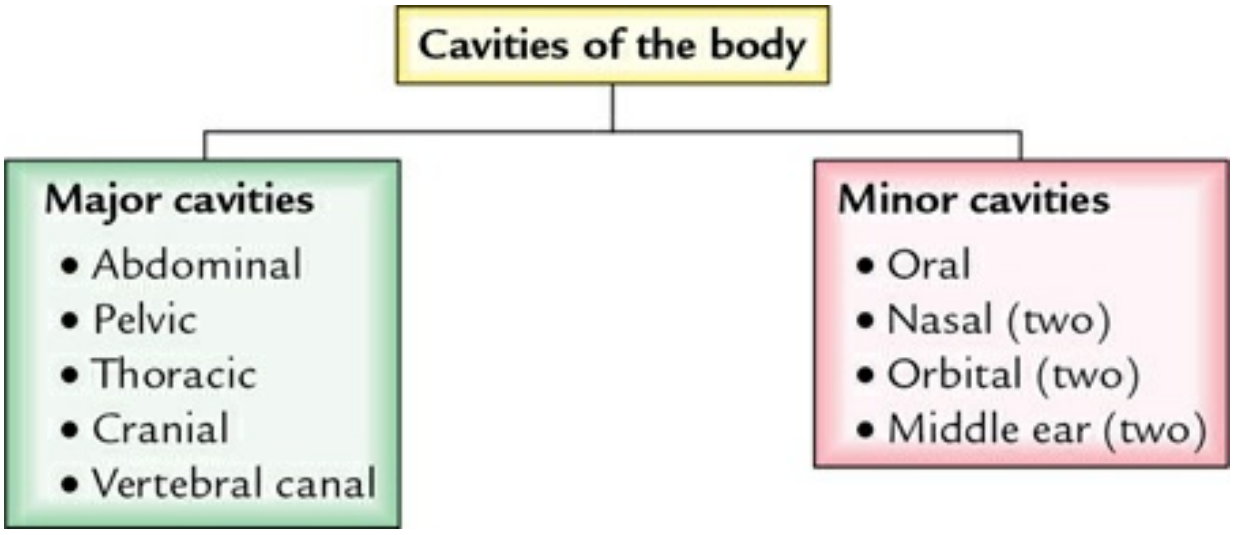


FIG. 3.3 ■ Major cavities of the body: **(A)** lateral view, **(B)** anterior view.

The smaller/minor cavities of the body are:

1. **Oral (buccal cavity):** It contains teeth and tongue.
2. **Two nasal cavities**: These are concerned with respiration and sense of smell.
3. **Two orbital cavities**: Each of them houses the eyeball and its associated muscles, nerves and vessels.
4. **Two middle ear cavities**: Each of them contains ear ossicles.

The various cavities of the body are summarized in Flowchart 3.1.



FLOWCHART 3.1 ■ Body cavities.

Body membranes

The membranes of the body are mostly sheets of epithelial cells and their supporting thin connective tissue layers. They cover the body surface or line the inner aspect of hollow organs or body cavities. The three main membranes are:

1. **Cutaneous membrane/skin:** It is made up of keratinized stratified squamous epithelium and an underlying layer of dermis made up of dense irregular connective tissue. It protects the body surface from drying and keeps it moist and oily by the secretion of its sweat and sebaceous glands (for details see Chapter 5 on Skin, Superficial Fascia and Deep Fascia).
2. **Mucous membranes:** It is made up of epithelium (type of epithelium varies from site to site) resting on the layer of loose connective tissue called *lamina propria*. It secretes a thick, viscid substance called **mucus** which lubricates or protects the associated organs.
   They line the various cavities and tubes that enter or exit from the body, *namely*, oral and nasal cavities, tubes of respiratory, reproductive, urinary and digestive systems.
3. **Serous membranes:** It is a layer of simple squamous epithelium resting on a thin layer of loose areolar tissue. The serous membranes cover the organs within the thoracic and abdominal cavities.
   The important serous membranes are:

– *Pleural membrane*, covering the lungs
– *Pericardial membranes*, covering the heart
– *Peritoneal membranes*, covering the abdominal pelvic viscera.

They secrete a thin watery fluid called *serous fluid* which acts as a lubricant.

The serous membranes are invaginated by the viscera and divided into two layers: (1) the visceral layer adhering to the outer surface of the organ and (2) the parietal layer lining the wall of the body cavity.

The space between the visceral and parietal layer forms a serous cavity such as pleural cavity, pericardial cavity and peritoneal cavity (the largest serous cavity in the body).

The pericardial cavity surrounds the heart (Fig. 3.4A), the pleural cavity surrounds the lung (Fig. 3.4B) and the peritoneal cavity surrounds the abdominal and pelvic viscera (Fig. 3.4C).

The space between the visceral and parietal serous membranes (serous cavity) is normally filled with a thin lubricating film of serous fluid produced by the membranes. As organs rub against the body wall or another organ, the serous fluid and serous membranes reduce the friction.

The important serous membranes and serous cavities of the body are summarized in Table 3.1.

4. **Synovial membrane:** It is a connective tissue membrane that is made of only connective tissue and does not contain the epithelium at all. It lines the inner aspect of the fibrous capsule of joints to provide a smooth surface for the joints. It secretes clear, sticky, oily **synovial fluid** which acts as a lubricant. The synovial fluid is secreted by fibroblasts (synoviocytes) of this membrane.

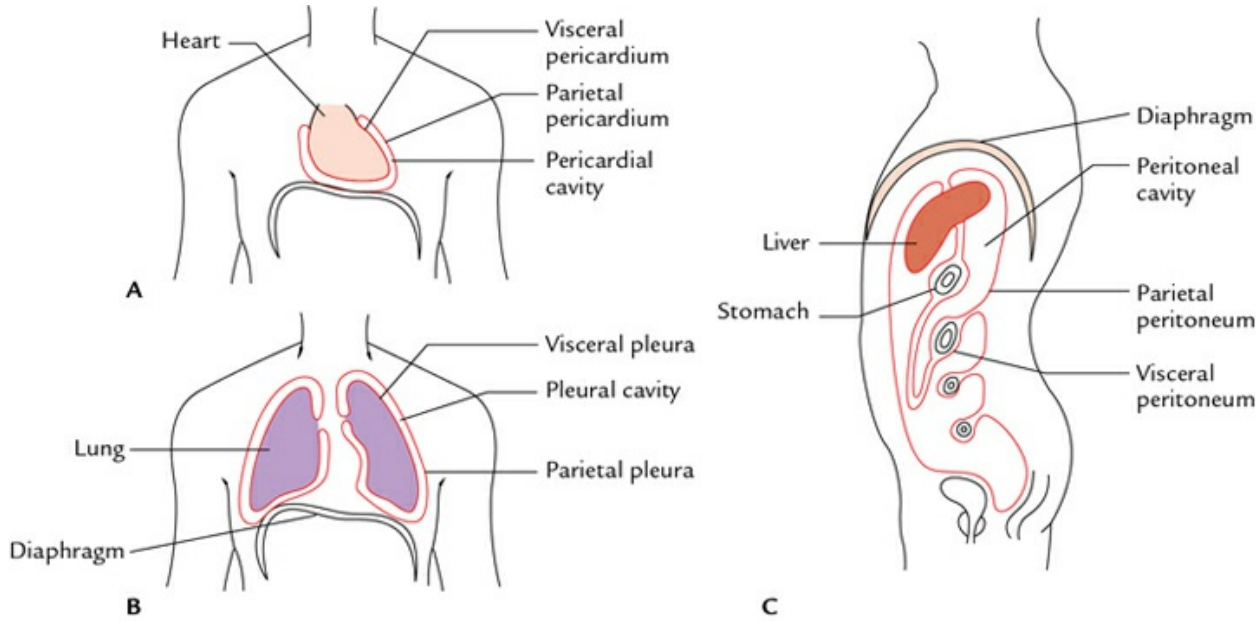


FIG. 3.4 ■ Serous cavities surrounding the organs within thoracic and abdominal cavities: **(A)** pericardial cavity surrounding the heart, **(B)** pleural cavity surrounding the lungs, **(C)** peritoneal cavity surrounding the abdominal organs.

TABLE 3.1

Serous membranes and serous cavities of the human body

Serous membranes	Serous cavities
Pleura	Pleural cavity
Pericardium	Pericardial cavity
Peritoneum	Peritoneal cavity

Clinical correlation

Inflammation of serous membranes: The serous membranes sometimes become inflamed, usually as a result of infection. The inflammation of the pericardium is called *pericarditis*, that of the pleura is called *pleuritis* and that of the peritoneum is called *peritonitis*. When inflamed, the serous membranes produce an increased amount of serous fluid within serous cavities leading to clinical conditions such as *pericardial effusion* (accumulation of fluid in the pericardial cavity), *pleural effusion* (accumulation of fluid in the pleural cavity) and *ascites* (accumulation of fluid in the peritoneal cavity).

Body fluids

About 60% of body weight is formed by fluids present within the body. The body fluid is of two types:

1. **Extracellular fluid:** It accounts for 22% of body weight. The extracellular fluid consists of blood, plasma, lymph, cerebrospinal fluid and fluid in the interstitial spaces of the body (interstitial fluid).
   The **interstitial fluid**, i.e. intercellular fluid (also called **tissue fluid**) bathes all the cells of the body except the outer layers of the skin.
   It is the medium through which substances pass from the blood to the body cells and from cells to the blood.
   For example, O_2 and nutrients pass from blood (in capillaries) to the interstitial fluid while CO_2 and wastes pass from cells into intercellular fluid. The interstitial fluid containing CO_2 and waste products is drained by veins (75%) and lymph vessels (25%).
   The well-being of every cell is dependent upon the composition of the intercellular fluid, which is therefore maintained at a constant level by many control mechanisms in the body. This is called **homeostasis**.
2. **Intracellular fluid:** It accounts for 38% of body weight. The composition of intracellular fluid is largely controlled by the cell itself because selective uptake and discharge mechanisms present in the cell membrane.

General disposition of the body structures

During dissection, generally following structures are encountered from superficial to deep (Fig. 3.5).

1. **Skin:** It is the outermost covering of the body.
2. **Superficial fascia:** It is made up of loose connective tissue and filled with a variable amount of fat in different regions.
3. **Deep fascia:** It is a thin, tough, inelastic fibrous membrane deep to the superficial fascia and superficial to the muscles.
4. **Muscles (skeletal muscles):** They are present deep in the deep fascia as red fleshy masses of different sizes and shapes.
5. **Blood vessels and nerves:** They are present between the muscles

embedded in loose connective tissue. When traced distally, they give branches.

6. **Bones and joints:** Bones are hard structures of different sizes and shape lying deep into the muscles. The junctions between the bones are called *joints*. The bones along with joints form the skeletal framework of the body.

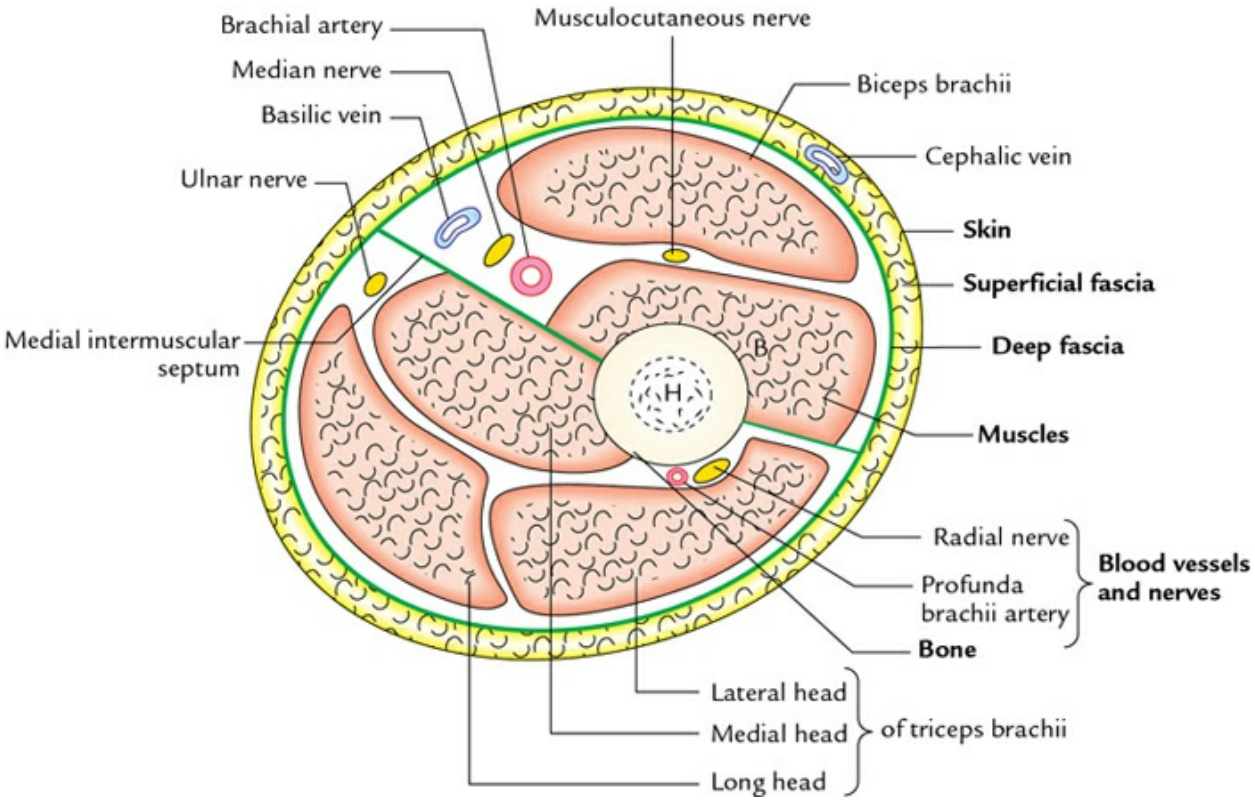


FIG. 3.5 ■ Cross-section of arm showing structures met during dissection. (H, humerus; B, brachialis.) (Source: Fig. 8.2, Page 90, Textbook of Anatomy: Upper Limb and Thorax , 3e, Vishram Singh. Copyright Elsevier 2018. All rights reserved.)

Introduction to the study of illness

In order to understand the anatomical basis of specific diseases described in later chapters, it is necessary to adopt a systematic approach as outlined below:

1. **Aetiology:** the cause of a disease.
2. **Pathogenesis:** the nature of the disease process and its effect on normal body functioning.

3. **Complications:** other consequences which might arise if the disease progresses.
4. **Prognosis:** the likely outcome.

Aetiology

The disease is caused by one or more factors. The common factors causing the disease are:

1. **Genetic abnormalities**, inherited or acquired
2. **Infection** by microbes or parasites, *namely*, worms, bacteria or viruses
3. Chemicals
4. Ionizing radiation
5. Physical trauma
6. **Degeneration**, *namely*, excessive use or aging.

N.B.

- If no specific cause of the disease is identified, the cause is described as *idiopathic*.
- If the disease is caused by the carelessness of the doctor, the cause is described as *iatrogenic*.

Pathogenesis

The main processes causing the illness are as follows:

1. **Inflammation,** the tissue's response to its damage is due to trauma or invasion by microbes.
2. **Tumours**, they arise when the rate of cell production exceeds that of normal cell destruction causing a mass to develop rapidly.
3. **Abnormal immune mechanisms,** sometimes the normally protective immune mechanisms of the body may cause undesirable effects.
4. **Thrombosis, embolism and infarction,** the effects and consequences of abnormal changes in the blood and/or walls of blood vessels.
5. **Degeneration**, which leads to impaired function.
6. **Metabolic abnormalities**, such as phenylketonuria cause undesirable effects.

Terminology associated with the disease

- **Acute:** a disease with sudden onset.
- **Chronic:** a long-standing disorder.
- **Congenital:** a disorder which one is born with.
- **Acquired:** a disorder that develops any time after birth.
- **Symptom:** an abnormality or disorder described by the patient.
- **Sign:** an abnormality or disorder noted by the doctor.
- **Syndrome:** a group of signs and symptoms which together constitute a disease.

Complications

These include:

1. Spread of disease involving surrounding structures
2. Septicaemia
3. Metastasis.

Prognosis

It is the forecast of the probable course and outcome of a disease, e.g. the prognosis of benign tumours is generally good, whereas that of malignant tumours are poor.

Golden Facts to Remember

• **Scientific name of modern man**	*Homo sapiens*
• **Two most important characteristics of human beings**	(1) Highly developed brain and (2) opposable thumb
• **Mode of locomotion of human beings**	Bipedal
• **Number of cells in the human body**	60–100 trillion
• **Sole living members of the family Hominidae**	Humans
• **Most primitive endoskeletal structure of vertebrates**	Notochord

• Hardest tissue in the body	The enamel of tooth/bone
• Largest region of the body	Abdomen
• Largest bony cavity of the body	Cranial cavity
• Longest bony cavity of the body	Vertebral canal
• All the chordates have three common structures	(a) Notochord (b) Hollow neural tube (c) Pharyngeal pouches
• First organ of the body to start functioning	Heart
• Largest cavity of the body	Abdominal cavity
• Largest serous membrane in the body	Peritoneum
• Largest serous cavity of the body	Peritoneal cavity
• Smallest level of body organization	Cell level
• Highest level of body organization	System-level
• Vital functions of life are carried out at	Cellular level of body organization
• Cranial capacity in man	1200–1600 cm^3 (1500 cc)
• Oldest fossil of man discovered in South Africa	Proconsul
• The scientist who had given the scientific name of the man	Carolus Linnaeus
• Nearest relatives of man among the primates	Great ape
• Organs that are similar in appearance and perform similar functions but differ in basic structure and origin	Analogous
• Organs that exhibit different functions but have similar embryonic development function	Homologous
• Family to which human beings belong	Hominidae

• **Direct ancestor of the modern living man**	Cro-Magnon
• **Animals who do not possess tail**	Ape, modern man

Multiple choice questions

1. **All are correct regarding the taxonomic classification of humans *except*:**
   (a) Phylum: Chordata
   (b) Class: Mammalia
   (c) Order: Primata
   (d) Family: Homo sapiens
2. **All are characteristics of a human being *except*:**
   (a) A large well-developed brain
   (b) A well-developed articulated speech
   (c) A well-developed sense of smell
   (d) An opposable thumb
3. **Prehensile hands, opposable thumb, well-developed brain and prominent chin are structural characteristics of the grouping of animals termed:**
   (a) Primates
   (b) Humans
   (c) Mammals
   (d) Chordates
4. **Regarding serous membranes, which of the following word pairs is incorrect?**
   (a) Peritoneum/thoracic cavity
   (b) Pleura/thoracic cavity
   (c) Peritoneum/abdominal cavity
   (d) Pleura/lungs
5. **Aggregations of similar cells that perform specific functions are called:**
   (a) Organelles
   (b) Organs
   (c) Tissues
   (d) Glands
6. **The largest body cavity is:**
   (a) Cranial cavity

(b) Thoracic cavity
(c) Abdominal cavity
(d) Vertebral cavity

7. **All are examples of an organ *except*:**
(a) Heart
(b) Skin
(c) Muscle
(d) Spleen

8. **All are examples of tissue *except*:**
(a) Epithelium
(b) Muscle
(c) Skin
(d) None of the above

Answers

1. *d*, **2.** *c*, **3.** *b*, **4.** *a*, **5.** *c*, **6.** *c*, **7.** *c*, **8.** *c*

Chapter 4: Cells, epithelium, glands and connective tissue

Specific learning objectives

After studying this chapter, the student should be able to:

- Describe the cell in brief and explain the structure and functions of organelles within it.
- Outline the two types of cell divisions.
- Describe the structure and functions of epithelium and connective tissue.
- Classify different glands.
- Compare and contrast the structure and functions of exocrine and endocrine glands.
- Classify the exocrine gland according to the mode of their secretion.
- Explain the capacity of regeneration in different types of tissue.
- Discuss the disorders of cells and tissues.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

The cells are the basic structural and functional units of the body (cell theory). The multicellular human body develops from a single cell called **zygote**, which results from the fusion of the ovum (female germ cell) and the spermatozoon (male germ cell).

The zygote (a single cell embryo) undergoes mitotic division (cleavage) and after several such cellular divisions, an embryonic mass consisting of 16 or more cells (blastomeres) is formed. It is called a **morula**. The fluid secreted by the uterine endometrium enters the intercellular spaces of the morula and forms a fluid-filled cavity within the morula called **blastocoele**.

The appearance of a blastocoele segregates the cells into distinct groups:

1. A single layer of cells forming the outer wall known as **trophoblast**.
2. An inner mass of cells known as **embryoblast**.

With the establishment of these two groups of cells, the morula becomes a **blastocyst** (Fig. 4.1). After further development, the trophoblast forms the **placenta** (fetal component) and the inner cell mass forms the **embryo**. The placenta provides nutrition to the embryo.

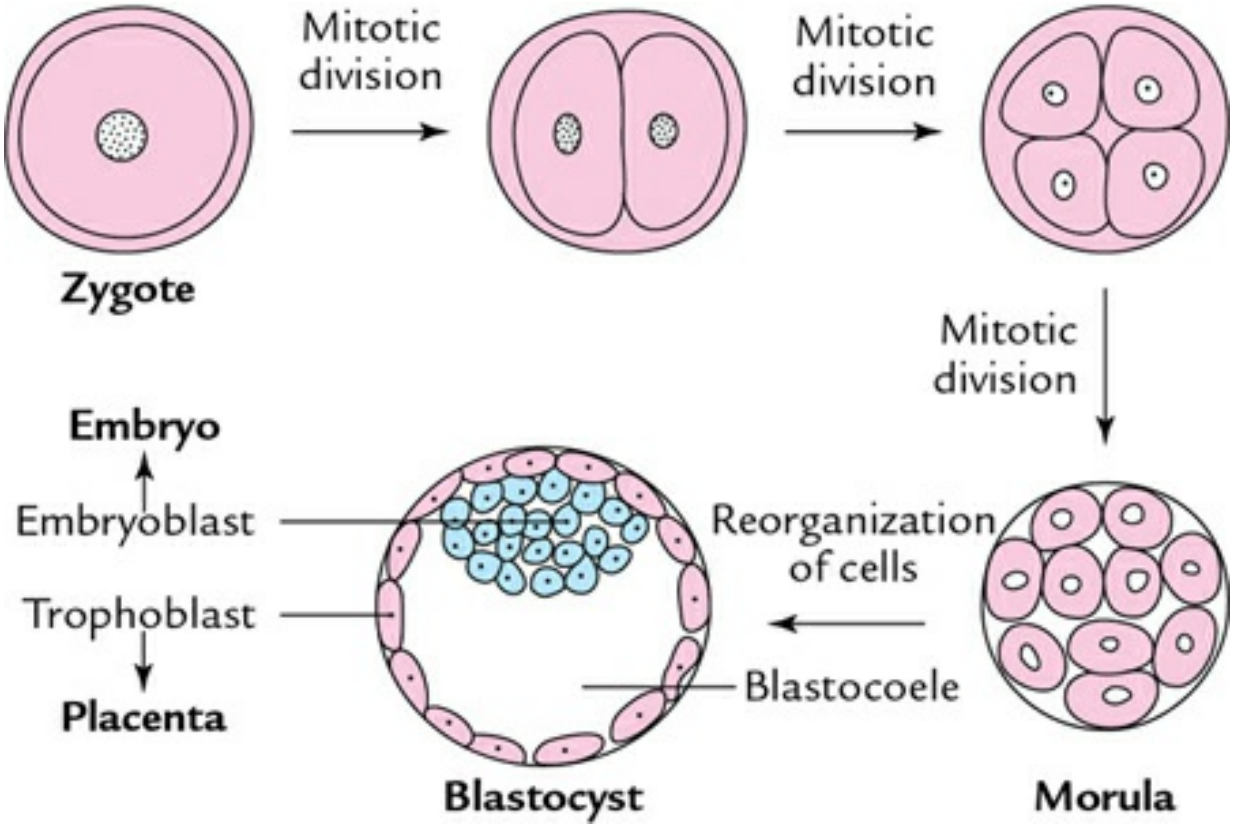


FIG. 4.1 ■ Formation of blastocyst from zygote.

The inner cell mass then differentiates into three layers of cells from superficial to deep, these are:

1. Ectoderm
2. Mesoderm
3. Endoderm.

These three layers are called the **primary germ layers**. All the organs and tissues of the body are derived from these layers (Table 4.1).

 **TABLE 4.1**

Derivatives of three primary germ layers

Ectoderm	Mesoderm	Endoderm
• Nervous system • The epidermis of skin including hair, nails and skin glands • The epidermal lining of the surface of the body and orifices on the surface of the body • The lens of the eye, the enamel of teeth • Adrenal medulla	• The musculoskeletal system, that is muscles, bones and cartilages • Cardiovascular system (heart vessels) • Dermis of skin • Dentine of teeth • Connective tissue, genitourinary system, adrenal cortex	• The lining of the gastrointestinal tract, respiratory tract, urinary bladder and urethra • Epithelium of thyroid, parathyroid, thymus, liver and pancreas

Cells

The humans are most complex organisms made up of trillions of cells. It is amazing that a single cell, the fertilized ovum (zygote) gives rise to hundreds of different kinds of cells, which compose **60–100 trillion cells** that make up an adult human body. The body cells are broadly divided into two types: **somatic cells** and **germ cells**. The somatic cells are essential for the growth, development, regeneration and maintenance of various tissues of the body, whereas germ cells are essential for the production of gametes. The somatic cells contain 46 chromosomes arranged in 23 pairs. The cells containing two

sets of chromosomes like this are called **diploids**. One set of chromosomes is derived from the mother and the other from the father. Twenty-two pairs look alike, that is they are homologous. The twenty-third pair is the sex chromosomes. In a female, the 23rd pair has two X chromosomes, while in the male there is one X and one Y chromosome.

The germ cells are essential for the production of gametes (ova and sperms). The gametes contain 23 chromosomes, that is a single set of chromosomes. The cells containing a single set of chromosomes such as gametes are called **haploids**.

Cell division, growth, differentiation, maturation, and programmed cell death (apoptosis) are the fundamental processes of a living body. Therefore, it is essential to consider the microscopic cellular anatomy:

1. The **cell membrane** separates the interior of the cell from the extracellular environment.
2. The **nucleus** contains the genetic material of a cell.
3. The **cytoplasm** (watery fluid between the nucleus and cell membrane) contains a number of minute structures called organelles plus deposits of carbohydrates, lipids and pigments. Most of the metabolic activities of a cell occur within the cytoplasmic organelles.

Structure

A cell consists of a **plasma membrane** enclosing the nucleus and a watery fluid called **cytoplasm** (Fig. 4.2).

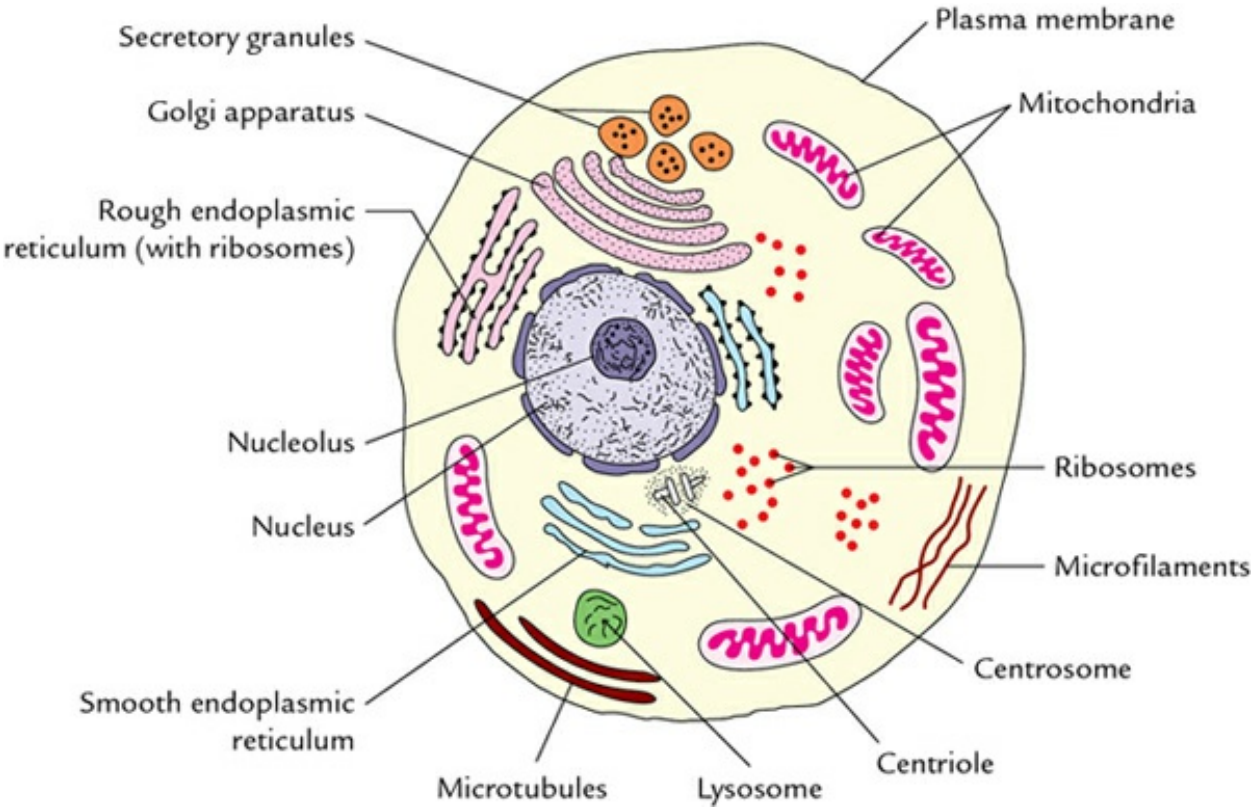


FIG. 4.2 ■ Structure of a cell.

Plasma membrane (Fig. 4.3A and B)

The plasma membrane is composed of two layers of phospholipids (fatty substances) with some protein molecules embedded in it (fluid mosaic model). Some proteins traverse the entire thickness of the membrane and are called **transmembrane proteins** which contain channels for diffusion, while others penetrate only partly through it and are called **surface membrane proteins**. The phospholipid molecules have a head which is electrically charged and is hydrophilic (i.e. water-loving) and a tail which has no charge and is hydrophobic (i.e. water-hating). The two layers of phospholipids are arranged like a sandwich with hydrophilic heads aligned on the outer surface of the membrane and the hydrophobic tails towards the middle of the membrane (Fig. 4.3B).

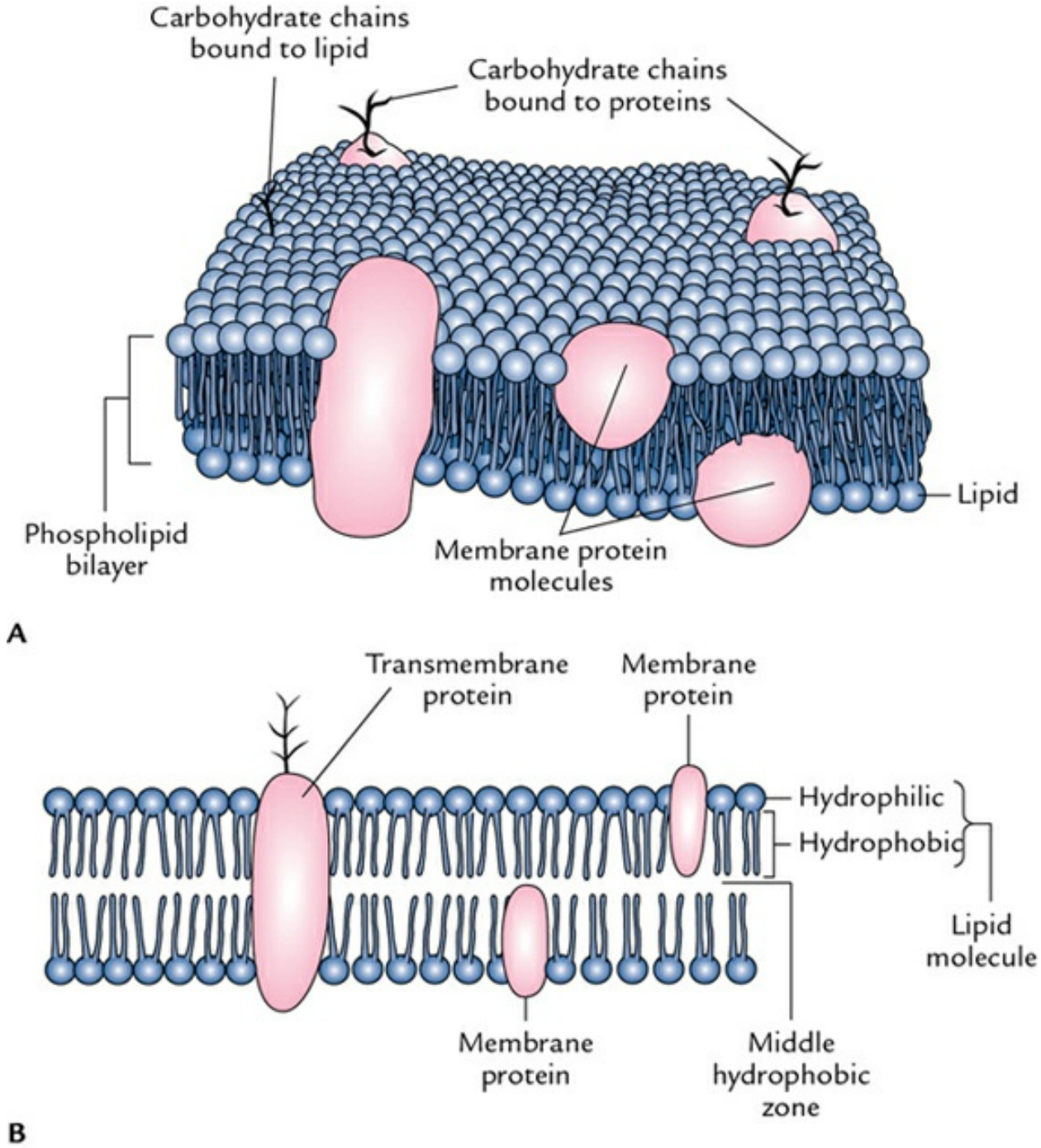


FIG. 4.3 ■ Plasma membrane: (A) fluid mosaic model and (B) membrane showing two layers of phospholipids.

The outer surface of the cell membrane is covered by a layer of a glycoprotein called **glycocalyx** or **cell-coat**. The tissue antigens, including major histocompatibility antigens (MHC), are located in the cell-coat.

The membrane proteins perform several functions:

1. They provide the cell with its immunological identity.

2. They act as specific receptors for hormones and other chemical messengers.
3. Some of them act as enzymes.
4. Some of them are involved in transportation across the membrane.

Nucleus

The nucleus is a large, generally spheroid body surrounded by a membrane similar to the plasma membrane, but it has tiny pores through which some substances can pass between it and the cytoplasm. The material within the nucleus is frequently called **nucleoplasm**.

The nucleus contains the genetic material of the body which directs all the activities of the cell. The genetic material is made up of **deoxyribonucleic acid (DNA)** and proteins called **histones**. These (DNA and histones) together form a fine network of threads called **chromatin**. The chromatin resembles tiny strings of beads.

During cell division, the chromatin replicates and becomes more tightly coiled forming **chromosomes** (Fig. 4.4). The functional subunits of chromosomes are called **genes**. Each cell contains the total complement of genes (genome) required to synthesize all the proteins in the body but most cells synthesize only those proteins which are essential for their own specialized functions. Thus each cell uses only a part of the **genome** or genetic code.

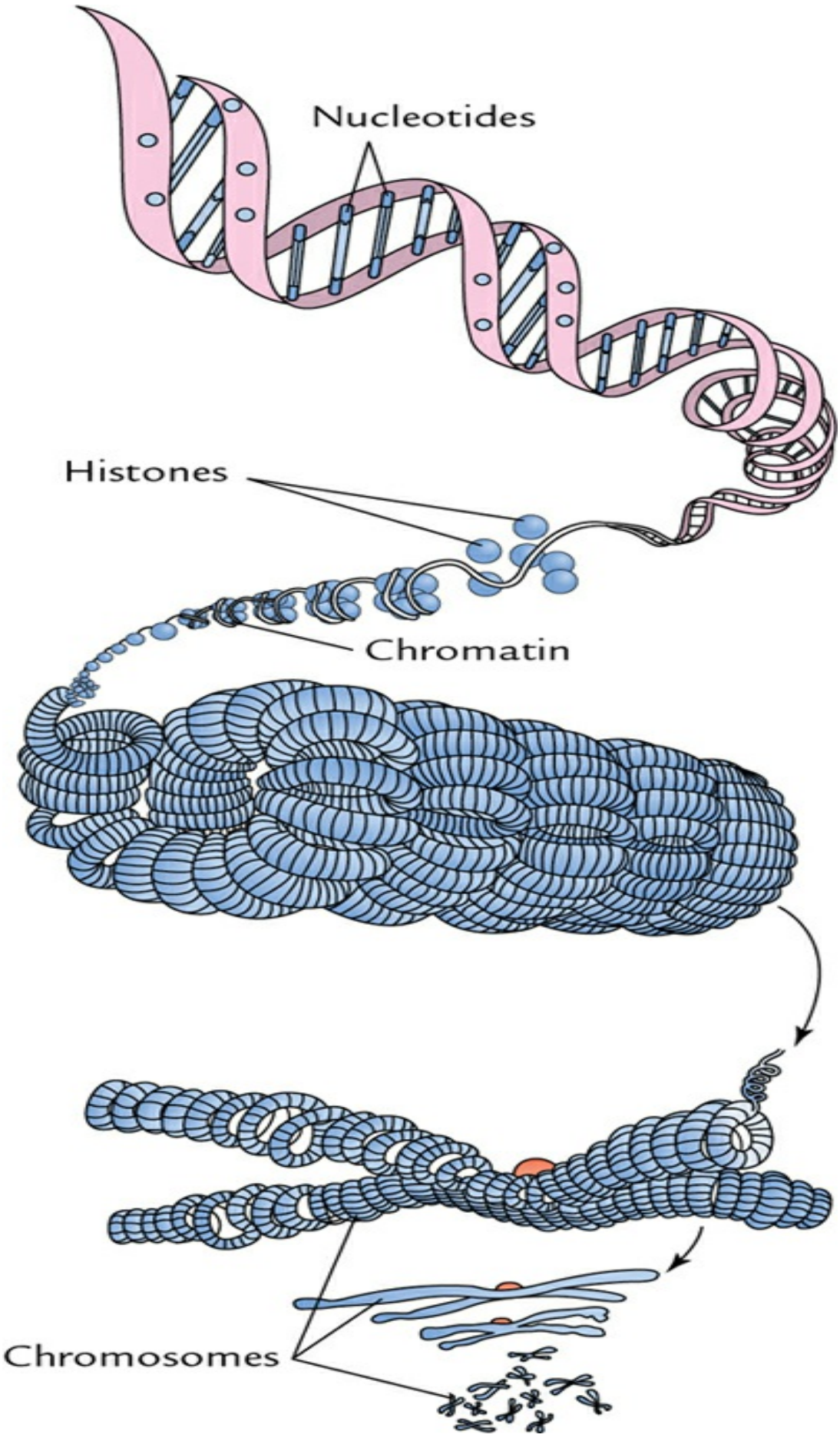

Nucleotides
Histones
Chromatin
Chromosomes

FIG. 4.4 ■ Structural features of chromosomes during cell division.

A highly refractile spherical body situated within the nucleus close to the nuclear membrane is called the **nucleolus**. It is a compressed mass of RNA granules and proteins. The RNA is liberated from the nucleolus through nuclear pores and appears in the cytoplasm.

N.B.

All cells except mature red cells contain a nucleus.

Cytoplasmic organelles

They include mitochondria, ribosomes, endoplasmic reticulum, Golgi apparatus, lysosomes, centrioles, microfilaments and microtubules.

Mitochondria

The mitochondria are sausage-shaped organelles and are often described as the **powerhouse of the cell**. They are involved in aerobic respiration, the process by which the chemical energy in the form of **adenosine triphosphate (ATP)** is made available to the cell through a series of chemical reactions. The ATP is further broken down into free energy when required by the cell. The distribution of mitochondria varies in cells. They tend to accumulate in parts of the cytoplasm where metabolic activity is more intense.

Metabolically active cells such as muscle cells and liver cells, have a large number of mitochondria because they use energy at a high rate.

Clinical correlation

Cytoplasmic inheritance: The sperm (male gamete) contains nuclear DNA in head and mitochondrial DNA in body. All the mitochondria in a fertilized egg (zygote) belong to the mother because only the head of sperm enters the ovum during fertilization. Thus all the mitochondrial DNA of the foetus belongs to the mother. This accounts for a unique form of inheritance that is passed only from mother to child. This type of inheritance is known as *cytoplasmic inheritance.* A rare cause of blindness, *Leber's hereditary optic neuropathy* is believed to be inherited in this manner.

Ribosomes

These are tiny electron-dense granules (having a density that prevents electrons from penetrating, therefore, structures appear as dark bodies). They are composed of ribonucleic acid (RNA) and proteins. They are found in the nucleus and nucleolus. They are also found on the outer surface of the rough endoplasmic reticulum. The ribosomes synthesize **proteins** from amino acids.

Endoplasmic reticulum

It is a series of interconnecting membranous canals. It is of two types: smooth and rough.

The smooth endoplasmic reticulum (SER) is devoid of ribosome granules. It synthesizes **lipids, glycogen and steroid** hormones and is associated with the **detoxification of drugs**, viz. alcohol.

The rough endoplasmic reticulum (RER) is studded with ribosomes. It is the site of synthesis of proteins, viz. the **enzymes and hormones** that are exported from the parent cell to be used by other cells of the body.

Clinical correlation

Drug resistance and smooth endoplasmic reticulum: A person who repeatedly uses addictive drugs such as phenobarb, larpose or alcohol develops tolerance to these drugs; consequently, they require greater quantities of these drugs to achieve their effects. This is because the repeated use of drugs causes the smooth endoplasmic reticulum to proliferate in an effort to detoxify these drugs and protect the cell. With an increased amount of smooth endoplasmic reticulum, the cells can handle an increased amount of drugs.

Golgi apparatus

It is a supranuclear organelle that is composed of stacks of closely folded flattened membranous sacs. It is the site of the **processing and packaging of proteins** synthesized by the RER. The proteins move from the RER to the Golgi apparatus where they are processed first and then packaged into small

membrane-bound vesicles called **secretory granules**. These vesicles are stored and when needed, move to the plasma membrane through which proteins are exported.

Lysosomes (Lysis = solution, soma = body)

These are membrane-bound vesicles that contain a large variety of hydrolytic enzymes whose main function is **intracytoplasmic digestion**. They are involved in the digestion of waste and harmful material of the cell taken into the cell from the environment. The lysosomes are present in almost all cells, but they are particularly abundant in cells exhibiting phagocytic activity, viz. macrophages, neutrophilic leukocytes.

Centrioles

Each cell capable of division contains two centrioles close to the nuclear membrane. The dense region of cytoplasm containing centrioles is called the **centrosome**. Each centriole presents two cylindrical bodies, placed at right angles to each other. Each cylinder consists of 27 microtubules arranged in nine bundles. Each bundle is composed of three microtubules called **triplets**. During cell division, two centrioles divide to form two new centrioles. The parent centrioles migrate to the opposite sides of the cell.

The centriole synthesizes microtubules to form spindle during cell division.

Microfilaments

These are tiny strands of protein that provide structural support to the cell and maintain its characteristic shape. They are also involved in many other functions of the cell, for example, the contractile activity of muscle cells is primarily a result of the interaction between two types of microfilaments: myosin and actin.

Microtubules

These are tiny tubular structures made up of protein. They have a variety of

functions such as **intracellular transport** of other organelles of the cell and movements of cell and cilia.

N.B.

All the cell organelles described previously are membrane-bound organelles *except* ribosomes, centrioles, microtubules and microfilaments which are nonmembrane-bound organelles.

Cell division

There are two types of cell division: mitosis and meiosis (Fig. 4.5).

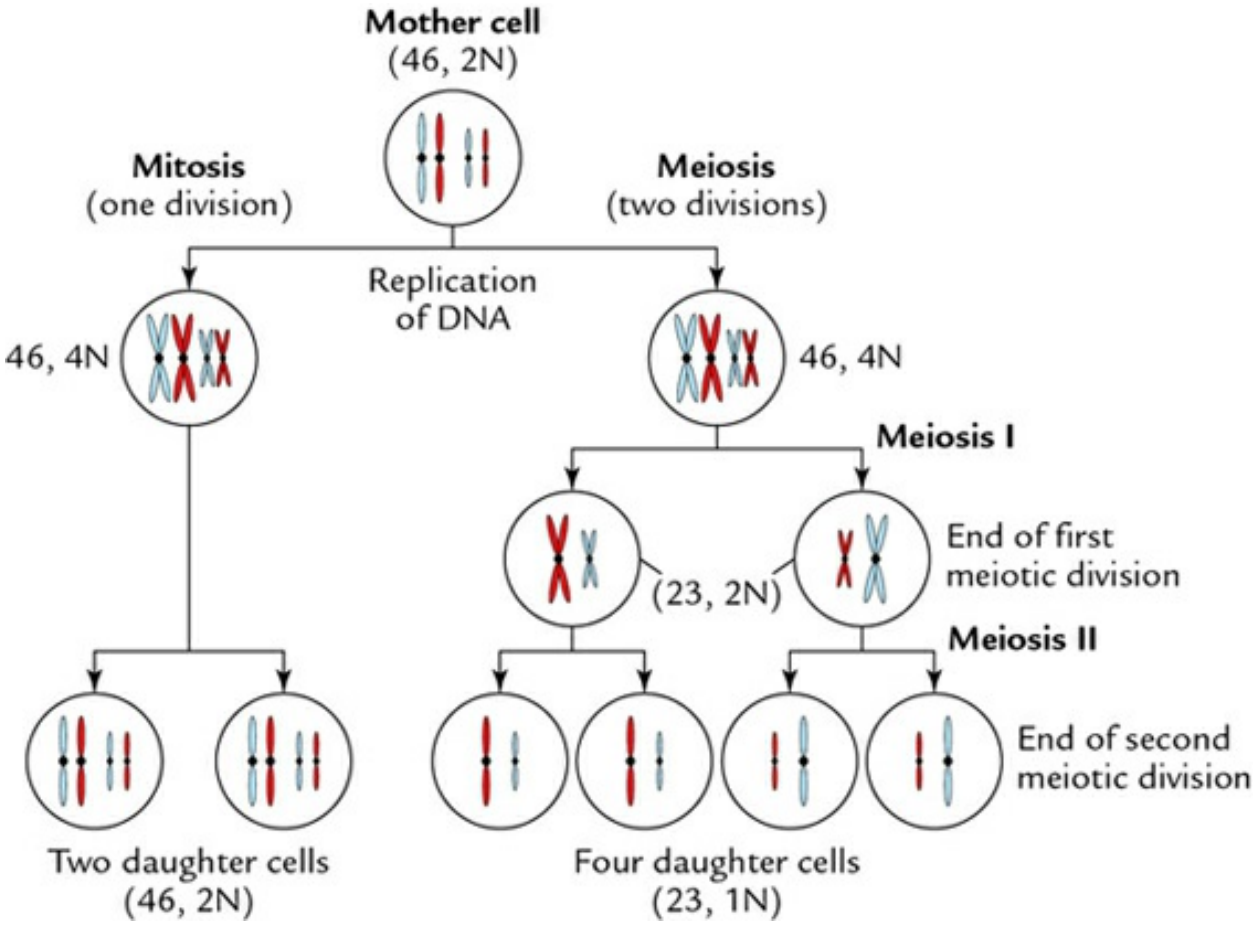


FIG. 4.5 ■ Cell division: mitosis and meiosis.

Mitosis (Fig. 4.5)

It is a method of cell division in which a diploid parent cell gives rise to two

identical diploid daughter cells in terms of genetic material and cytoplasm. It is the most common method of cell division and occurs in almost all somatic cells and immature germ cells. It occurs in two stages: **replication** of DNA and **cell division**.

The life span of most of the cells of the body is limited. Many cells become worn out and die; they are replaced by identical cells produced as a result of cell division or mitosis. Most tissues undergo constant turnover because of continuous cell division and the ongoing death of cells. The nerve tissue and cardiac muscle are an exception since they do not multiply postnatally and, therefore, cannot regenerate. The turnover rate of cells varies greatly from one tissue to another. It is rapid in the epithelium of the alimentary canal and epidermis of the skin, whereas it is slow in the pancreas and the thyroid.

During mitosis, 23 pairs of chromosomes replicate. The two identical sets of chromosomes move to the opposite poles of the parent cell which then divides; each daughter cell receives a set of 23 pairs of chromosomes (diploid number).

Cell cycle (Fig. 4.6)

The cell cycle is defined as a period of time taken by a cell to divide into two daughter cells. It is divided into four phases of different durations:

1. **G1 phase, 12 h**—is the crucial period of the cell cycle during which the cell determines to undergo cell division. It is the period of synthesis of various metabolites required for cell division.
2. **S phase (synthetic phase), 6 h**—is the period of DNA synthesis.
3. **G2 phase, 4 h**—is the period during which fidelity of DNA replication is checked and errors, if any, are corrected.
4. **M phase, 2 h**—is the period during which the cell actually divides.

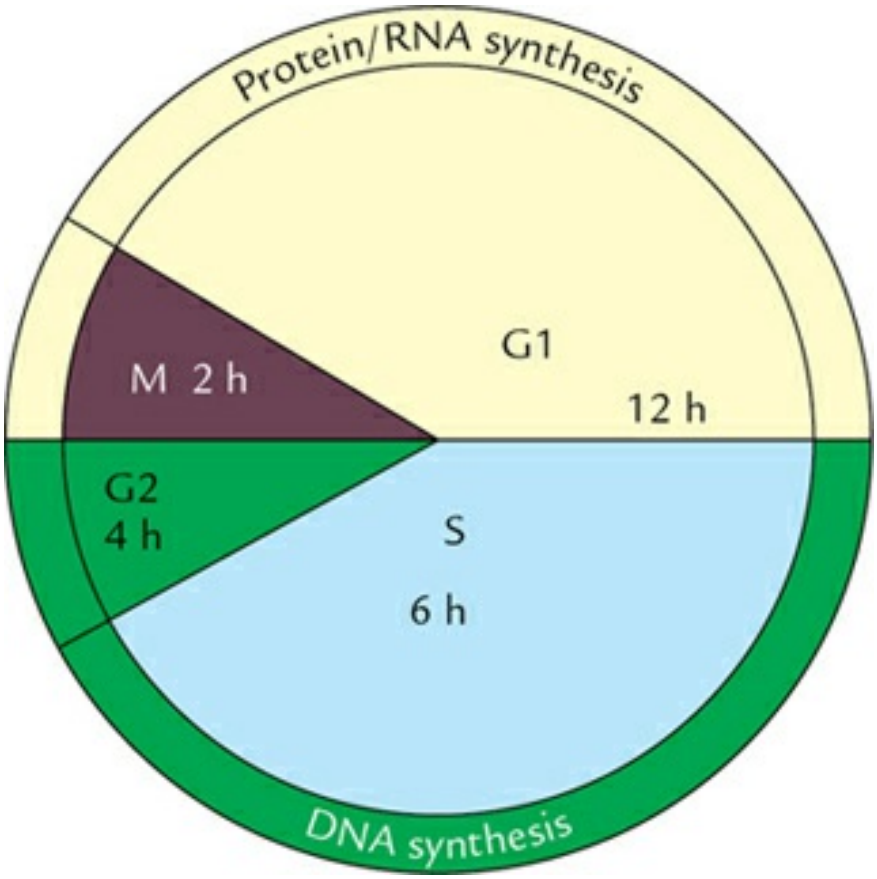


FIG. 4.6 ■ Cell cycle.

N.B.

- The transition between G2 and M phases is regulated by the mitosis-promoting factor.
- There are regulatory mechanisms for the controlled division of cells according to the need.
- The several factors that inhibit cell reproduction are collectively called *chalones.*

Meiosis (Fig. 4.5)

It is a special type of cell division that occurs only in germ cells during the production of gametes. It consists of two cell divisions (meiosis I and meiosis II). By meiotic division, the diploid germ cell gives rise to four haploid gametes. During meiosis, the pairs of chromosomes separate and one from each pair moves to the opposite poles of the parent cell. When it divides,

each of the daughter cells has only 23 chromosomes called **haploid number**. This means that when the ovum is fertilized with a spermatozoon, the resultant zygote has 46 chromosomes called **diploid number**. Thus the child has some characteristics inherited from the mother and some from the father.

The differentiating features of mitosis and meiosis are listed in Table 4.2.

TABLE 4.2

Differences between mitosis and meiosis

Mitosis	Meiosis
Occurs in somatic cells	Occurs in germ (gametic) cells
Completes in one sequence	Completes in two sequences
Forms two daughter cells (containing the same number of chromosomes as in the mother cell)	Forms four daughter cells (containing half number of chromosomes as in the mother cell)
Daughter cells are identical to the mother cell	Daughter cells are not identical to the mother cell
No exchange of maternal and paternal DNA occurs	Exchange of small amount of maternal and paternal DNA occurs (to ensure genetic variability)

Tissues

The tissues are collections of cells performing a similar function. The term tissue includes a collection of cells and intervening intercellular substances.

Basic tissues: There are four basic types of tissues in the body:

1. ***Epithelial tissue,*** derived from all 3 germ layers
2. ***Connective tissue,*** derived mainly from mesoderm
3. ***Muscle tissue,*** derived mainly from mesoderm
4. ***Nervous tissue,*** derived from ectoderm.

Only epithelial glandular and connective tissues are discussed in detail in this chapter. The other tissues are described in detail in subsequent chapters.

Epithelium

The epithelium is a sheet of cells. The deep surface of this sheet rests on the basement membrane, an extracellular structure mainly made up of collagen fibres. The cells of the epithelium form continuous layer/layers. The cells are tightly packed together with little or no intercellular matrix between them.

Epithelium covers the body surface, lines body cavities (e.g. pleural, peritoneal), lines tubes (e.g. gastrointestinal tract, respiratory tract, genitourinary tracts, blood vessels) and forms glands (e.g. exocrine, endocrine). The epithelium has a high regeneration capacity ranging from a few days (e.g. epithelial lining, small intestine) to a month (e.g. epidermis of the skin).

Classification of epithelium

The epithelium is classified into two main types: simple epithelium and compound (stratified) epithelium.

If the sheet is made up of a single layer of cells, it is termed a **simple epithelium** and if it is made up of multiple layers of cells, it is termed a **compound** or **stratified epithelium**.

A. Simple epithelium (Fig. 4.7)

It is classified into three types depending upon the shape of the cells forming the epithelium:

1. **Simple squamous epithelium**: It is made up of a single layer of flattened/squamous cells having centrally placed flattened nuclei, that are bound together. In surface view, they appear polygonal with crenated margin and arranged in a mosaic-like pattern, for example lining endothelium of blood vessels, lining mesothelium of serous membranes, and lining epithelium of alveoli of lungs (Fig. 4.7A).
2. **Simple cuboidal epithelium**: It is made up of cube-like cells with rounded central nuclei, for example, the lining of thyroid follicles and the germinal epithelium of the ovary (Fig. 4.7B).
3. **Simple columnar epithelium**: It is made up of tall columnar cells, with long elongated nuclei, for example, lining epithelium of the

gastrointestinal tract, gallbladder, and bile duct (Fig. 4.7C).

If the simple columnar epithelium is characterized by the presence of cilia along its free surface, it is termed a **simple ciliated columnar epithelium**, for example, the lining epithelium of the central canal of the spinal cord and brain vesicles (Fig. 4.7, 1).

4. **Pseudostratified columnar epithelium**: This is a special variety of simple epithelium. The details are as follows:

   If the simple columnar epithelium is made up of two types of columnar cells: (a) tall cells, and (b) short cells.

   Both types of cells lie on the basement membrane. However, only the tall cells reach the surface and the short cells fail to reach the surface. In such a situation nuclei of these cells lie at different levels **giving a stratified appearance**. Hence, the name pseudostratified columnar epithelium (Fig. 4.7D). If the tall cells are (almost always) ciliated, this type of epithelium is termed **pseudostratified ciliated columnar epithelium**, (Fig. 4.7, 2); It is further divided into two types: (a) pseudostratified non-ciliated columnar epithelium, for example, lining epithelium of prostatic follicles and membranous urethra, (b) pseudostratified ciliated columnar epithelium, for example, lining epithelium of upper respiratory passages, air sinuses. The pseudostratified ciliated columnar epithelium is always associated with interspersed mucous secreting goblet cells. Hence, it is often called pseudostratified columnar epithelium with interspersed goblet cells. Since pseudostratified ciliated columnar epithelium with interspersed goblet cells lines the respiratory tract (viz., nasal cavity, trachea, bronchi), it is also called the **respiratory epithelium**. The cilia act like brooms to transport or move material across the cell surface.

   A brief description of the goblet cell is given below: ***Goblet cells (Fig 4.8)****:* The goblet cells are so called because of their goblet-like shape. They contain mucin granules in their upper dilated part and elongated/oval nucleus in the lower narrow part. The primary function of goblet cells is to synthesise and secrete mucus which forms a protective mucous layer on the epithelial surface. They are found in the lining epithelium of the respiratory and gastrointestinal tracts.

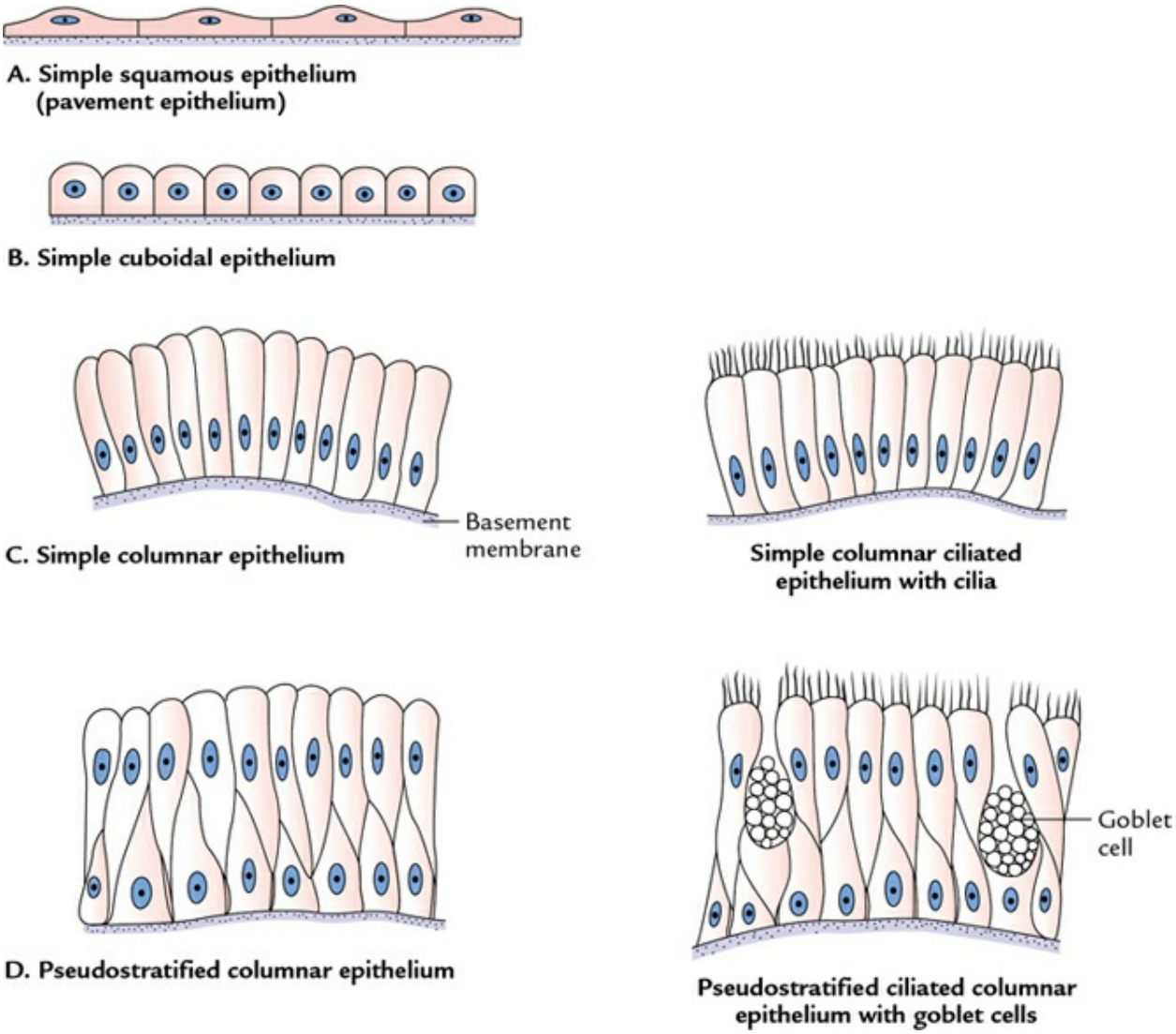


FIG. 4.7 ■ Types of simple epithelium.

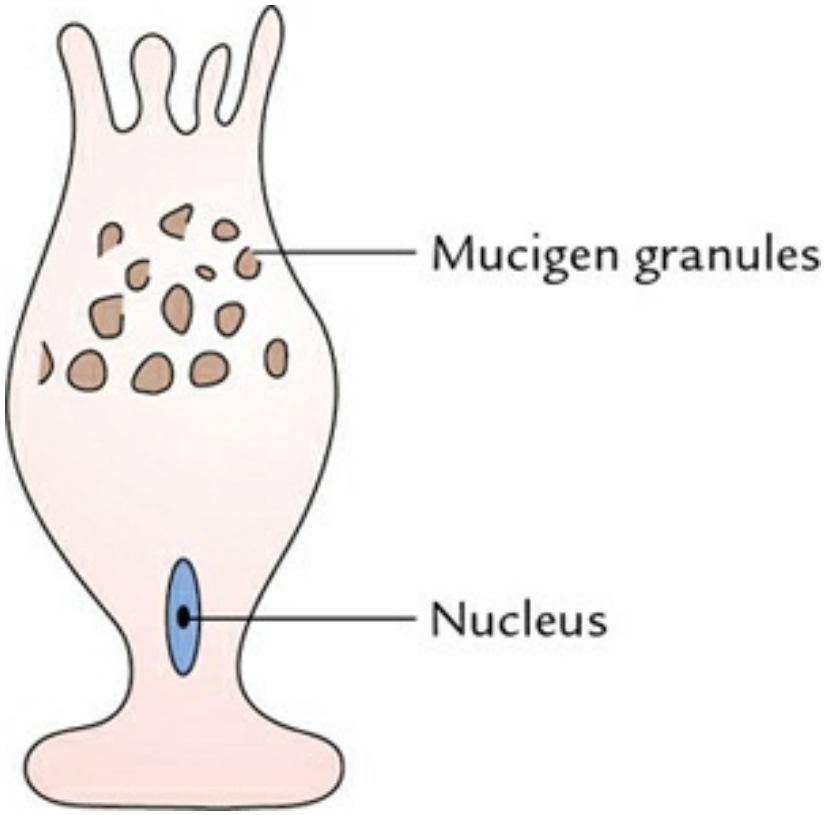


FIG. 4.8 ■ Goblet cell

B. Compound/stratified epithelium (Fig. 4.9)

It is also classified into three types depending upon the shape of the cells of the surface layer:

1. **Stratified squamous epithelium**: It is usually made up of 4-6 layers. The surface layer is made up of squamous cells. It is further subdivided into two types:
   - If the surface layer is moist, the surface cells are not keratinized, it is called the **stratified squamous nonkeratinized epithelium**, for example, the epithelium lining the oral cavity, lower part of the anal canal, vagina.
   - If the surface layer is not moist, i.e. it is exposed to air, the surface cells undergo keratinization (i.e. cells die and the cytoplasm is replaced by keratin), it is called **stratified squamous keratinized epithelium**, for example, the epidermis of the skin.
2. **Stratified cuboidal epithelium**: It is usually double-layered epithelium. The surface layer is made up of cube-shaped cells, for example, ducts of sweat glands, excretory ducts of salivary glands, etc.

3. **Stratified columnar epithelium**: It is also usually double-layered. The surface layer is made of columnar cells, for example, large ducts of salivary glands. If surface cells are ciliated, it is called as stratified ciliated columnar epithelium.

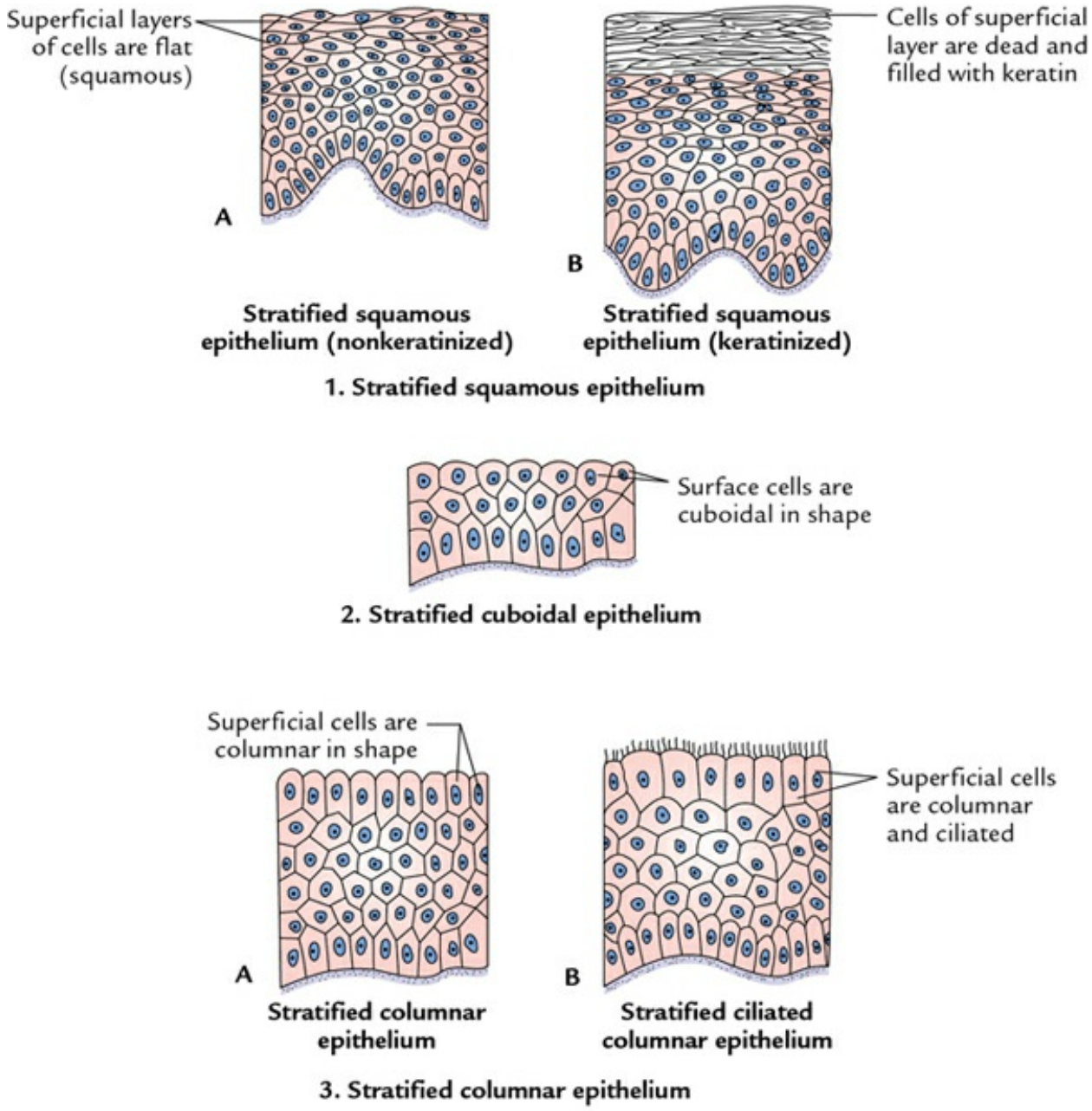


FIG. 4.9 ■ Types of compound/stratified epithelium.

Transitional epithelium

It is a special variety of stratified epithelium lining the urinary tract, viz.

ureter, urinary bladder, urethra, etc. Hence, it is also called the ***urothelium.*** It is somewhat similar to the nonkeratinized stratified epithelium. But unlike the flattened surface cells of stratified epithelium, the surface cells of transitional epithelium are large and umbrella-shaped with abundant cytoplasm and prominent nuclei (Fig. 4.10). The surface cells are connected by tight junctions and are covered by a thick cuticle. The transitional epithelium is so called because it exhibits two types of transitions:

1. **Transition in surface of cells**, i.e. when the organ or the tube is relaxed, they are umbrella-shaped but when the organ or the tube is distended, they become flattened (Fig. 4.10).
2. **Transition in number of layers of cells**. When the organ or the tube is relaxed, it is made up of 5–6 layers of cells but when stretched or distended, it is made up of only 2 or 3 layers.

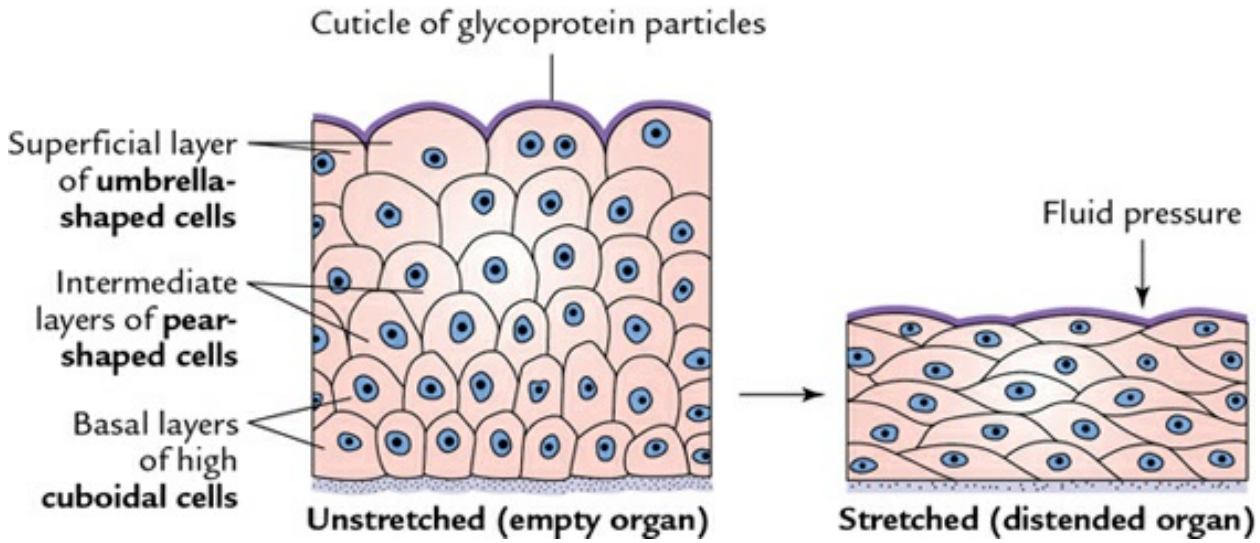


FIG. 4.10 ■ Transitional epithelium.

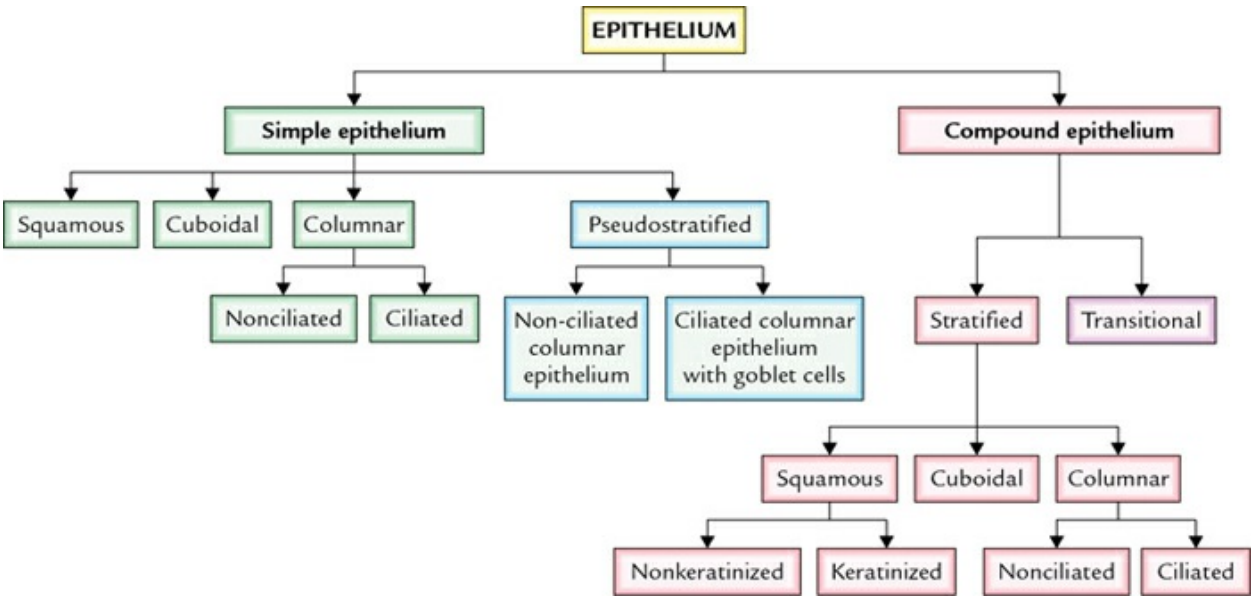
The transitional epithelium is classically described to consist of three layers: the *superficial layer* of large polyhedral cells **(umbrella cells),** the *intermediate layer* of **pear-shaped cells,** and the *deeper layer* of smaller **(low columnar or cuboidal)** cells.

The cells of all the layers are connected to the basement membrane through cell junctions. Hence, they do not get disrupted during stretching.

Clinical correlation

The luminal surface of transitional epithelium is covered by thick plates of glycoprotein particles (uroplakin particles) which may account for the impermeability of urine into the blood that is it **prevents the reabsorption of waste material of urine back into the blood**. Hence, this is called as **'blood urine barrier'**.

The classification of epithelium is summarized in Flowchart 4.1.



FLOWCHART 4.1 ■ Classification of the epithelium.

Specialization on the free (apical) surface of the epithelial cells (Fig. 4.11)

1. **Microvilli**: These are small finger-like projections (1–2 μm in length) containing a core of actin filaments that are anchored to the *terminal web* in the apical cytoplasm. They are coated with a layer of glycoprotein (glycocalyx). Microvilli increase the surface area of the cell membrane to enhance absorption, for example, lining the epithelium of the gallbladder and small intestine.
2. **Stereocilia**: These are long microvilli (about 5–10 μm in length) that lack a core of actin filaments, hence they are nonmotile, for example, in the epithelial lining of epididymis where they enhance absorption; in the cochlear and vestibular receptors where they act as sensory transducers.

3. **Cilia**: They are motile filamentous cytoplasmic projections from within the cell. Each cilium contains a core of microtubules (α and β tubulin) called an **axoneme**. The axoneme consists of globules of microtubules surrounding two central microtubules (*9 + 2 arrangement*). Ciliary cells are interspersed with mucous-secreting **goblet cells**. There is always a film of mucus on the free surface of ciliary cells, for example, the epithelial lining of the respiratory tract where they move the mucus towards the pharynx, the epithelial lining of fallopian tubes where they move the ova towards the uterine cavity. At the base of each cilium is a *basal body* that consists of 9 triplet microtubules and no central microtubules (*9 + 0 arrangement*).

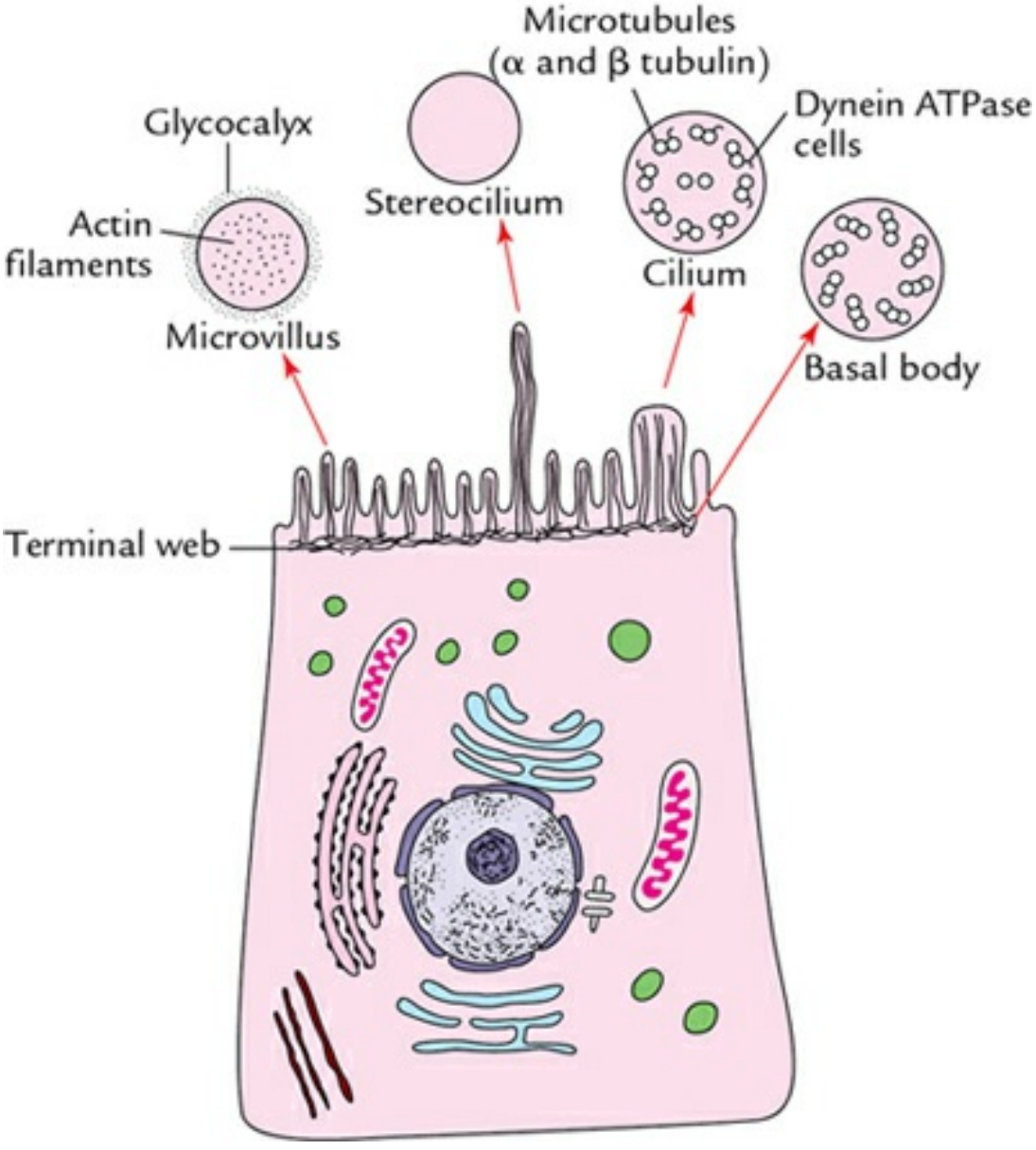


FIG. 4.11 ■ Specializations on the apical surface of the epithelial cells.

As glands are composed of epithelial cells (these cells become specialized to produce a fluid secretion that differs in composition from blood or intercellular fluid), it is worthwhile to include a brief account of the glands in this section.

Glands

The glands are specialized epithelial cells that produce secretion. Usually, they exist in groups to form a highly coherent group of epithelial cells with a common secretory function. Such cells may exist singly in isolation among other nonsecretory cells of the epithelium, for example, **goblet cells**.

Thus the glands are of two types: **unicellular** and **multicellular**:

1. **Unicellular glands** are single-celled glands, for example, mucous-secreting **goblet cells** interspersed in the columnar epithelia of the respiratory tract and intestine. They pour their secretion on the surface of epithelium. The structure of goblet cell is described on page 36 and shown in Figure 4.8.
2. **Multicellular glands** are derived from the surface epithelial lining by the process of proliferation and evagination into the underlying connective tissue.

If the glands retain their connection with the surface epithelium, of course, by a tubular duct lined by epithelial cells, they are termed **exocrine glands or glands with the duct**. The secretions of these glands reach the surface through their ducts.

If the glands lose their connection with the surface epithelium, they are called **ductless** or **endocrine glands**. The secretion of these glands passes into the bloodstream.

Types of glands

The glands are classified into two types according to the mode in which they release their secretion.

A. Exocrine glands (Fig 4.12A)

They release their secretion directly into the surface through the duct either on the surface of body, viz. sweat glands or on the surface of hollow organs like GIT, viz. digestive glands.

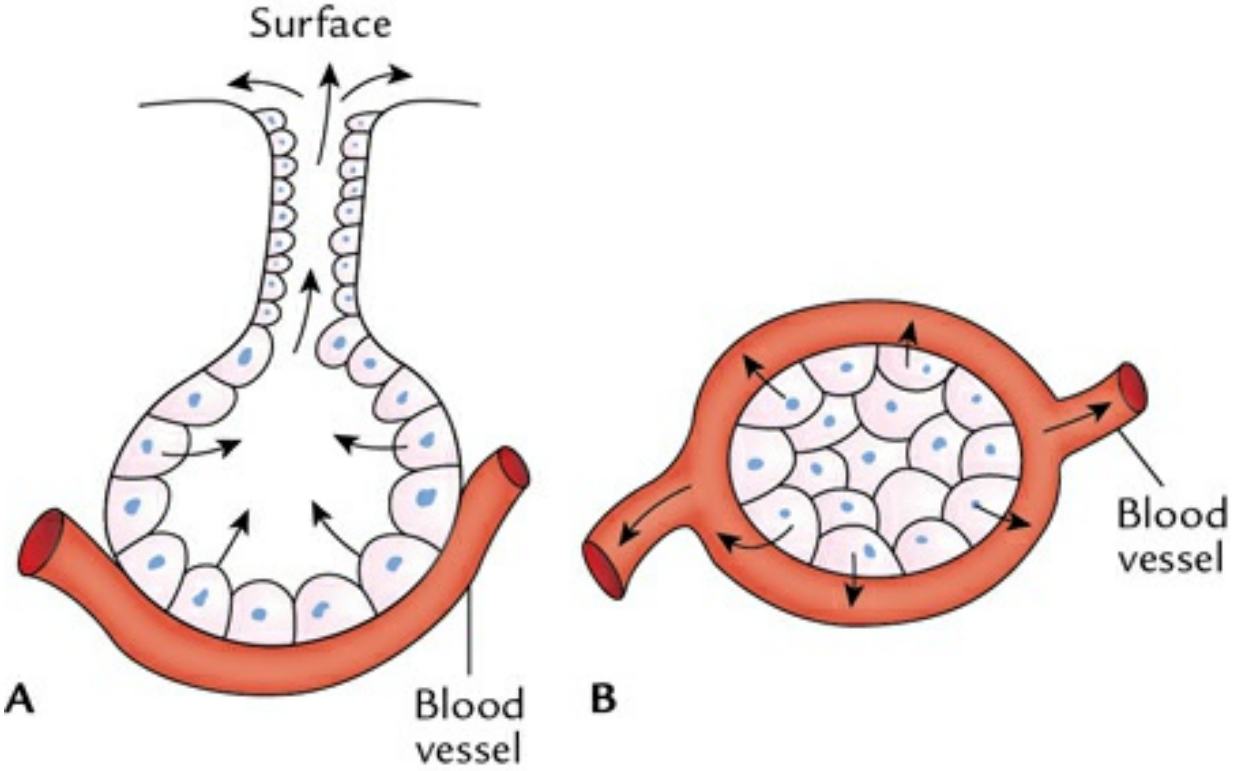


FIG. 4.12 ■ Types of Glands: **A.** Exocrine gland, **B.** Endocrine gland.

Since unicellular glands also pour their secretion on the surface they are usually classified with exocrine glands.

B. Endocrine glands (Fig 4.12B)

They release their secretion directly into the blood which carries them to the various parts of the body.

Classification of exocrine glands

1. According to the branching pattern of the duct and types of secretory units (Fig. 4.13)

(a) *Simple glands*: The duct of the gland does not branch.
(b) *Compound glands*: The duct of the gland branches repeatedly.

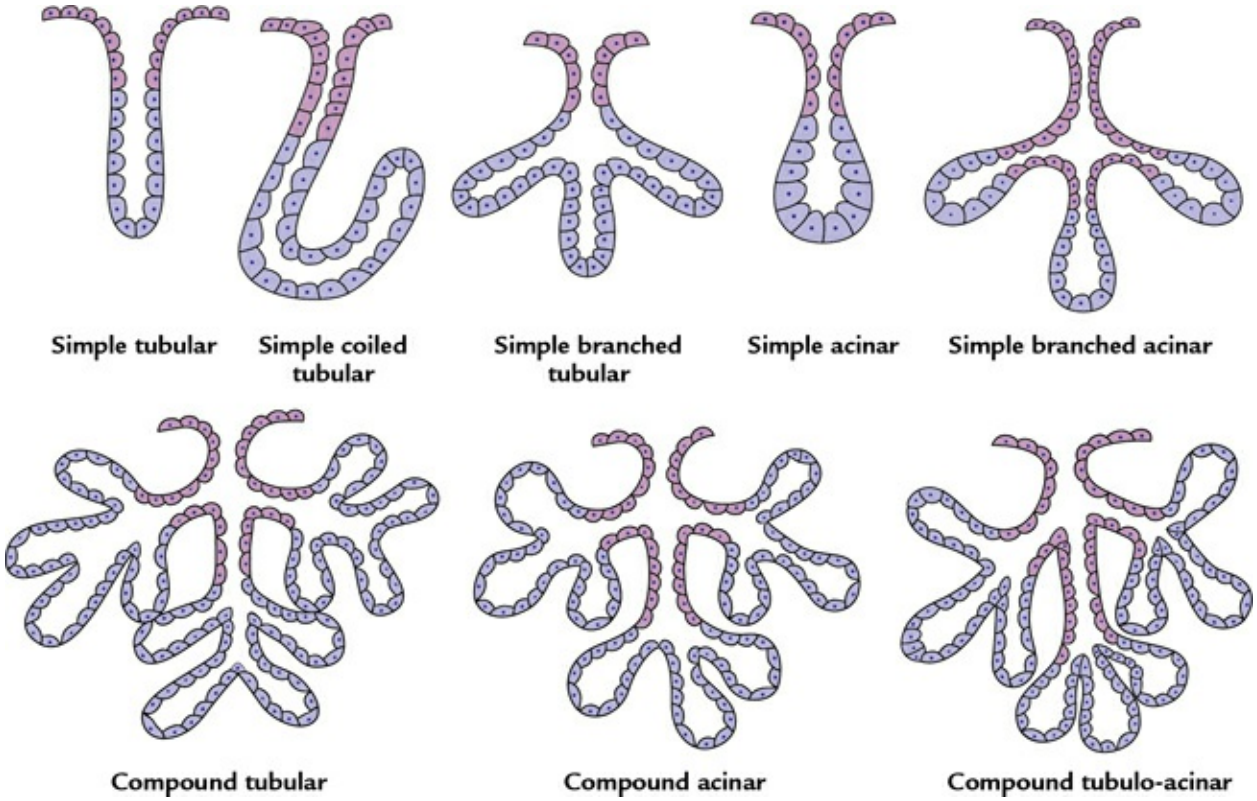


FIG. 4.13 ■ Classification of exocrine glands according to the branching pattern of duct and types of secretory units.

Further classification of these glands is based on the shape of the secretory portions/secretory units.

Types of secretory units:

- *Tubular*: The duct is connected to the tubular secretory portion, for example, gastric glands.
- *Acinar*: The duct is connected to the round or oval (sac-like) secretory portion, for example, salivary glands.
- *Alveolar*: The duct is connected to the flask-shaped secretory portion.

Simple glands: The simple glands can be tubular or acinar:

- **Tubular glands** are further divided into three types:
  - *Straight tubular*, for example, intestinal glands (crypts of Lieberkuhn).

- *Coiled tubular*, for example, sweat glands.
- *Branched tubular*, for example, gastric and uterine glands.

– **Acinar glands** are further subdivided into two types:
- *Simple acinar*, for example, urethral and paraurethral glands in the male.
- *Simple branched acinar*, for example, sebaceous glands.

Compound glands: The compound glands are further classified into three types according to the shape of their secretory portions:

– *Compound tubular*, for example, bulbourethral glands of males.
– *Compound acinar*, for example, salivary glands, exocrine pancreas.
– *Compound tubulo-acinar*, for example, prostate gland.

N.B.

The terms **acini** and **alveoli** are often used synonymously.

2. According to the mode of secretion (Fig. 4.14)

(a) **Merocrine**: The secretion is released by exocytosis through the cell membrane, for example, most glands of the body such as salivary glands.
(b) **Apocrine**: The secretion first accumulates within the cell (in the apical portion); then a portion of the cell along with the secretion is pinched off to be discharged. The pinched-off portion of the cell becomes a part of secretion, for example, mammary glands.
(c) **Holocrine**: Entire secretory cell is discharged along with the secretory product. In this way, the entire cell becomes a part of the secretion, for example, sebaceous glands.

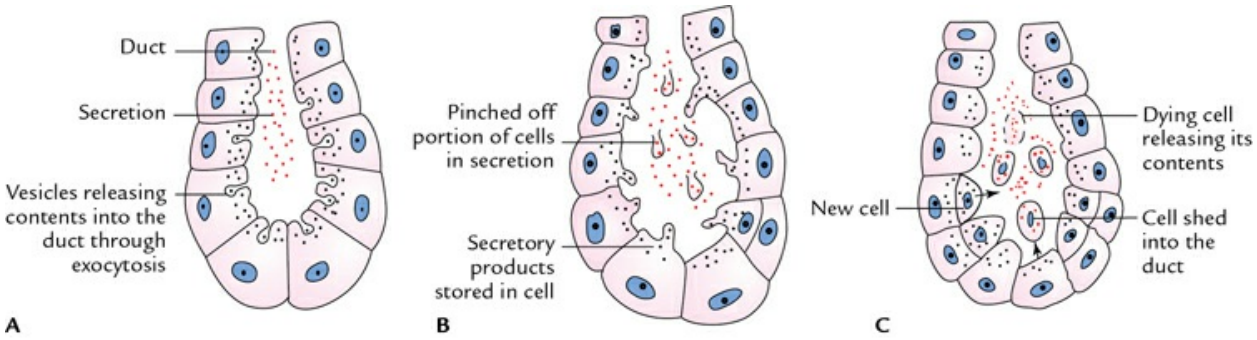
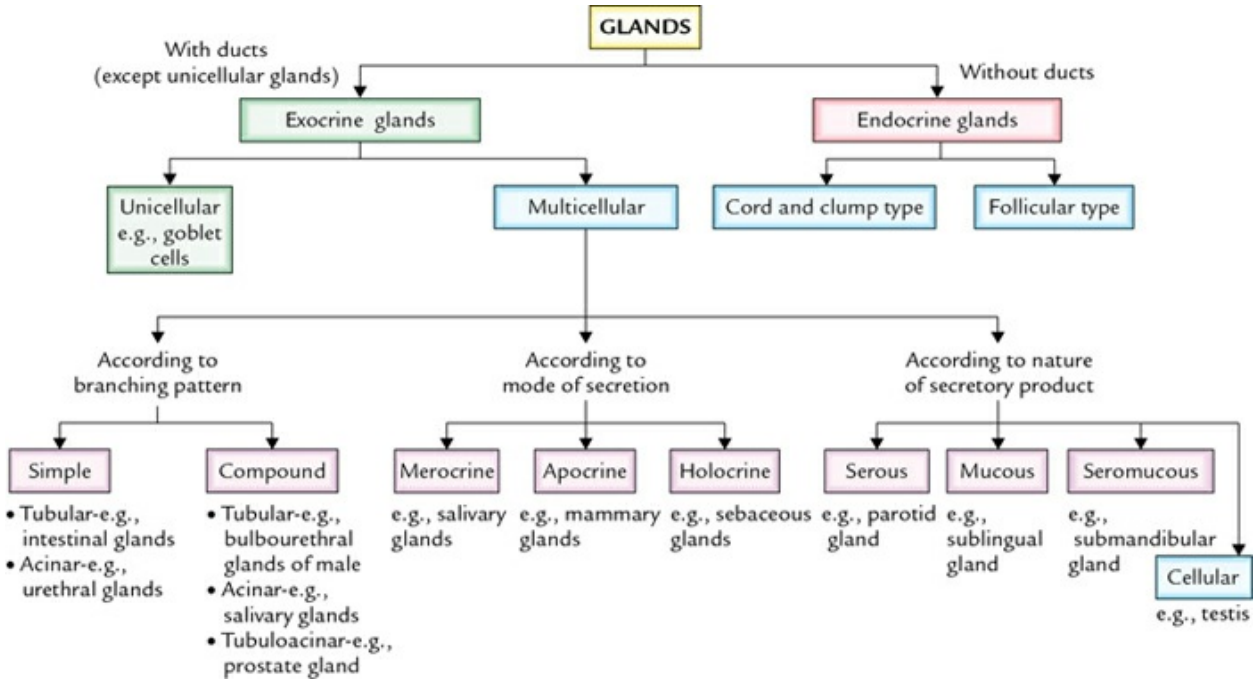


FIG. 4.14 ■ Classification of exocrine glands according to their mode of secretion: (A) merocrine glands empty their secretion into the duct through exocytosis; (B) in apocrine glands, the apical portion of the cell storing secretion is pinched off in the duct; and (C) in the holocrine gland, the entire cell containing the secretion is shed off and the lost cell is replaced by cells deeper in the gland.

3. According to the nature of secretory product

(a) **Serous**, for example, parotid gland.
(b) **Mucous**, for example, sublingual salivary gland.
(c) **Seromucous**, for example, submandibular gland.
(d) **Cellular**, for example, testis and ovary.

The classification of glands is summarized in Flowchart 4.2.



FLOWCHART 4.2 ■ Classification of the glands.

Classification of endocrine glands

The endocrine glands are so variable in their structure that they cannot be classified easily. However, two types of endocrine glands can be differentiated according to the grouping of their cells, viz., cord and clump type, and follicular type (Fig. 4.15).

1. **Cord and clump type**: These are the endocrine glands in which **cells form anastomosing cords or clumps.** Interspersed between these interconnecting cords and clumps lie dilated blood capillaries called **sinusoids**. The secretion is directly poured out into the capillaries/sinusoids. **Most endocrine glands belong to this type**.
2. **Follicular type:** These are the endocrine glands in which cells are arranged in such a way that they form secretory follicles. The secretion is stored into the cavity of follicles and is released into the capillaries/sinusoids as per the body requirement by again passing through secretory cells into the blood. **An example of such type of endocrine gland is the thyroid gland**.

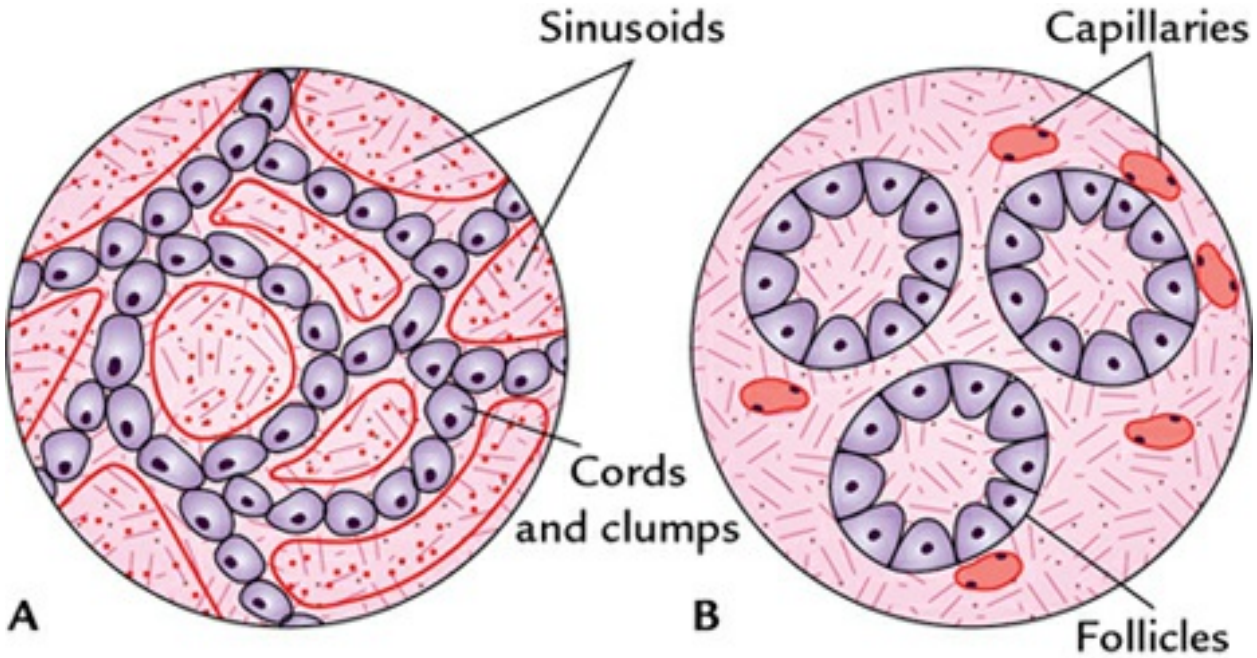


FIG. 4.15 ■ Types of endocrine glands: (A) cord and clump and (B) follicular.

N.B.

All the endocrine glands pour their secretion directly into the blood after formation except the thyroid gland where secretions are first stored in follicular cavities after formation and then released into the blood as per the requirement of the body.

Connective tissue

The connective tissue is the most widely distributed tissue and found throughout the body As its name indicates, it binds and supports the other tissues of the body.

The connective tissue consists of cells that are separated from each other by an abundant extracellular matrix which is secreted by the cells themselves. The matrix itself is made up of two components: (a) fibres and (b) ground substance.

Thus the **three essential components of connective tissue** are:

1. Ground substance
2. Fibres
3. Cells.

Ground substance

It is composed of nonfibrous protein (e.g. hyaluronic acid and chondroitin sulphate) and complex molecules of polysaccharides.

Fibres

They are of three types: **collagen fibres, elastic fibres** and **reticular fibres** (Fig. 4.16). All the three types of fibres are made up of two types of proteins, viz. collagen and elastin.

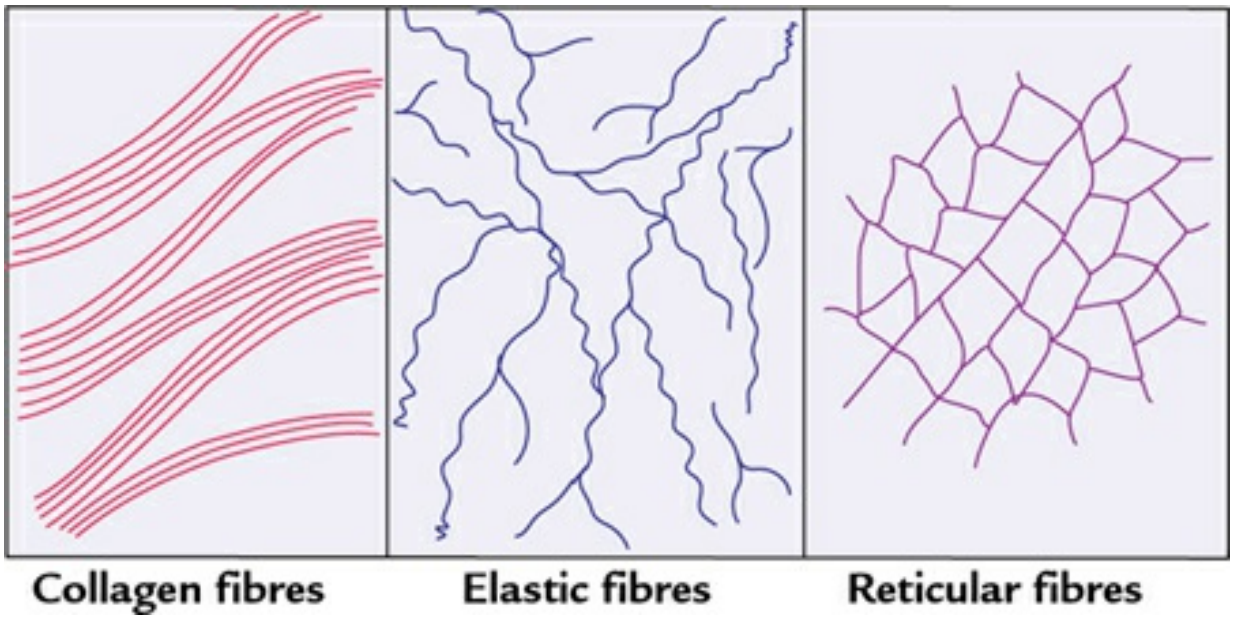


FIG. 4.16 ■ The three types of connective tissue fibres.

Collagen fibres are made up of a protein called *collagen*. They are flexible but have tremendous strength. Collagen fibres mostly occur in bundles that may branch and join with neighbouring bundles (the individual fibres do not branch). There are 19 types of collagen fibres and each is designated by a Roman numeral, viz. type I, type II, type III,..., type XIX. Type I is the most common (90% of the body collagen is of type I).

The collagen fibres are the main fibres of connective tissue. They provide support and strength to the connective tissue. They are found in abundance in bone, cartilage, tendon and ligament.

N.B.

Collagen is the most abundant protein in the body and constitutes 30% of the total protein in the body.

Elastic fibres are made up of a protein called *elastin*. They can be stretched and recoiled in their original position, thus providing elasticity to certain tissues such as skin, blood vessels and lung tissue. The elastic fibres run singly and can branch.

Reticular fibres are made up of protein *collagen (type III)*. They are fine delicate strands that branch and join to form a delicate network, which forms the framework of certain organs such as the spleen, lymph node, liver and

bone marrow.

N.B.

All the three types of connective tissue fibres (collagen, elastic, reticular) are synthesized by fibroblasts.

Clinical correlation

Keloid: The keloid formation is a deviation from normal wound healing whereby an excessive accumulation of collagen fibres occurs, resulting in a raised tumourous scar. Osteogenesis imperfecta is a genetic defect involving type I collagen resulting in spontaneous fractures of the bones.

Cells

The **cells of the connective tissue** are of two types: *fixed cells* and *free cells*.

1. **Fixed cells**: These are permanent residential cells of connective tissue. They are long-lived cells and form stable population of cells that remain in the connective tissue (Fig. 4.17). Thus they are connective tissue cells proper. They are responsible for the regeneration of: connective tissue components, viz. by fibroblasts, storage of energy, viz. by fat cells, providing immunity, viz. by macrophages, mast cells and plasma cells, providing colour, viz. by pigment cells and forming framework, viz. by reticular cells.
2. **Free cells**: These cells are actually blood cells viz, neutrophils, eosinophils, basophils, monocytes, lymphocytes and plasma cells which enter the connective tissue from blood usually during inflammation. They are described in detail in Chapter 10 on Cardiovascular System. The types of connective tissue cells are given in Table 4.3.

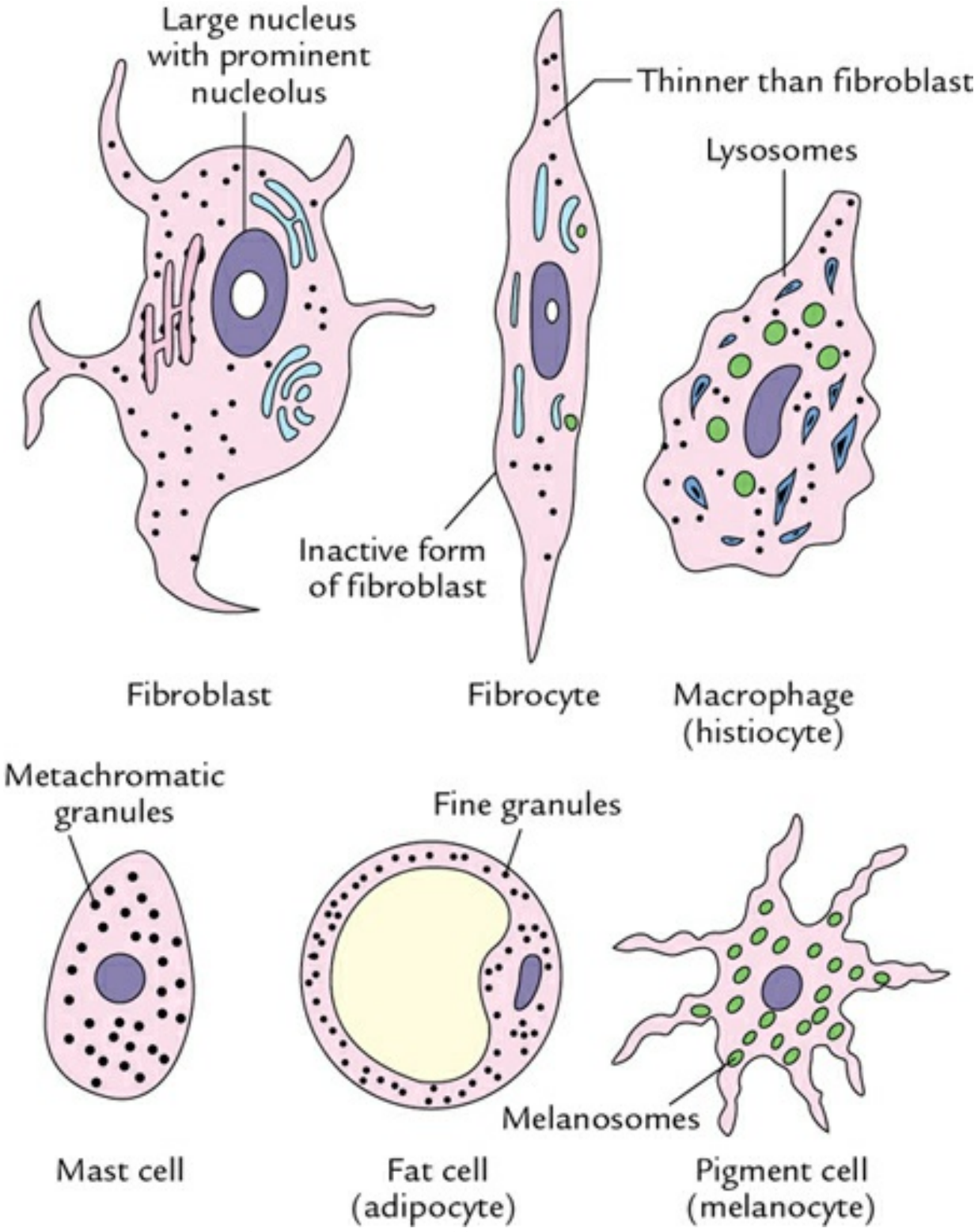


FIG. 4.17 ■ Types of fixed connective tissue cells.

TABLE 4.3

Types of connective tissue cells

Fixed permanent cells	Free cells
Fibroblasts (fibrocytes)	Neutrophils
Macrophages (histiocytes)	Eosinophils
Mast cells	Basophils
Adipocytes (fat cells)	Monocytes
Pigment cells (melanocytes)	B and T lymphocytes
Reticular cells	Plasma cells

The permanent cells are described in detail in the following text.

Permanent cells

1. ***Fibroblasts/fibrocytes***: They are the most abundant connective tissue cells and present in almost all types of connective tissues. They are large and irregular cells. They have an ovoid nucleus with a prominent nucleolus. Fibroblasts are involved in the synthesis and secretion of ground substance and all types of connective tissue fibres (e.g. collagen, elastin and reticular). The fibroblasts and fibrocytes are the same cells with a functional difference:
   (a) ***Fibroblast*** is the active form that produces matrix.
   (b) ***Fibrocyte*** is the inactive form of fibroblast which retains the capability to revert to 'blast' form. They are smaller and thinner than fibroblasts; hence, they are morphologically different.
   Fibroblasts play a key role in wound healing by synthesizing collagen fibres. The fibrocytes perform only the maintenance level of activity. In cases of need such as wound healing, the fibrocytes revert to the active fibroblastic form. Collagen formation is impaired in vitamin C deficiency.

N.B.

The fibroblasts act as stem cells for other cellular components of the connective tissue.

2. ***Macrophages (histiocytes)***: They are a type of white blood cells. They are irregularly shaped cells with short branching projections. They are derived from monocytes within the circulating blood. Once monocytes enter the tissue they mature and are called **macrophages**. The macrophages are present in almost all the tissues. Macrophages have a

phagocytic function.

3. ***Mast cells***: These are small oval cells with a centrally placed nucleus and contain many metachromatic granules in their cytoplasm. They are found along the small blood vessels. They arise from the stem cells in the bone marrow. Mast cells have a function in **immediate (type I) hypersensitivity reactions** (**anaphylactic reaction**). The surface of mast cells possesses receptors for immunoglobulins (antibodies) produced by plasma cells upon first exposure to an allergen (e.g. plant pollen, snake venom, foreign serum) which sensitizes the mast cells.

   Mast cells secrete the following substances upon second exposure to the same allergen causing a classical '**wheal and flare reaction in the skin**':

   - *Heparin,* an anticoagulant.
   - *Histamine* dilates small blood vessels to increase vascular permeability and causes smooth muscle contraction of bronchi.
   - *Leukotrienes,* which increase vascular permeability, cause vasodilation and smooth muscle contraction of bronchi.
   - *Eosinophilic chemotactic factor* attracts eosinophils to the inflammation site.

4. ***Adipocytes (fat cells/adipose cells)***: These are connective tissue cells that synthesize and store large quantities of lipid globules. They are spherical in shape. The lipids occupy almost the whole of the cell, pushing the cytoplasm as a thin rim around it. The nucleus is flattened and displaced to one side-towards the periphery. The fat cells are found singly in loose areolar tissue and in groups in adipose tissue. They take up and metabolize glucose to provide energy (via glycolysis).
5. ***Pigment cells (melanocytes)***: They synthesize a dark brown pigment called **melanin,** which protects the tissue from the harmful effects of ultraviolet rays. The pigment cells are found in the skin, iris and choroid of the eyeball, and some areas of the brain. They are star-shaped cells with many branching processes.

   The cytoplasm contains melanin granules in membrane-bound organelles called **melanosomes**.

6. ***Reticular cells***: The reticular cells are found in the reticular connective tissues. They have branched flattened cells with poorly staining nuclei and cytoplasm. They resemble fibroblasts and produce reticular fibres to which cells are attached.

Classification of connective tissue

Connective tissue can be classified into the following two broad categories:

1. Connective tissue proper
    (a) Loose (areolar) connective tissue
    (b) Dense regular connective tissue
    (c) Dense irregular connective tissue
    (d) Elastic connective tissue
    (e) Adipose connective tissue
    (f) Reticular connective tissue
2. Specialized connective tissue
    (a) Bone
    (b) Cartilage
    (c) Blood.

Loose connective tissue (Fig. 4.18)

It is the most widely distributed connective tissue of the body. It consists of a loosely woven network of all three types of fibres (collagen, elastic and reticular) and contains almost all kinds of connective tissue cells, predominantly fibroblasts. The fibres and cells are dispersed in semifluid ground substance. Much of the body fluid is found within loose connective tissue. Loose connective tissue is the packing and binding tissue that surrounds muscles, nerves and vessels, and binds the skin to the underlying deep fascia. It permits the skin to move when a part of the body is rubbed.

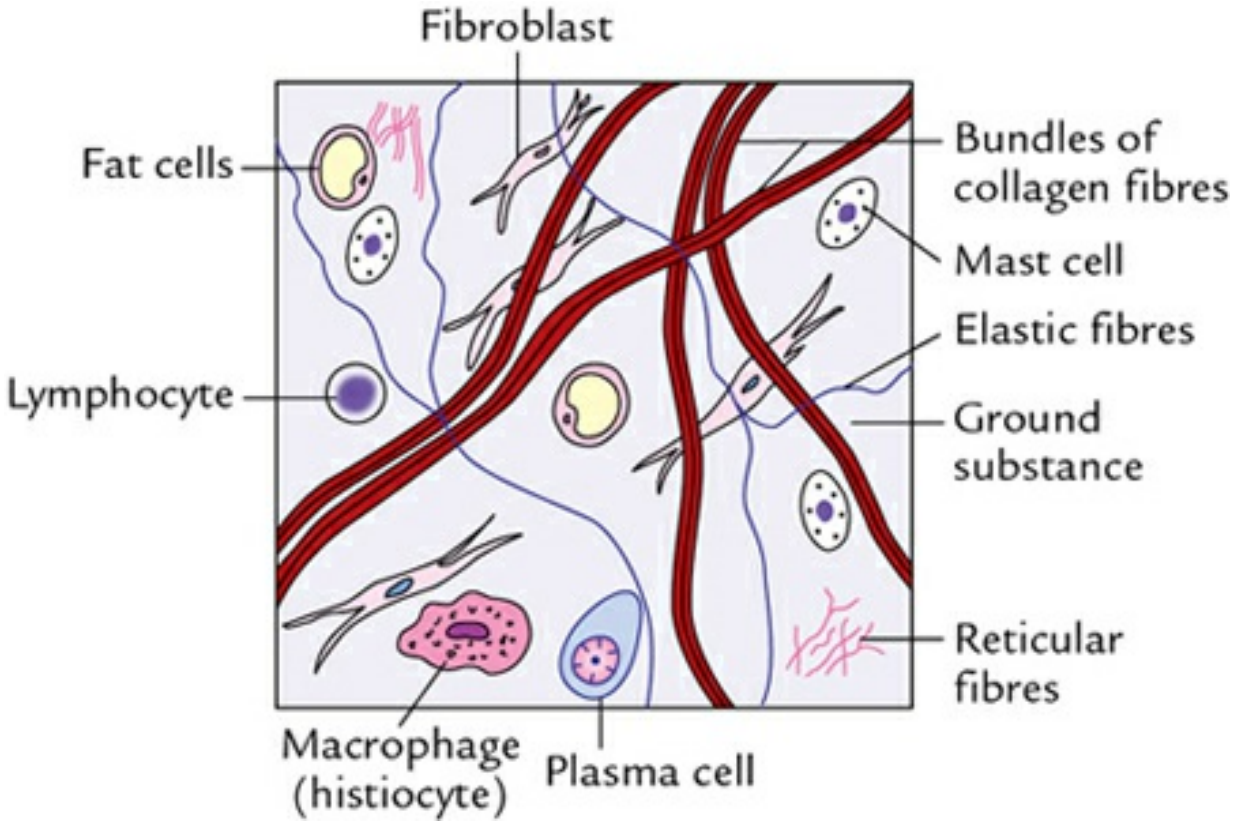


FIG. 4.18 ■ Loose areolar connective tissue.

Dense regular connective tissue (Fig. 4.19)

It consists predominantly of densely packed bundles of collagen fibres. The bundles of collagen fibres lie parallel to the direction of force placed on this tissue. The fibroblasts are present in rows between bundles of collagen fibres. Dense connective tissue is silvery-white in appearance and forms tendons, aponeuroses and ligaments.

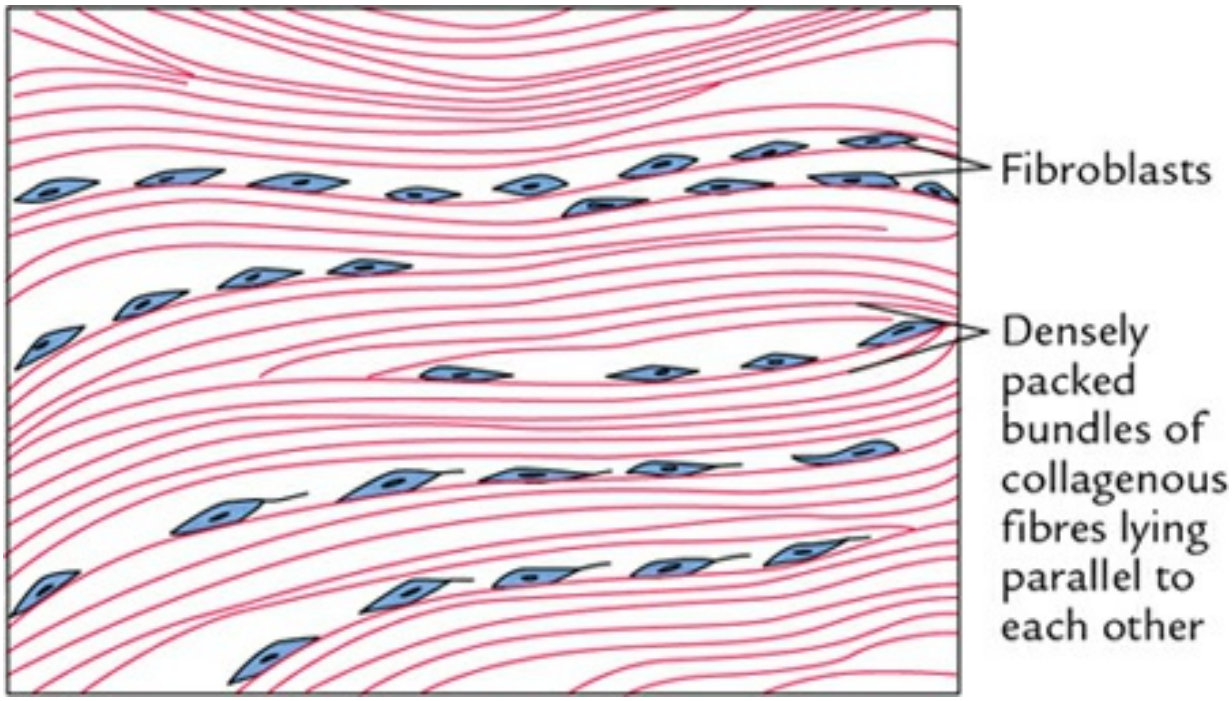


FIG. 4.19 ■ Dense regular connective tissue (white fibrous connective tissue, e.g. tendons, ligaments).

Dense irregular connective tissue (Fig. 4.20)

It consists of densely packed bundles of collagen fibres that are interwoven to provide a tensile strength in any direction. The dense irregular connective tissue forms the dermis of skin, periosteum, fibrous capsule of joints and collagenous matrix of bone called osteoid.

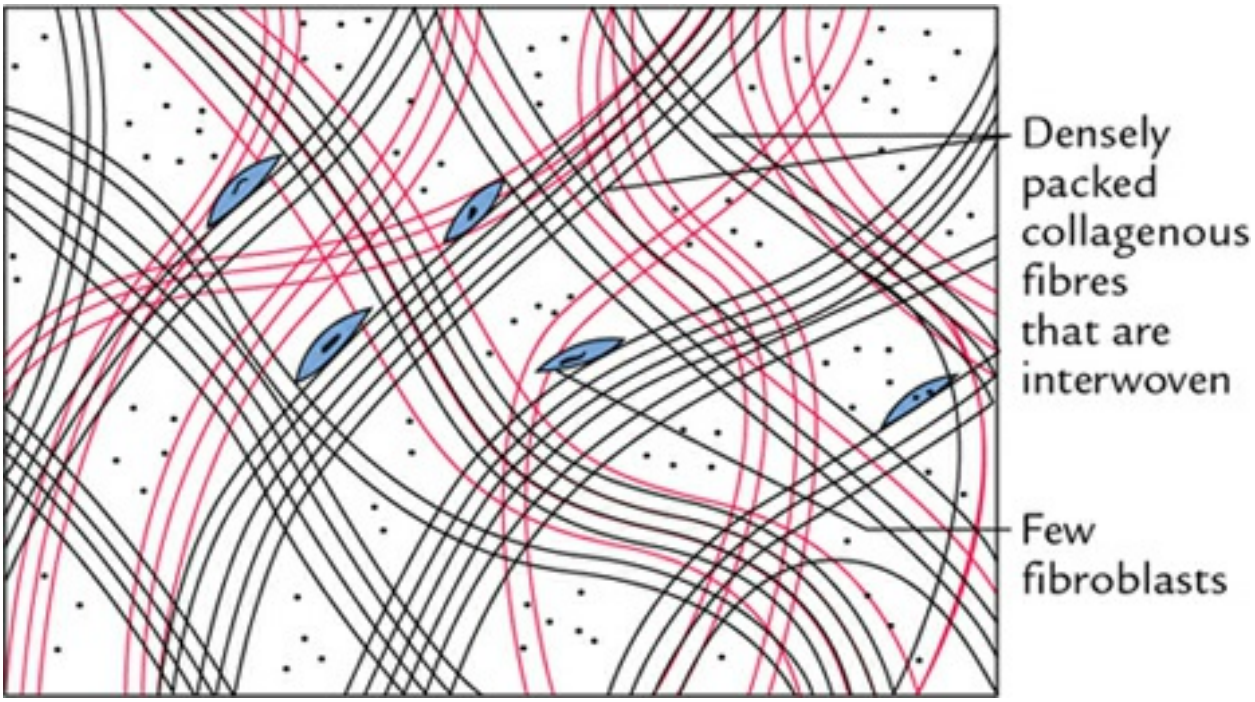


FIG. 4.20 ■ Dense irregular connective tissue (e.g. reticular layer of the dermis, fibrous capsules of joints and organs, periosteum and perichondrium).

Elastic connective tissue

It consists predominantly of elastic fibres that are yellowish and irregularly arranged. They can be stretched to 1.5 times their original length and will snap back to their original form. Elastic connective tissue is found in the walls of elastic arteries (e.g. aorta and large arteries), vocal cords of the larynx, ligamentum nuchae on the back of the neck, ligamenta flava between arches of vertebrae, etc.

Adipose connective tissue (Fig 4.21)

It consists of large aggregations of **adipose cells** or adipocytes. Adipose cells store droplets of fat within their cytoplasm, causing them to swell, thus forcing their nuclei to one side, and the cytoplasm is present as a thin rim around it. The fat functions not only as a food reserve but also protects and supports various organs. The adipose tissue is present in abundance in superficial fascia deep to the skin, around kidneys, blood vessels around the heart, in breasts of sexually mature females, etc.

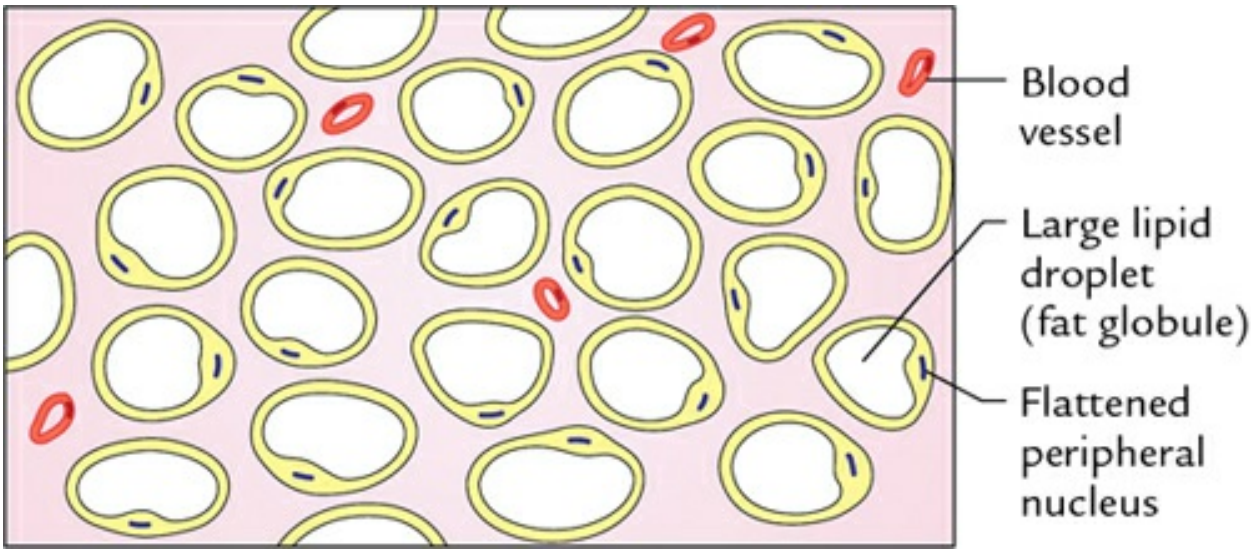


FIG. 4.21 ■ Fatty tissue/adipose connective tissue.

Reticular connective tissue:

It consists of a network of reticular fibres and reticular cells. Reticular tissue also contains macrophages (phagocytic cells). The reticular connective tissue forms stroma or a reticular framework of certain organs (e.g. spleen, lymph node, liver, bone marrow) and reticular lamina of the basement membrane.

N.B.

Mucoid tissue: It consists of a copious matrix having fine meshwork of collagen fibres with fibroblasts, for example, Wharton's jelly of the umbilical cord and vitreous humour of the eyeball.

The specialized types of connective tissues such as scleral (cartilage and bone), lymphoid and haemopoietic tissues are described in separate chapters.

Functions of connective tissue

The major functions of connective tissues are:

1. Binding and supporting other tissues
2. Protection from injury and infection
3. Storing reserve fuel and cushioning
4. Transporting substances within the body
5. Repair of injuries/wound healing

6. Retaining tendons and other structures in place
7. Providing pathways to blood vessels and nerves
8. Maintains the characteristic contours of limbs.

The details are as under:

1. **Binding and supporting:** Loose areolar tissue serves as packing material between other tissues, thus help in binding and supporting other tissues.
2. **Protection:** The loose areolar tissue protects from infection as it contains phagocytic cells and immune cells, viz. lymphocytes, plasma cells, etc.
3. **Storing reserve fuel:** Adipocytes of adipose tissue store energy in the form of lipids.
4. **Transporting substances from the body** through the interstitial fluid present in loose areolar tissue.
5. **Repair of injury and wound healing** by fibroblast which lay down collagen fibres to form scar tissue.
6. **Provides convenient pathways for neurovascular structures** by forming fascial planes.
7. **Retaining tendons** in place by forming retinacula, and pulleys and keeping eyeball in place by forming cheek ligaments.
8. **Maintains the characteristic contours of limbs** by forming a light sheath around them like a sleeve of stocking.

Structures derived from various connective tissues

1. **Superficial fascia/subcutaneous tissue**: It is derived from loose areolar tissue and contains a lot of adipose tissue (Fig 5.1; for details see Chapter 5)
2. **Dermis of skin** is derived from dense irregular connective tissue (Fig. 5.2)
3. **Deep fascia** is derived from dense regular connective tissue (fibrous connective tissue). The important modifications of deep fascia include *intermuscular septa* (Fig. 5.10), retinacula, **fascial sheath around muscles and neurovascular structures**, interosseous membranes, aponeuroses etc.
4. **Ligaments of joints** (Fig. 7.19) are derived from dense regular

connective tissue (fibrous connective tissue). If the ligaments contain more elastic fibres they are called **elastic ligaments,** viz. ligamentum nuchae on the back of the neck and ligamenta flava between adjacent vertebrae.

5. **Fibrous capsules of joints** (Fig 7.8) are derived from dense irregular connective tissue.
6. **Raphe** are linear fibrous bands usually formed by interdigitation of aponeurotic ends of opposite muscles. For example, *median pharyngeal raphe*, *mylohyoid raphe*, *anococcygeal raphe*, etc.
7. **Tendons (Fig 9.10)** are derived from dense regular connective tissue, i.e. parallel bundles of collagen fibres. For details see page 122, Chapter 9.

Clinical correlation

Common diseases of connective tissue

- **Rhematoid arthritis** is characterised by pain and stiffness of small joints of the hand and fingers due to fibrinoid necrosis of joint capsules.
- **Scleroderma** is chronic hardening and contraction of the skin due to the deposition of excessive connective tissue within it. It is an autoimmune disease.
- **Sprains** are stretching and twisting of ligaments of various joints, viz. ankle, wrist etc. Clinically they present as pain, swelling and loss of movements.
- **Marfan's syndrome** is an inherited autosomal dominent connective tissue disorder. Clinically it presents as the high arched palate, ectopic eye lenses, etc. For details see Chapter 17 on Medical Genetics.
- **Dupuytren's contracture** occurs due to the contracture of fibrous tissue of palmar aponeurosis on its medial side causing flexion deformities of the ring and little fingers. For details, see vol I TB of Anatomy: *Upper Limb and Thorax.*
- **Ganglion,** a nodular swelling that often develops on the back of the wrist around a part of the tendon due to leakage of fluid from the joint or tendon tunnel in the connective tissue sheath around it. For details see TB of Anatomy: Upper Limb and Thorax Vol 1.

Tissue regeneration

The tissue regeneration occurs by replication of original cells (by mitosis). The rate of regeneration depends on the normal rate of physiological turnover of particular types of cells. Those with rapid turnover regenerate very fast. According to the rate of physiological turnover, the cells are divided into the following three types:

1. **Labile cells**: These are cells in which replication is a continuous process. They include cells of:
   (a) Epithelium of skin, mucous membrane, secretory glands, ducts, the lining of the uterus
   (b) Bone marrow
   (c) Blood
   (d) Spleen and lymphoid tissue
2. **Stable cells**: These are cells that are capable of replication but do so infrequently. They include:
   (a) Liver, kidney and pancreatic cells
   (b) Fibroblasts
   (c) Smooth muscle cells
   (d) Osteoblasts and osteoclasts of bone
3. **Permanent cells**: These cells are incapable of replicating after the normal growth is complete. They include:
   (a) Nerve cells (neurons)
   (b) Skeletal and cardiac muscles.

Cell differentiation

The cells are differentiated into different types with particular structural and functional characteristics in an early stage of development, viz. epithelial cells develop different characteristics from lymphocytes.

In postnatal life when cells replicate to produce daughter cells, if daughter cells have the same appearance, functions and genetic make-up as the parent cells they are easily recognized and are called **well-differentiated cells**. On the other hand, if daughter cells cannot be recognized due to changes in their appearance, function and genetic make-up, they are called **poorly differentiated cells**.

Clinical correlation

Tumour or neoplasm: It is a mass of tissue when the cells replicate faster than normal in an uncoordinated manner and continue to do so even after the initial stimulus is ceased. Remember that normal cells divide in an orderly manner.

The tumours are of two types: benign and malignant. The *benign tumours* grow slowly and are not likely to spread and become worse. On the other hand, *malignant tumours* grow fast. They are likely to spread and cause harm.

The differentiating features of benign and malignant tumours are presented in Table 4.4.

TABLE 4.4

Differences between benign and malignant tumours

Characteristics	Benign tumour	Malignant tumour
Growth	Slow	Rapid
Cell differentiation	Well-differentiated	Poorly differentiated
Encapsulation	Usually encapsulated	Nonencapsulated
Spread	Does not spread	Spreads: • by local infiltration • via lymph • via blood
Recurrence	Rare	Common

Apoptosis

Apoptosis is programmed cell death (i.e. regulated cell suicide). It is a central mechanism controlling multicellular development. It mediates activities such as the separation of developing digits and has an important role in regulating the number of neurons (several neurons die during development). Apoptosis also ensures that the inappropriate or inefficient cells of the immune system are eliminated.

It is characterized by **chromatin clumping** into a distinct crescent pattern

along the inner aspect of the nuclear envelope and then into a dense body. The chromatin is eventually cleaved by a specific **endonuclease** into DNA fragments, the pathognomonic of apoptotic cell death. The **Bcl-2 (B-cell lymphoma 2) gene** encodes an intracellular inhibitor of apoptosis. The signals that trigger apoptosis include withdrawal of survival factors or exposure to inappropriate proliferative stimuli.

N. B.

Dense regular connective tissue is made up of parallel bundles of collagen fibres and often called **fibrous connective tissue**.

Golden Facts to Remember

• **Largest cell in the body**	Ovum (130 μm)
• **Least differentiated cell in the body**	Zygote
• **Most differentiated cells in the body**	Neurons, myocytes of cardiac muscle
• **Largest membrane-bound structure within the cell**	Nucleus
• **All the cells in the body possess a nucleus except**	Mature erythrocytes
• **Longest cell in the body**	Neuron (sensory neurons of S1 spinal nerve)
• **The longest period of the cell cycle**	G1 phase (12 h)
• **Most common type of cell division**	Mitosis
• **Powerhouse of cell**	Mitochondria
• **Unicellular glands**	Goblet cells
• **Most widely distributed connective tissue in the body**	Loose connective tissue
• **Most abundant connective tissue cells**	Fibroblasts
• **Most abundant protein in the body**	Collagen

• **Most numerous connective tissue cells**	Fibroblasts
• **Most common connective tissue fibres**	Collagen fibres
• **Three most common fixed cells of connective tissue**	Fibroblast, macrophage and mast cell

Multiple choice questions

1. **All of the following structures are derived from ectoderm *except*:**
   (a) Lens of eye
   (b) Enamel of tooth
   (c) Dermis of the skin
   (d) Adrenal medulla
2. **All of the following structures are derived from mesoderm *except*:**
   (a) Muscles
   (b) Bones
   (c) Thyroid
   (d) Dentine of teeth
3. **Lumen of all of the following structures is lined by transitional epithelium *except*:**
   (a) Urinary bladder
   (b) Ureter
   (c) Urethra
   (d) Oesophagus
4. **Connective tissue, muscle and dermis of skin are derived from:**
   (a) Ectoderm
   (b) Mesoderm
   (c) Endoderm
   (d) None of the above
5. **Exocrine glands are considered merocrine in nature, if:**
   (a) The secretion is discharged along with pinched off apical portion of the cell
   (b) The secretion is released by exocytosis through a cell membrane
   (c) The entire cell is discharged along with the secretory product
   (d) The secretion is not discharged
6. **Most abundant protein in the body is:**

(a) Collagen
(b) Elastin
(c) Reticulin
(d) Globulin

7. **All of the following are fixed cells of connective tissue *except*:**
(a) Fibrocytes
(b) Mast cells
(c) Adipocytes
(d) Monocytes

8. **All of the following are free cells of connective tissue *except*:**
(a) Neutrophils
(b) Eosinophils
(c) Basophils
(d) Macrophages

9. **Which of the following cell is called histiocyte?**
(a) Fibroblast
(b) Monocyte
(c) Macrophage
(d) Plasma cell

Answers

1. *c*, **2.** *c*, **3.** *d*, **4.** *b*, **5.** *b*, **6.** *a*, **7.** *d*, **8.** *d*, **9.** *c*

Chapter 5: Skin, superficial fascia and deep fascia

Specific learning objectives

After studying this chapter, the student should be able to

- Describe the structure and functions of the skin and its appendages. **AN 4.2**
- Describe the different types of skin and dermatomes. **AN 4.1**
- Compare and contrast thin and thick skin.
- Enumerate the types of surface irregularities of the skin and write a note on the 'fingerprints'.
- Describe the appendages of the skin. Discuss their structure and function. **AN 4.2**
- Present the anatomical basis of: clubbing, acne and sebaceous cyst.
- Explain the principles of skin incision. **AN 4.5**
- Estimate the surface area of skin applying the 'rule of nine' and discuss its importance in the treatment of burns.
- Discuss the structure and functions of superficial fascia with fat distribution in the body. **AN 4.3**
- Describe the modifications of deep fascia with its functions. **AN 4.4**
- Correctly solve the Multiple Choice questions given at the end of the chapter.

Skin AN4.1

The skin is the outer covering of the body. It provides the dynamic interphase between the body and the external environment.

The skin is considered an **organ** because it consists of several kinds of tissues that are structurally arranged to function together.

It is the *largest organ of the body*, covering over 7600 sq. cm (3000 sq. in) area in an average adult and accounts for approximately 7% of the person's total body weight.

The general appearance and condition of the skin are clinically important because it provides clues to certain body functions and dysfunctions. Thus, skin reflects our general health. Healthy skin indicates a healthy body.

Structure of skin

The skin consists of two principal layers: the epidermis and the dermis (Fig. 5.1).

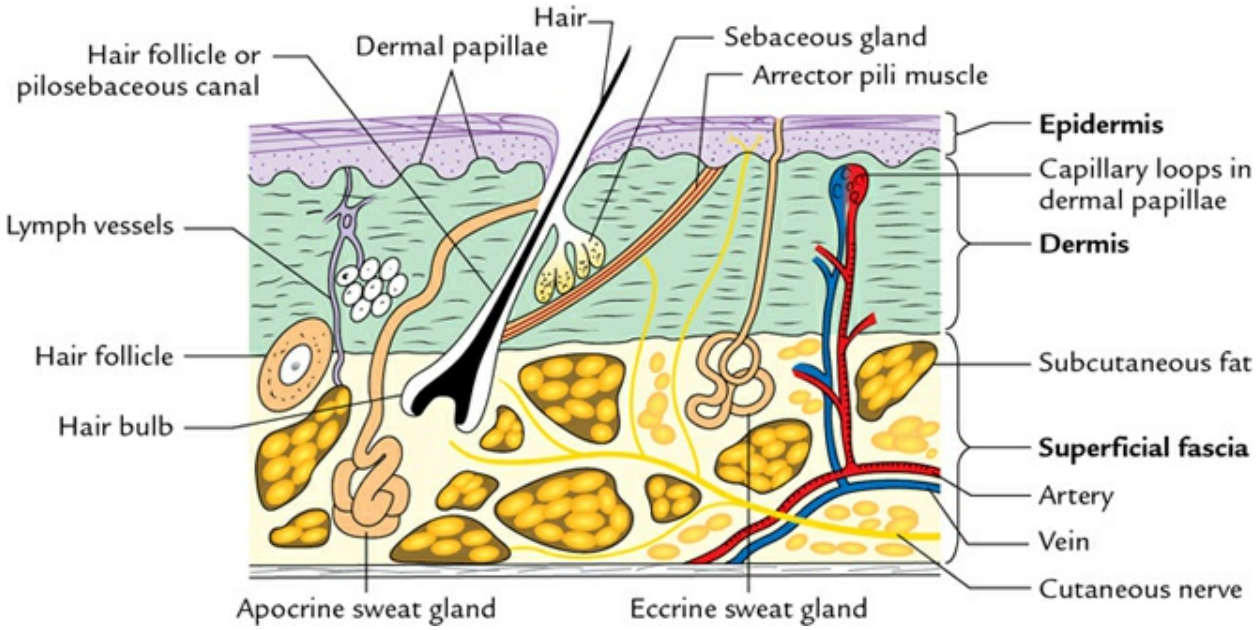


FIG. 5.1 ■ Structure of the skin.

The surface epithelium of skin is the **epidermis**. It is made of the keratinized stratified squamous variety. The various appendages of skin, viz. sweat glands, sebaceous glands, hair and nails are specialized derivatives of

this epidermis. The deeper **dermis** consists mainly of bundles of collagen fibres together with some elastic tissue, blood vessels, lymphatics and nerve fibres.

Epidermis

The epidermis is a superficial avascular layer of stratified squamous keratinized epithelium derived from the surface ectoderm of the body. It varies in thickness from 0.007 to 0.12 mm.

It consists of four main types of cells:

(a) Keratinocytes (90%)
(b) Melanocytes (8%)
(c) Langerhans cells
(d) Merkel cells.

The *keratinocytes* are arranged in four or five layers. They produce keratin, a protein that protects the skin from heat, microbes and chemicals.

The *melanocytes* produce melanin pigment that imparts colour to the skin and absorbs ultraviolet light to protect the skin from cancer to a certain extent.

The *Langerhans cells* arise from bone marrow and migrate to the epidermis. They participate in immune response and protect the skin against viral and other infections.

The *Merkel cells* are located in the deeper part of the epidermis and come in contact with sensory neurons. They act as receptors for touch sensations.

Layers of epidermis

Depending on the skin type—thin or thick, the skin is made up of four or five layers (Fig. 5.2).

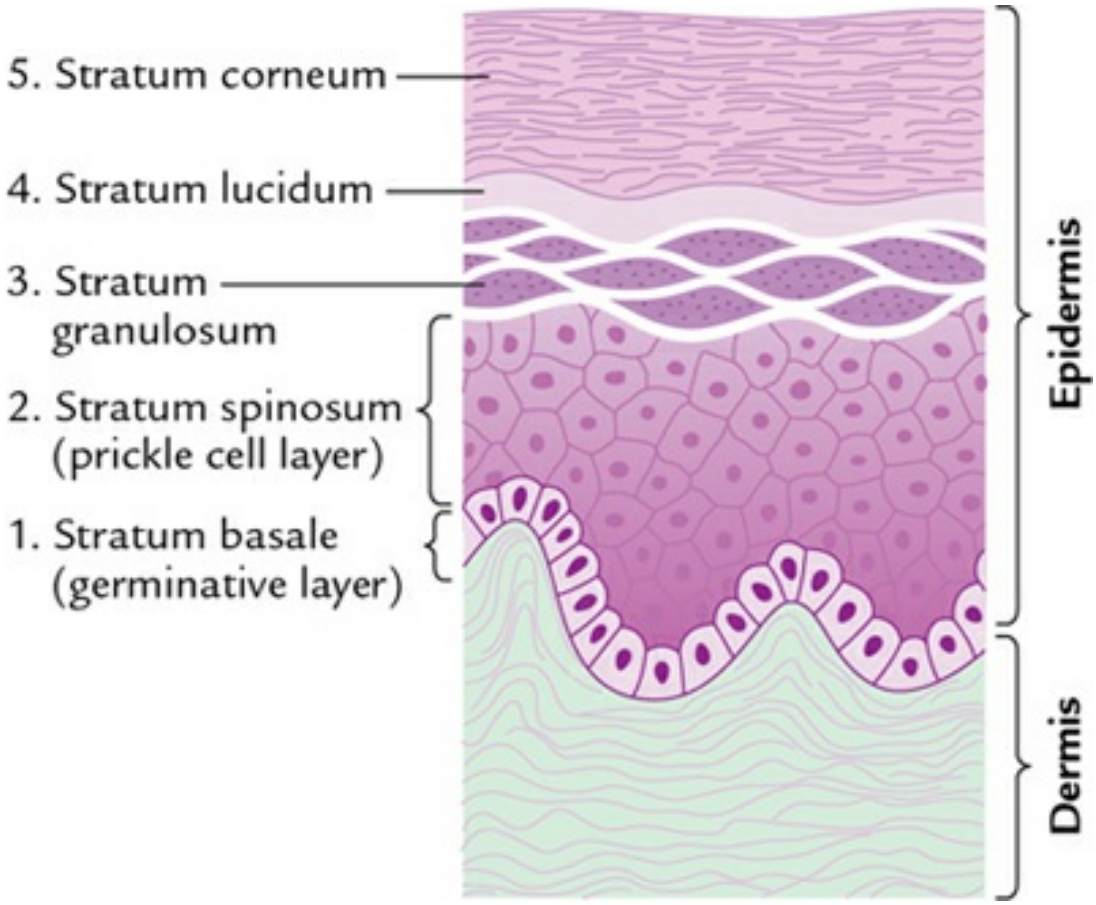


FIG. 5.2 ■ Structural features of the epidermis of thick skin.

From deep to superficial 5 layers of thick skin are:

Stratum **B**asale, Stratum **S**pinosum, Stratum **G**ranulosum, Stratum **L**ucidum, and Stratum **C**orneum
Mnemonic: **B**ritish and **S**panish **G**uardians **L**ove **C**ornflakes.

The details are discussed in the following text.

1. **Stratum basale/stratum germinatum (syn. basal layer, malpighian layer).** It is the deepest layer and consists of a single layer of cuboidal or columnar cells. A thin basement membrane is situated between the stratum basale and dermis. The cells of this layer constantly divide by mitotic activity. The newly formed cells move towards the superficial layer to renew the epidermis. It usually takes about 6–8 weeks for the cells to move from the stratum basale to the surface of the skin. This layer also contains *melanocytes* which synthesize and produce melanin pigments that protect the skin from the harmful effects of ultraviolet rays of sunlight.

2. **Stratum spinosum (spiny layer).** It consists of several layers of polygonal cells, each with a centrally located large oval nucleus. The cells are held together by desmosomes. Fixation during histological preparation causes shrinkage of the cell membrane, giving the cell a spiny appearance, i.e. cells present spine-like processes, hence, the name stratum spinosum or **prickle cell layer**.
3. **Stratum granulosum (granular layer).** It consists of three or four rows of flattened cells with pyknotic nuclei showing signs of degeneration. The cytoplasm contains **keratohyalin granules** which are made up of a histidine-rich protein called filaggrin.
4. **Stratum lucidum (clear layer).** It is a thin clear homogenous glassy layer. The nucleus, organelles and membrane of cells are not visible under a light microscope. It is a highly refractile layer of the epidermis. It is found only in thick glabrous skin such as the soles of feet and palms of hands.
5. **Stratum corneum.** It is the most superficial layer of the skin. It consists of many (25–30) layers of fully keratinized flattened scale-like dead cells. These cells are filled with a protein called **keratin**. This layer is cornified and is the real protective layer of the skin. When desmosomes between the cells of the outermost layers become weak, the surface cells desquamate, i.e. shed off.

Clinical correlation

Skin cancer: Skin cancers are relatively common in fair-skinned persons who are exposed too much to sunlight. The skin is protected from ultraviolet rays of the sun by melanin pigment. It is common in fair persons because they have less amount of melanin pigment. Types of skin cancers are:

(a) *Basal cell carcinoma*, is the most common type and is mostly located in the upper part of the face. It arises from the cells of the stratum basale.

(b) *Squamous cell carcinoma*, arises from cells of stratum spinosum and occurs in sun-exposed parts of the body, generally in the region of the face.

(c) *Malignant melanoma/melanocarcinoma*, arises from melanocytes and is rapidly spreading malignant tumour of the skin.

N.B.

The thickness of the stratum corneum is maximum where the surface of the skin is exposed to maximum friction, e.g. on palms and soles.

Dermis

The dermis is the deep vascular layer of the skin derived from mesoderm. It is thicker than the epidermis and consists of collagen (type I) and elastic fibres. In addition, it contains glands, nerves, lymphatics and blood vessels. The smooth muscles of the dermis are associated with hair follicles as **arrectores pili muscles**.

Layers of dermis

The dermis is usually divided into two layers:

1. a superficial papillary layer and
2. a deep reticular layer.

Papillary layer

This layer is in contact with the epidermis and accounts for about one-fifth of the entire thickness of the dermis. It forms numerous conical blunt projections called **dermal papillae** extending into the epidermis.

The **dermal papillae** interlock with the reciprocal extensions from the undersurface of the epidermis which project into the dermis. These downgrowths of epidermis are called **rete ridges** or interpapillary pegs.

This interlocking between the epidermis and dermis at the *epidermo-dermal junction* prevents the separation of two layers.

The dermal papillae contain vascular loops and specialized nerve endings.

Reticular layer

It is mainly composed of numerous collagen fibres arranged mostly in parallel bundles. The direction of these bundles produces **cleavage lines** or **Langer's lines**. The cleavage lines are horizontal in the trunk and neck, and are longitudinal in the limbs.

This layer is quite distensible, as is evident in pregnant women and obese

individuals, but if stretched too much, the white fibres rupture and their repair causes scar formation. These scars are seen as white streaks called **stretch marks** or **linea albicans**. The linea albicans are frequently found in the lower part of the abdomen, buttock, thigh, and breasts of multiparous females.

Clinical correlation

Making of leather: The strong resilient reticular layer of the dermis in domestic animals is used in making leather. In the tanning process (i.e. treatment with chemicals), the epidermis with its hair and the papillary layer of the dermis is separated from the reticular layer. The reticular layer is then softened and treated with protective chemicals to make it usable in various forms such as leather jackets, purses, etc.

Colour of skin

The colour of the skin is impacted by a combination of the following three pigments:

1. Melanin
2. Carotene
3. Haemoglobin.

Melanin is a black-brown pigment produced by melanocytes, which are derived from neural crest cells and migrate to the epidermis.

The amount of melanin leads to variation in the colour of skin from pale to tan to black. Melanocytes are plenty in the epidermis of the penis, nipple and areolae of the breast.

Carotene is a yellow-orange pigment. It is an exogenous pigment taken up from the food. It is present in the stratum corneum and the fat cells of the dermis and superficial fascia.

The **purple haemoglobin** and **red oxyhaemoglobin** present in cutaneous blood vessels are responsible for the pink colour of the skin.

N.B.

All races have the same number of melanocytes, but the amount of

melanin produced and distribution of melanocytes and melatonin determines whether the colour of the individual will be black, brown or white.

Clinical correlation

- **Albinism:** It is a clinical condition in which the skin, hair and eyelashes of an individual are white. It occurs due to the failure of the development of melanin pigment. It is important to remember that the skin of the genetically determined albinos has a normal number of melanocytes in the dermis but lacks the enzyme tyrosinase that converts amino acid tyrosine to melanin.
- **Vitiligo:** It presents as white spots in the skin and occurs due to partial or complete loss of melanocytes at that site.

Types of skin AN4.1

The skin varies in thickness. It is thickest in palms and soles, which are exposed to wear and tear. In these areas, it is 6 mm thick. Skin is thinnest on the eyelids, external genitalia and tympanum (eardrum), where it is approximately 0.5 mm thick. The average thickness of the skin is 1.0–2.0 mm.

On the basis of thickness, the skin is classified into the following two types (Fig. 5.3):

1. Thin hairy skin
2. Thick hairless skin.

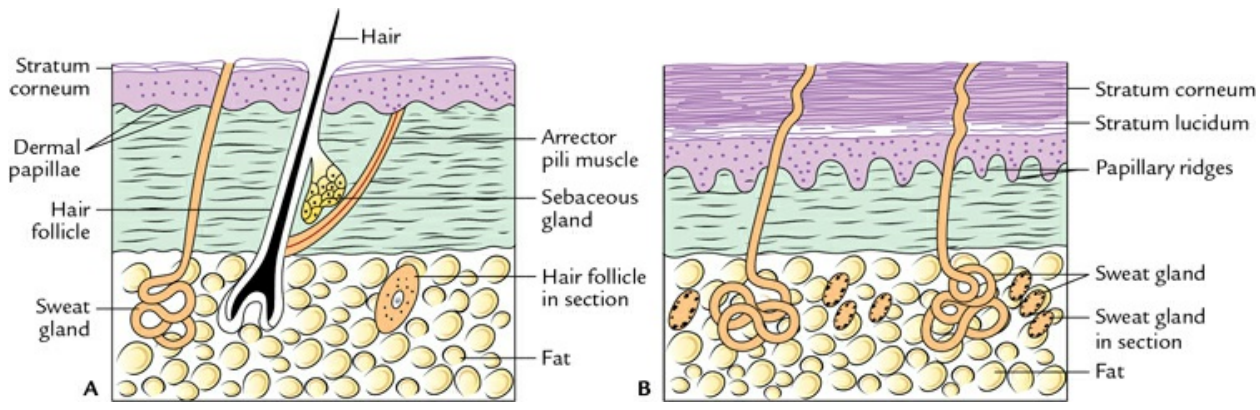


FIG. 5.3 ■ Features of skin: **A**, thin skin; **B**, thick skin.

Thin skin is present all over the body except on the palms and soles. In thin skin, the epidermis is thin.

Thick skin is present only in the palms and soles. In thick skin, the stratum corneum is very thick, an adaptation to resist trauma in the skin of the palms and soles. There is an additional layer of stratum lucidum underneath the stratum corneum. It is a homogenous layer where the cells are not clearly seen. The hair follicles and sebaceous glands are totally absent in thick skin. At the same time, sweat glands are seen in abundance.

The differences between the thin and thick skin are provided in Table 5.1 (see also Fig. 5.3).

TABLE 5.1

Differences between the thin and thick skin

	Thin skin	Thick skin
Epidermis	Thin (0.10–0.15 mm)	Thick (0.6–4.5 mm)
	Stratum corneum thin	Stratum corneum thick
	Stratum lucidum absent	Stratum lucidum present
Friction ridges	Absent	Present
Hair follicles	Present (hairy)	Absent (non-hairy)
Sebaceous glands	Present	Absent
Sweat glands	Few	More
Sensory nerve endings	Few	More
Distribution	Present all over the body except for palms and soles	Present in palms, soles and palmar surfaces of fingers

N.B.

Thick skin is composed of five layers, whereas thin skin is composed of

four layers (stratum lucidum is absent).

Surface irregularities of skin

The surface of the skin presents three types of irregularities:

1. Tension lines
2. Flexor lines
3. Epidermal ridges (friction ridges).

1. **Tension lines (synonym: cleavage lines, Langer's lines)**, as mentioned earlier, are caused by the patterns of arrangement and pull of collagen fibres within the dermis. These are in the form of linear furrows invisible to the naked eye. They are horizontal in the trunk and neck and longitudinal in the limbs (Fig. 5.4).

Clinical correlation

Langer's lines and principles of skin incisions AN4.5 : These are tension lines which are of special interest to surgeons. The incisions made parallel to these lines heal more rapidly and produce a hairline scar after healing as the minimum number of fibres are cut and pull is along the longitudinal axis of the incision, whereas incisions made across these lines heal poorly and produce wide ugly scars because most of the fibres are cut and the pull is at right angles to the long axis of the incision.

2. **Flexor lines and flexor creases** are acquired permanent lines and creases in the skin. The flexor creases are well marked in the palms and soles and are produced by habitual movements. The skin along these lines is thin and firmly bound to the deep fascia. The lines are prominent on the flexure aspects of the joints.
   Wrinkle lines are caused by the contraction of underlying muscles and are usually perpendicular to the lines of the muscle pull.
   The furrows or lines on the forehead and face are produced due to continuous contraction of the muscles of facial expression. Hence on the face, they are known as **lines of expression**.
3. **Epidermal ridges *(friction ridges)*** (Fig. 5.5 A): The epidermal ridges are formed when the epidermis adapts to the contour of dermal papillae. The sweat pores open on the epidermal ridges; thus, the surface of the

epidermis is characterized by elevations and depressions. These are most prominent on the finger and toe pads of the palms and soles. They form narrow ridges separated by parallel grooves arranged in curved arrays. They correspond to the dermal ridges. A fingerprint is an impression produced by friction ridges.

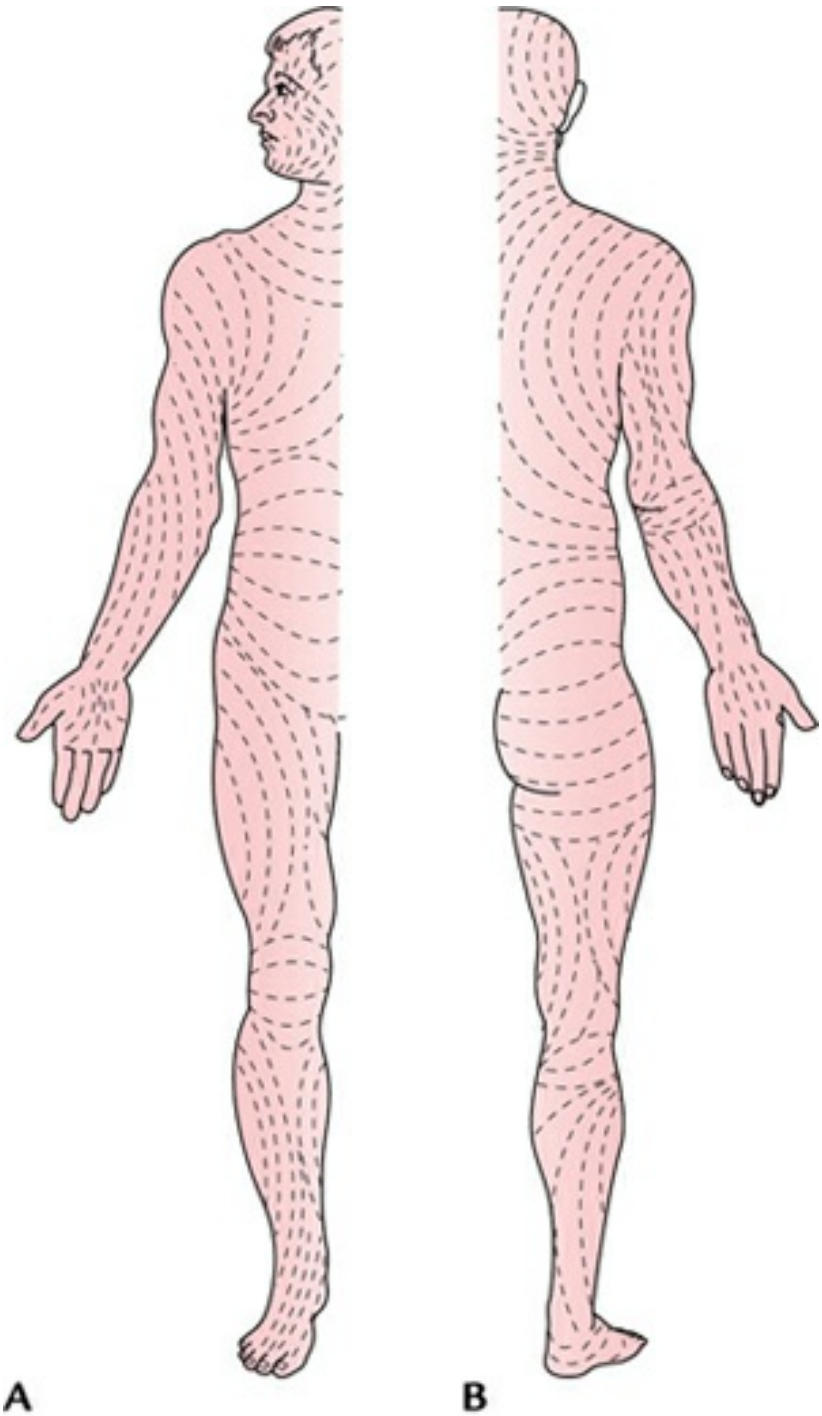


FIG. 5.4 ■ Tension lines of the skin: **(A)** on the front of the body and **(B)** on the back of the body.

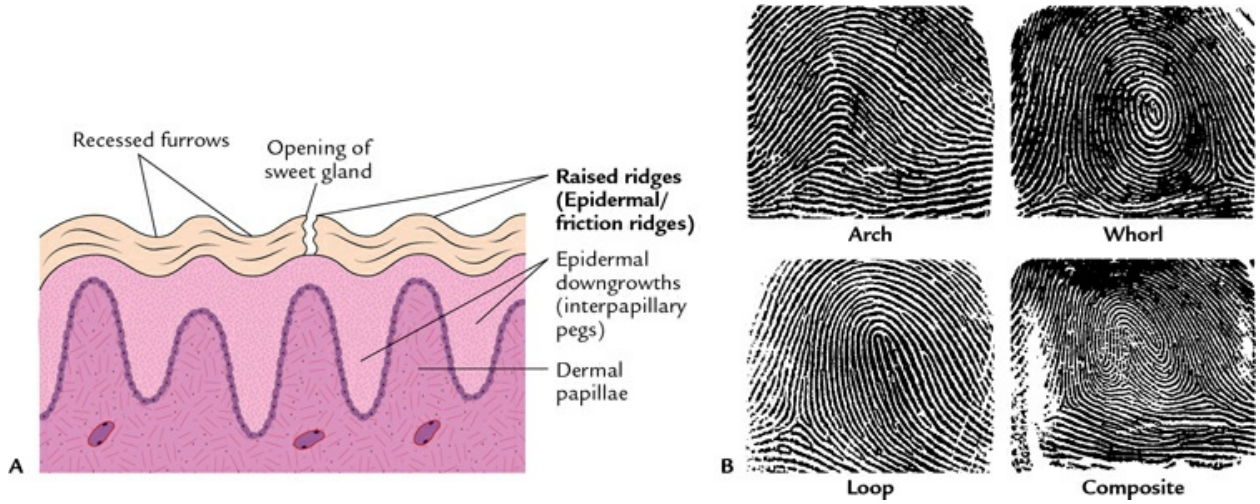


FIG. 5.5 ■ **(A)** Schematic diagram to show epidermal/friction ridges and **(B)** four types of fingerprints. (Source : Fig. 7.3, Page 77, Textbook of Clinical Embryology , Vishram Singh. Copyright Elsevier 2017, all rights reserved.)

The designs formed by these lines have basic similarities, but they are not identical in any two individuals. Because they are precise and easy to reproduce, **fingerprints** are customarily used for identifying individuals. The study of these ridges is termed **dermatoglyphics**. There are four basic dermatoglyphic patterns in the digits: (a) **arches**, (b) **whorls**, (c) **loops** and (d) **composite**. There may be a combination of the above three patterns (Fig. 5.5B). These patterns are determined genetically.

Clinical correlation

Fingerprints: The science, known as dermatoglyphics, deals with the classification and identification of fingerprints. Every individual's print is unique, including those of identical twins. So, fingerprints are used for the medicolegal purpose to identify criminals. Further, in certain diseases, particularly mental disorders, there is a deviation from normal patterns.

Appendages of skin (accessory structures of skin) AN4.2

The appendages of the skin are epidermal (i.e. ectodermal) derivatives. These include nails, hair, sweat glands and sebaceous glands.

Nails (Fig. 5.6)

These are hardened plates of keratinized epithelial cells of stratum corneum (i.e. nails consist of hard keratin) found on the dorsal surface of the tips of fingers and toes and are accordingly termed as finger and toenails.

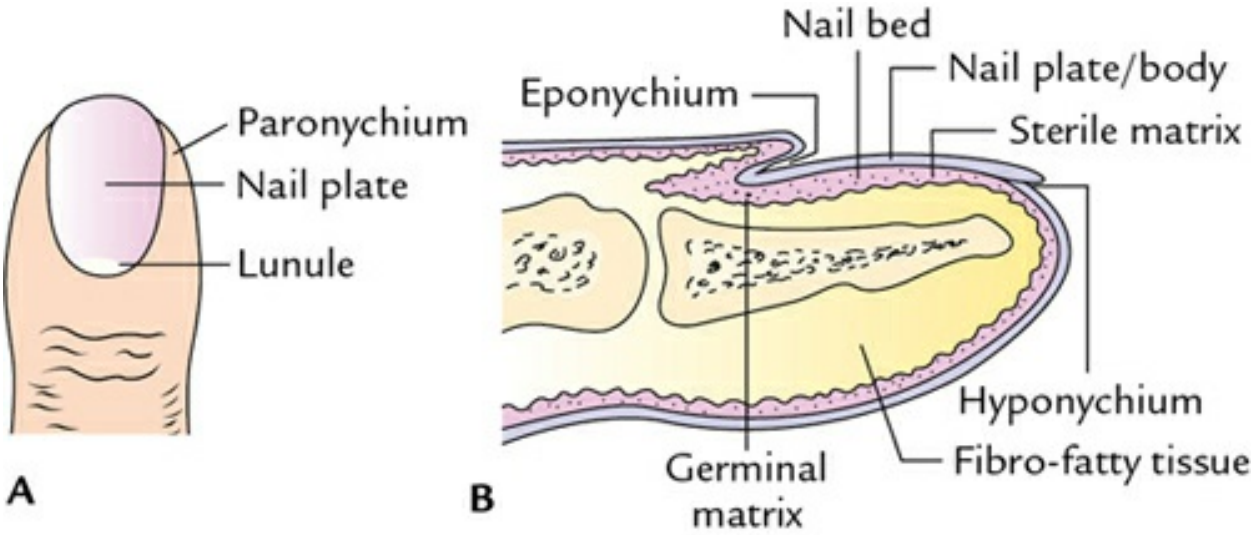


FIG. 5.6 ■ Structure of a nail. **A**. surface view; **B,** longitudinal section.

Both finger and toenails serve to protect the digits. The fingernails also help in grasping and picking small objects and are also used for scratching.

The nails are found only in primates, whereas most other mammals have claws or hooves.

Parts of the nail

Each nail consists of the following parts:

1. Root
2. Body
3. Free border
4. Hidden (attached) border.

Nail Plate

The nail plate rests on the nail bed, which is actually made of stratum basale and stratum spinosum of the epidermis. The large exposed part of the nail plate is called the **nail body** while the smaller proximal hidden part of the nail plate is called the **nail root**.

The proximal part of the body presents a white opaque crescent called a **lunule**.* The tissue (corneum) under the transparent body (except the lunule) is very vascular. This accounts for the pink colour of the nail. In anaemia, the nails look pale white.

The sides of the body of the nail are overlapped by a fold of skin called **nail folds** and the furrow between the two is called the **nail groove**.

The **free border** is the distal exposed border of the nail plate which is attached to the undersurface by **hyponychium**.** The proximal **attached border** of the nail plate is overlapped by a fold of the skin, the **eponychium**. The eponychium frequently splits, causing a hangnail.

The nail bed beneath the root and lunule is thick and is called the **germinal matrix**. The rest of the nail bed is thin and is called a **sterile matrix**. The nail matrix is the source of the nail plate.

N.B.

The *nail apparatus* consists of a nail plate, nail folds, nail matrix, nail bed, and hyponychium.

Clinical correlation

The condition of a person's nails can be indicative of his or her personal hygiene and personality. The dirty or ragged nails indicate poor personal hygiene and chewed nails may suggest emotional problems.

Growth of nails

Like hair, nails grow from the base. The nail grows by the proliferation of the germinal matrix and transformation of the superficial cells of the matrix into the nail cells. The hard transparent nail cells are then pushed forward over the thin sterile matrix. The nails grow continuously throughout life and do not have a resting phase.

The fingernails grow at an average rate of about 1 mm/week. The growth rate of toenails is somewhat slower. It takes about 3–4 months for the whole nail to grow. For this reason in fungal diseases of the nails, the course of treatment should last for not less than this period.

N.B.

The growth of the nail is fastest (0.1 mm/day) in the middle finger (longest finger) of the hand.

Clinical correlation

Examination of the nail: It is clinically important as it often provides a clue of the underlying disease.

- **Clubbing.** The hypertrophy of the nail bed increases the convexity of the nail plate in chronic suppurative diseases, namely lung abscess, bronchiectasis, osteomyelitis, etc.
  In a normal nail, the angle between the nail plate and proximal nail fold measures 160°, but in clubbing, the angle increases and approaches or exceeds 180°.
- **Anonychia.** The congenital absence of a nail is termed anonychia.
- **Koilonychia.** The central depression of the nail with a lateral elevation of the nail plate produces a concave curvature, i.e. spoon-shaped nail is called *koilonychia*. It is commonly associated with iron-deficiency anaemia.
- **Paronychia.** It is the inflammation of the paronychium producing redness, swelling and tenderness of the lateral and proximal nail folds. Pus often accumulates under the cuticle.

Hair

These are thin elongated keratinized structures present over almost all of the body surface. Each hair is formed from a hair matrix, a region of epidermal cells at the base of the hair follicle. The hair follicles are derived from invaginations of epidermal epithelium. Hair is found everywhere on the body except on palms, soles, lips, glans penis, clitoris and labia minora.

The presence of hair is a characteristic of all mammals. Humans are relatively hairless, with only the scalp, the face, the pubis, and the axilla being densely-haired. Therefore, anthropologists have referred to humans as **naked animals**. The primary function of hair is protection.

Parts of hair

Each hair consists of three parts:

1. Shaft
2. Root
3. Bulb.

The **shaft of hair** projects above the surface of the skin. It is the dead portion of hair consisting of keratinous material and is diagonally placed.

The **root of the hair** is embedded within the skin. It is surrounded by a hair follicle (a sheath of the epidermis and dermis). The hair follicle is a tubular invagination of the epidermis and dermis.

The **bulb of hair** is the enlarged base of the root of the hair within the hair follicle. Each hair develops from stratum basale cells within the bulb of the hair. The bulb of the hair is invaginated by highly vascular connective tissue, the **dermal papilla,** which provides nutrition to the developing hair.

Clinical correlation

Growth and fall of hair: In a healthy person, hair grows at a rate of 1 mm every 3 days. The life span of a hair varies from 3 to 4 months (for eyelashes) to 3–4 years (for scalp hair). Each hair loss is replaced by new hair that grows from the bulb of hair and pushes the old hair out.

Baldness results when hairs are lost and not replaced by new hair. Baldness may occur due to disease but is generally inherited and most frequently occurs in males because of genetic influences combined with the male sex hormone testosterone. No treatment is effective in reversing genetic baldness; however, flaps of the skin containing healthy follicles from hairy parts of the body can be grafted.

Arrector pili muscles. These are thin slips of smooth muscle attached to the hair follicles. Arrector pili muscle makes an obtuse angle with the skin surface. A sebaceous gland is often enclosed between the arrector pili and hair follicle.

The arrector pili muscles are involuntary and respond to thermal or psychological stimuli. The contraction of the arrector pili muscle has two

effects: when they contract (a) the hair is pulled in a more vertical position (*stand on end appearance*) causing goosebumps (‘*goose skin*’) and (b) squeeze out sebum into the hair follicles. The ‘goose flesh’ appearance of the skin is a common feature of exposure to cold or emotional stimuli.

N.B.

- The *pilosebaceous apparatus* (unit) consists of the hair follicle, sebaceous gland and *arrector pilorum* muscle.
- *Arrector pili muscles* are absent in facial and axillary hairs, eyebrows, eyelashes, hair of nostrils and hair of external auditory meatuses.

Structure of hair (Fig. 5.7)

The hair consists of three layers as seen in its cross-section. From deep to superficial these are:

1. Medulla
2. Cortex
3. Cuticle.

1. **Medulla** consists of moderately keratinized and loosely arranged cells. They are separated by many air spaces (also called air cells).
2. **Cortex** consists of keratinized and compactly grouped cells.
3. **Cuticle** consists of richly keratinized cells with serrate edges. They provide hair with a scaly appearance under a dissection microscope.

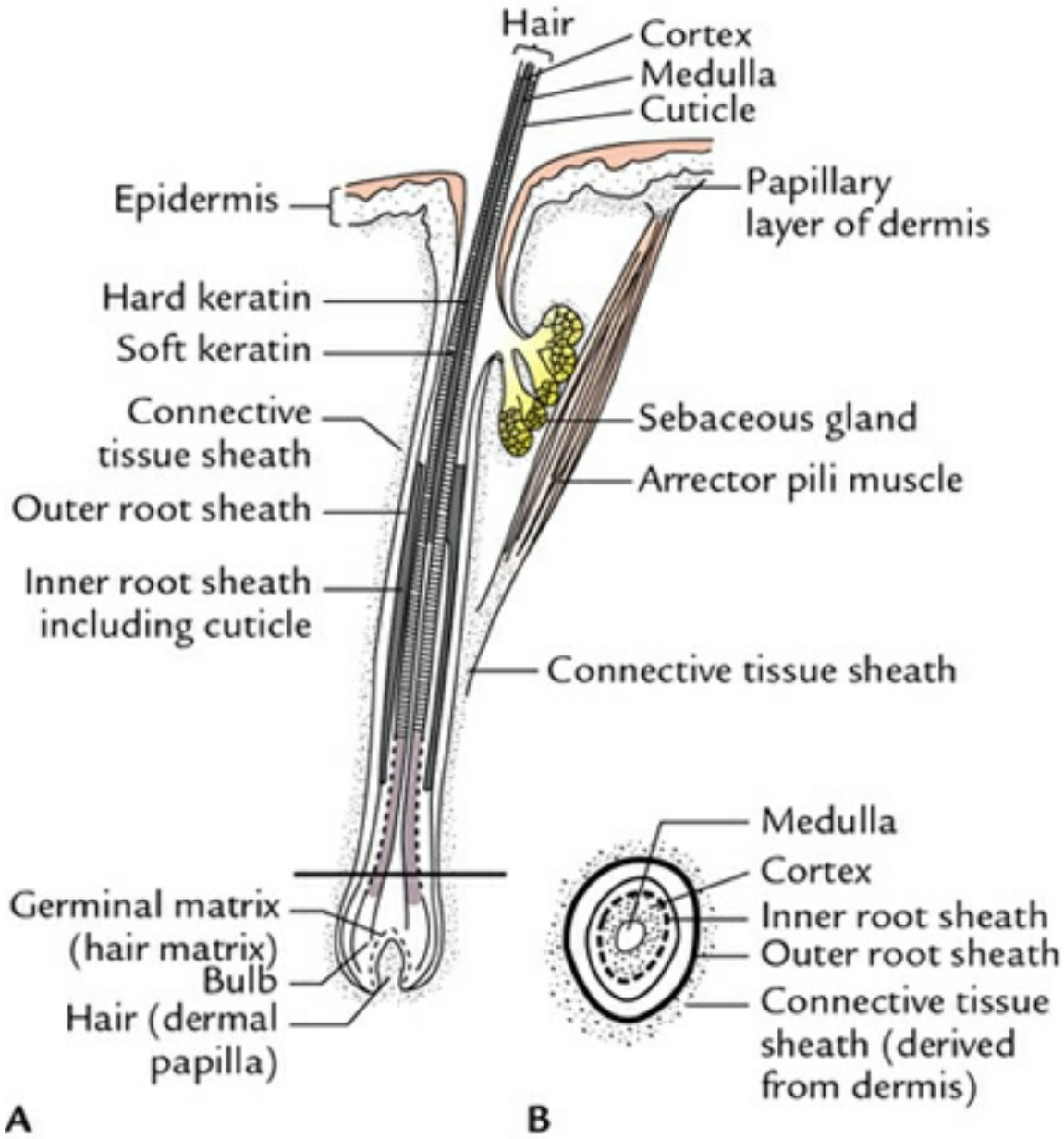


FIG. 5.7 ■ Detailed structure of the hair follicle: **(A)** longitudinal section of hair in a follicle and **(B)** transverse section of hair in the follicle.

A hair is surrounded by three sheaths:

1. Internal root sheath
2. External root sheath
3. Connective tissue sheath.

The **internal root sheath** completely surrounds the initial part of the shaft. Its cells degenerate and disappear above the sebaceous glands. It is made up of keratinized cells from the hair matrix. The type of keratin here is softer than hair.

The **external root sheath** is the tubular invagination of the epidermis which is not a part of the hair. It is continuous above with epidermal cells and near the surface, it shows all the layers of the epidermis. It is separated from the connective tissue sheath by a *glossy membrane*, the lamina propria.

The **connective tissue sheath** is derived from the dermis of skin.

Colour of hair

The colour of hair is determined by the amount of melanin produced by melanocytes in the germinal matrix of the hair follicle. The varying amounts of melanin produce hair colour, ranging from **blonde-**to-**brunette**-to-**black**.

Clinical correlation

Greying of hair: In old age, hairs become grey or white. It is due to a lack of production of melanin following a progressive decrease of tyrosinase and an increase in the number of air spaces between the cells of the medullary shaft that generally accompanies aging.

Texture of hair

The texture of the hair is determined by its cross-sectional shape. **Straight hair** is round in cross-section, **wavy hair** is oval and **kinky hair** is flat.

Types of hair

Humans have three types of hair:

1. Lanugo
2. Angora or terminal
3. Definitive or vellus.

1. **Lanugo** is fine silky hair that covers the foetus. They develop during the third trimester of development and are usually not evident in the baby's body at birth unless the baby is born prematurely.
2. **Angora or terminal hair** are long, coarse and pigmented. They grow continuously in length. Examples are hair on the scalp and face of a male, hair in axillary and pubic regions, eyelashes and eyebrows.
3. **Definitive or vellus hair** are the most common type. They grow to a certain length and then cease to grow. They are short, fine and usually

unpigmented.

Sweat (sudoriferous) glands

The sweat glands are long coiled tubular glands. Each sweat gland consists of two parts: a secretory portion and an excretory duct.

The **secretory portion** is located in the deep dermis in the form of a twisted coil. The **excretory duct** is long and extends from the secretory position to the surface of the skin. The sweat glands are most numerous in the palms, soles, axilla, pubic region and forehead.

Types of sweat glands

The sweat glands are of two types:

1. Eccrine
2. Apocrine.

The **eccrine sweat glands** are widely distributed all over the body, especially on the forehead, palms and soles. These glands are fully formed before birth.

The eccrine glands help in the regulation of the body temperature by evaporation of sweat and also help in the excretion of the body salt. In response to thermal and emotional stimuli, these glands are capable of producing 8–10 L of sweat per day. The eccrine sweat glands are stimulated by cholinergic fibres of sympathetic nerves.

The eccrine (or epicrine) glands are distributed throughout the body except for lip margins, eardrums, nail beds, the inner surface of the prepuce and glans penis.

The **apocrine sweat glands** are much larger sweat glands and their ducts open in the apical part of the hair follicles. They are found in axillary and pubic regions, areolae of breasts, labia minora and perianal region. Their secretion is viscous containing protein and lipid. It is poured into the hair follicles. The apocrine sweat glands are stimulated by adrenergic fibres of sympathetic nerves.

N.B.

- In apocrine sweat glands secretion is by exocytosis (merocrine); hence, the term apocrine is a misnomer.
- As a rule, postganglionic sympathetic neurons use norepinephrine as their neurotransmitters; however, there is an exception to the rule in the regulation of the body temperature.

The apocrine sweat glands differ from eccrine sweat glands in the following three ways:

1. They secrete a viscous product containing protein and lipids via merocrine secretion.
2. They discharge their secretion into the apical part of the hair follicle, i.e. pilosebaceous canal of a hair follicle (rather than directly onto the surface).
3. They are under endocrine control (androgens and oestrogens).

The apocrine glands are not functional until puberty and their odoriferous secretion is thought to attract the opposite sex.

N.B.

- In animals, the apocrine glands secrete *pheromones* that influence heterosexual drive, important for courtship and social behaviour.
- In humans, the secretion of the apocrine sweat glands is initially odourless but later due to bacterial decomposition produces a characteristic *adult body odour* in 'blacks' and 'whites'.

For this reason, people use different kinds of exogenous sexual attractions such as perfumes and scents while attending functions and parties.

The main differences between the eccrine and apocrine sweat glands are presented in Table 5.2.

TABLE 5.2

Differences between eccrine (merocrine) and apocrine sweat glands

	Eccrine sweat glands	Apocrine sweat glands
Nature of secretion	Watery, containing sodium chloride, potassium, urea and ammonia	Viscid, containing proteins and lipids
Site of discharge of secretion	On the skin surface on sweat pores	Into the pilosebaceous canal around the hair shaft
Distribution	Widely distributed throughout the body	Found in axilla, mons pubis and anal regions
Function	Regulate body temperature	Provide characteristic body odour (malodorous body scent)
Age of activity	Active throughout life	Active at puberty
Neurogenic control	*Cholinergic* postganglionic sympathetic neurons	*Adrenergic* postganglionic sympathetic neurons
Endocrine control	Absent	Present (androgens and oestrogens)

N.B.

- The *ceruminous glands* present in the external auditory meatus are modified apocrine sweat glands. They discharge waxy secretion called *cerumen* which provides a sticky barrier for foreign bodies and protects the tympanic membrane from damage. Accumulation of cerumen in the external auditory meatus (earwax) may prevent sound waves from reaching the tympanic membrane.
- The modified apocrine glands of eyelashes are called the *glands of Moll*.

The mammary glands or breasts are modified sweat glands, located in the superficial fascia in the region of the chest. They secrete milk during lactation. The mammary glands reach their greatest development during

child-bearing years.

The breast consists of 15–20 pyramidal lobes/acini of glandular tissue which are drained by lactiferous ducts onto the nipple.

The glandular tissue of each lobe is surrounded by fat or adipose tissue. Adipose tissue within the breast contributes largely to the contour and size of the breast. The proliferation of the glandular tissue during pregnancy is due to oestrogen and progesterone. The secretory activity of glandular tissue is due to prolactin.

The suspensory ligaments (of Cooper) which are connective tissue septa attach the breast to the skin and to the underlying deep fascia (pectoral fascia). They provide support and maintain the posture of the breast.

Clinical correlation

Gynaecomastia: The lobes of mammary glands are only slightly developed in males or remain rudimentary. If they develop, the condition is called *gynaecomastia*.

Sebaceous glands (oil glands)

They are associated with hair follicles as they develop from the follicular epithelium of the hair. Each hair follicle is provided with one to six sebaceous glands. They are simple branched glands that are connected to the hair follicle. They secrete an oily material, the sebum, onto the shaft of the hair. The sebum which mainly consists of lipids is dispersed along the shaft of the hair to the surface of the skin. It lubricates and waterproofs the surface of the skin and also prevents the hair from being brittle. They are widely distributed all over the skin of the body except palms and soles.

N.B.

Sebaceous glands mostly open into the hair follicles. However, in certain areas of the body sebaceous glands open directly onto the surface of the skin, e.g.

- *On the nose*, where the opening of the ducts when occluded with debris appear as 'black heads'.

- In *genital* and *perianal* regions.
- In *areola* around the nipple, where they form *Montgomery's tubercles*.
- In the *eyelids*, where they are called *tarsal glands*.

Clinical correlation

- **Acne at puberty:** Under the influence of sex hormones, the sebaceous glands grow in size and increase their production of sebum. If the drainage of sebum is blocked, the sebaceous glands become infected and produce acne. Acne is small elevations of skin (pimples). They may contain pus (pustule) and are usually confined to the face, particularly in teenage males.
- **Sebaceous cysts:** The mouth of sebaceous glands opens into the hair follicle. If the mouth of a sebaceous gland becomes blocked, the gland becomes distended by its own secretion producing a *sebaceous cyst*.
  Most sebaceous cysts are found in the hairy part of the body. The scalp, scrotum, neck, shoulder and back are the common sites, but they can occur wherever there are sebaceous glands. Most sebaceous cysts are tense and consequently spherical.
- **Sebaceous horn:** If the sebum of a sebaceous cyst exudes slowly, it may dry and harden into a conical spike called a sebaceous horn.

Functions of skin AN4.2

The skin is a dynamic organ. It not only protects the body from pathogens and external injury but also plays a major role in maintaining body homeostasis.

The major functions of the skin include:

1. protection
2. hydroregulation (i.e. prevent the loss of body fluids)
3. thermoregulation
4. sensory reception (i.e. acts as a sensory organ)
5. absorption of lipid-soluble substances and ultraviolet rays
6. synthesis of vitamin D

7. excretion of waste material
8. communication of emotions.

Protection

Skin acts as a protective barrier between the external environment and internal tissues of the body. It protects the body from pathogens and external injury.

Hydroregulation

Skin being (virtually) waterproof, prevents dehydration (loss of body fluids) in hot weather and absorption of water when immersed in water. The waterproofing is provided by a cornified layer of the skin.

Thermoregulation

Skin plays a crucial role in the regulation of body temperature. It maintains the normal body temperature, i.e. at 37°C, by effects of sweating and shivering. The excess heat is lost from the body in three ways, all involving the skin: (a) through the excretion and evaporation of sweat, (b) through radiation from dilated blood vessels and (c) through convection of heat directly through the skin. The heat is conserved by the fat and the hair.

Sensory reception

Skin is an important sensory organ for perceiving sensations like pain, touch, temperature and pressure. This is because the skin contains a large number of sensory nerve endings called **cutaneous receptors**.

Absorption

Skin being a protective barrier has a limited capacity for absorption. Lipid-soluble substances such as vitamins A, D, E, and K are absorbed slowly. Some gases, namely O_2 and CO_2, may pass through the skin into the blood, small amounts of ultraviolet light are absorbed readily and certain toxins and pesticides enter the body through the skin.

Synthesis

Vitamin D is synthesized in the skin with the help of ultraviolet rays of the

sun. In addition, keratin and melatonin are also synthesized in the skin. The melanin and keratin remain in the skin while vitamin D is used elsewhere in the body.

Excretion

The skin also acts as an excretory organ. The excess water, salts and waste products such as ammonia and urea are excreted through the skin by sweating.

Communication of emotions

Skin can also communicate emotions, e.g. in anger a person's face becomes red and in anxiety, the palms become cold and damp or the person may start sweating.

Blood supply to the skin

The epidermis of the skin is avascular. The blood vessels within the dermis supply the glands and hair follicles within the dermis and metabolically active stratum basale of the epidermis.

A special feature of the blood supply to the skin is the presence of numerous arteriovenous anastomoses which regulate blood flow through the capillary bed and thus help in maintaining the body temperature.

Clinical correlation

Bed sores: Proper circulation of blood in the skin is essential for healthy skin. When a person lies in one position on the bed for a long period, the dermal flow of blood is reduced at sites where the body presses against the bed. As a result, cell necrosis occurs at these sites, leading to ***ulceration***. The ulcers thus produced are called ***bed sores or decubitus ulcers***.

Nerve supply to the skin

The nerves supplying the skin are:

1. Motor nerves
2. Sensory nerves.

Motor nerves

These are autonomic nerve fibres that activate glands and control blood flow.

Sensory nerves

These are somatic nerve fibres that innervate the skin in the form of a large number of sensory nerve endings which carry different types of sensations from the skin.

Sensory nerve endings in the skin (Fig. 5.8)

(a) *Free nerve endings* enter the epidermis and carry pain and temperature sensations.
(b) *Merkel's discs* or *endings* terminate on the Merkel cells of stratum basale and function as **mechanoreceptors.**
(c) *Meissner's corpuscles* are present in the dermal papillae and function as **mechanoreceptors** to detect fine touch.
(d) *Pacinian corpuscles* are present in the dermis and function as **mechanoreceptors** to detect deep pressure and vibrations.
(e) *Ruffini's endings* are present deep within the dermis and function as **heat receptors** to detect heat.
(f) *Bulbs of Krause* are located in the superficial part of the dermis and function as **thermoreceptors** to detect cold.
(g) *Root hair plexuses* are the plexuses of nerve fibres around roots of hair follicles and function as **tactile receptors** to detect movement.

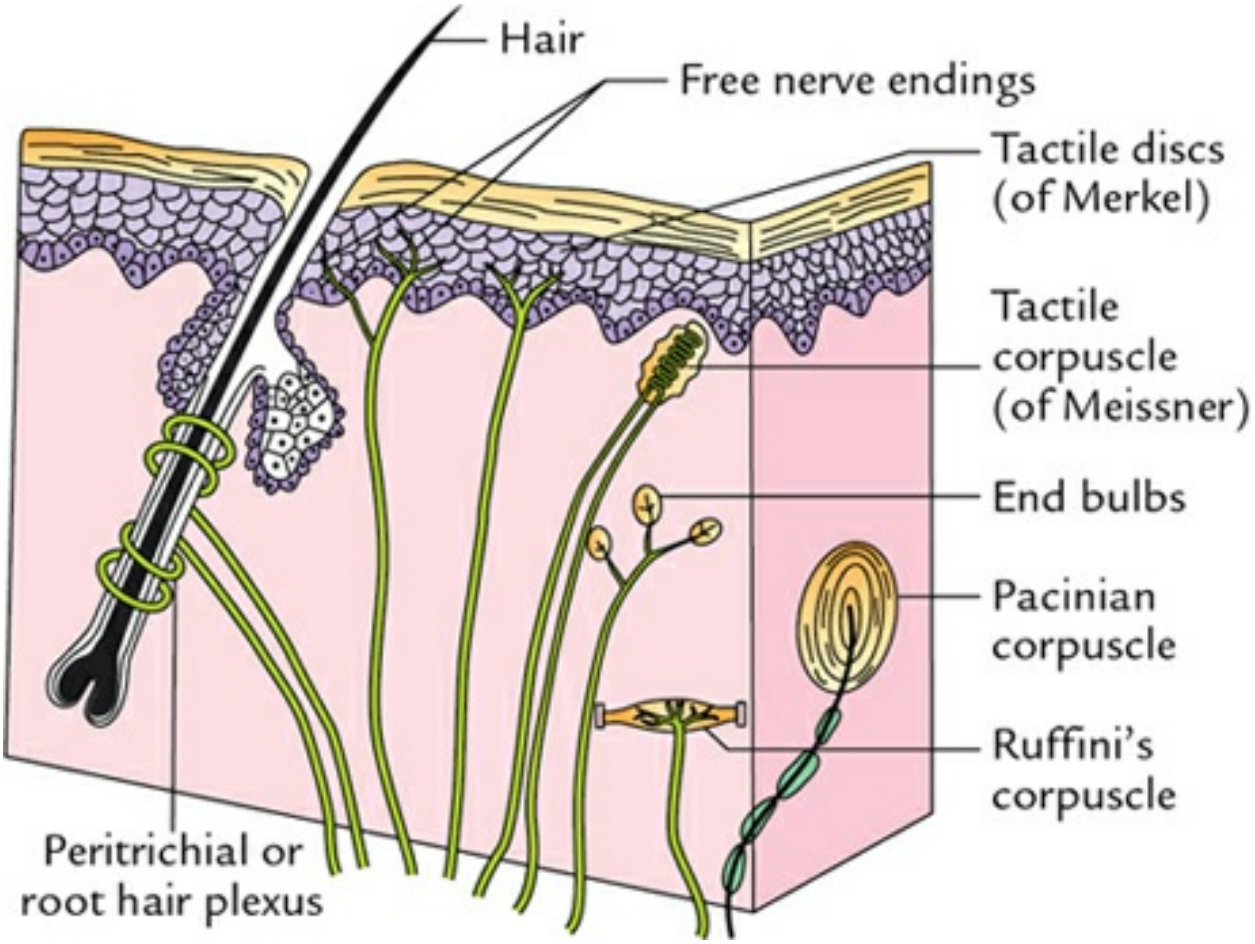


FIG. 5.8 ■ Sensory nerve endings in the skin. (Source : Fig. 4.1, Page 29, Textbook of Clinical Neuroanatomy , Vishram Singh. Copyright Elsevier 2017, all rights reserved.)

All the cutaneous receptors are located in the dermis except free nerve endings and Merkel's discs which are located in the epidermis.

Wound healing

The epithelium has a high regenerative capacity.

The healing of a wound occurs in three steps or stages:

1. Inflammation
2. Proliferation
3. Maturation.

Inflammation

The cut surfaces become inflamed, blood clots and cell debris fills the gap between them in the first few hours. The phagocytes and fibroblasts migrate

into the blood clot:

(a) Phagocytes remove the blood clot and cell debris.
(b) Fibroblasts secrete collagen fibres which bind the cut surfaces.

Proliferation

The epithelial cells proliferate mitotically across the clot. The epidermis meets and grows upwards until the full thickness is restored.

Granulation tissue

consisting of new capillary buds, phagocytes and fibroblasts develop. The fibroblasts continue to secrete collagen fibres as the clot and any bacteria are removed by phagocytosis. The clot above the new tissue becomes the **scab** and separates after 3–10 days.

Maturation

The granulation tissue is replaced by fibrous scar tissue.

N.B.

The healing is described to be of two types: (a) primary healing (healing by first intention), and (b) secondary healing (healing by second intention). The primary healing follows minimal destruction of tissue when the damaged edges of the wound are in close opposition. Secondary healing follows the destruction of a large amount of tissue or when the edges of a wound cannot be brought in opposition. The stages of healing are the same in both types.

Skin burns

The skin burns are generally caused by heat, electricity or chemicals. The skin burns are classified as **first degree, second degree** or **third degree** based on their severity.

First-degree burn

- Destroys only epidermis
- Presenting symptoms are redness, pain and oedema (swelling)

- Shedding of surface layer a few days later
- Heals in 3–6 days

Second-degree burn

- Involves epidermis and part of the dermis
- Blisters appear
- Heals completely within a few weeks

Third-degree burn

- Destroys both epidermis and dermis completely and frequently some of the underlying muscle
- Skin appears waxy or charred
- Are insensitive to touch
- Wounds develop
- Heals by forming scar tissue
- Requires skin grafting to promote healing.

N.B.

Major burns include: (a) third-degree burns involving 10% of the body surface or (b) second-degree burns involving over 25% of the body surface.

Estimation of surface area of skin

The total surface area of the skin covering the entire body is 1.5–2.0 sq. m. The estimation of the percentage of the surface area damaged in case of burns is important in treating the patient with intravenous fluid which replaces the fluids lost from tissue damage.

(a) **Rule of nine**. This rule is a quick means of estimating the surface area affected by burning. According to this rule, the total surface area of the body is divided into regions, each of which accounts for 9% (or a multiple of 9%) of the total skin surface (Table 5.3; Fig. 5.9).

(b) **Hand area rule**. A rough estimation of surface area affected by burn can be calculated by the *hand area rule*. According to this rule, the area of the patient's hand is approximately 1% of the total body surface.

 **TABLE 5.3**

The surface area of skin in percentage for various regions of the body

Region of the body	**% of the surface area of the skin**
1. Head and neck (both anterior and posterior surfaces)	9 (4.5 + 4.5)
2. Right upper limb (both anterior and posterior surfaces)	9 (4.5 + 4.5)
3. Left upper limb (both anterior and posterior surfaces)	9 (4.5 + 4.5)
4. Anterior surface of the trunk	18 (9 × 2)
5. Posterior surface of the trunk including buttocks	18 (9 × 2)
6. Right lower limb (both anterior and posterior surfaces)	18 (9 + 9)
7. Left lower limb (both anterior and posterior surfaces)	18 (9 + 9)
8. Perineum	1
Total	100

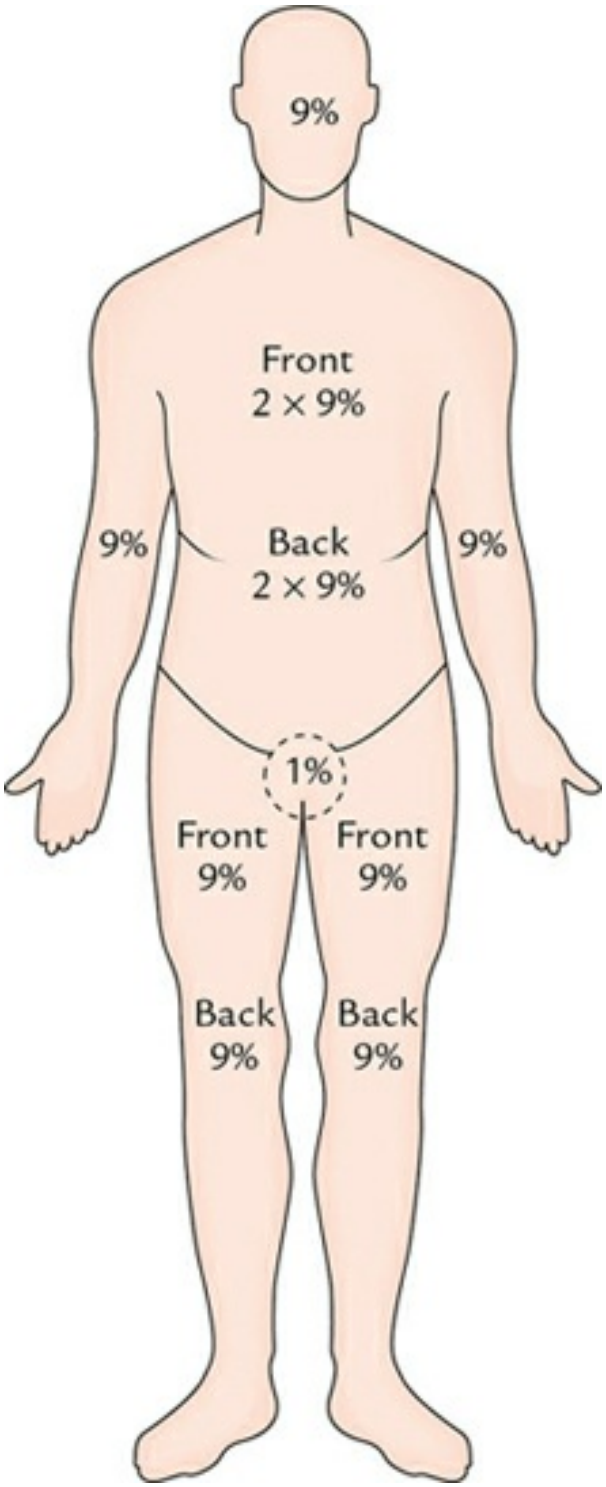


FIG. 5.9 ■ The rule of nine—to determine the surface of the skin affected by burns.

Regeneration of the skin

The skin has a high capacity for regeneration and repair. For this reason, skin grafting is a common procedure in plastic surgery, especially after burns. If a patch of epidermis gets removed, the repair and regeneration take place by a

proliferative activity of the stratum germinativum; however, there is no regeneration of hair follicles. If the dermis remains intact, the pattern of papillary ridges (fingerprints) is reproduced as earlier. If the dermis is damaged, the papillary ridges regenerate but do not conform to the original pattern.

Superficial fascia AN4.3

It is a subcutaneous layer of loose areolar tissue which unites the dermis of the skin to the underlying deep fascia (Fig. 5.10). It allows the mobility of the dermis on the underlying structures.

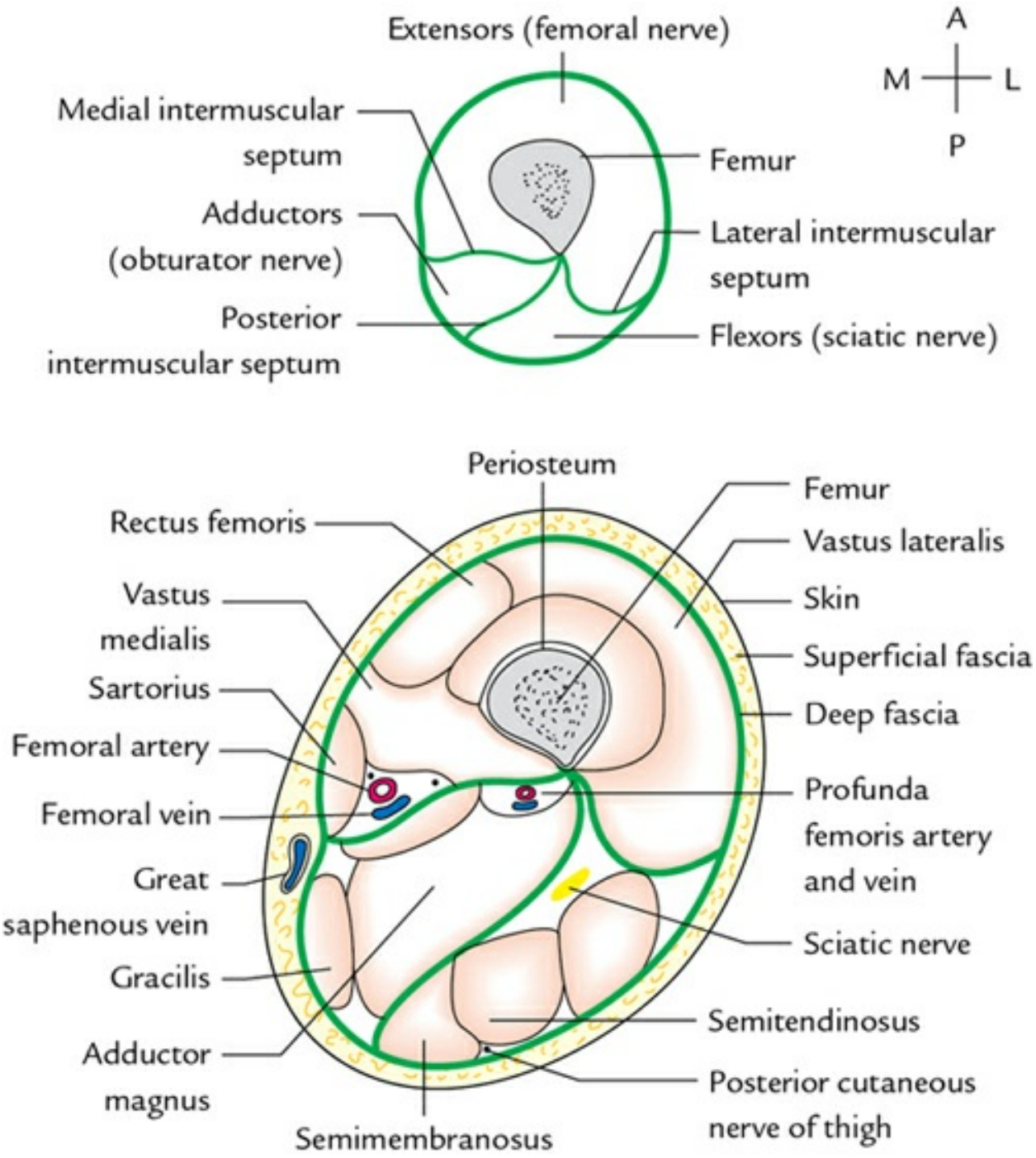


FIG. 5.10 ■ Transverse section through the middle of the right thigh to show the three intermuscular septa and three osteofascial compartments as seen from above.

It is heavily infiltrated with fat. The amount of fat varies in different parts of the body.

Distribution of fat in superficial fascia AN 4.3

The superficial fascia almost everywhere in the body contains fat *except* in

the:

1. Eyelids
2. External ear/pinna
3. Penis
4. Scrotum
5. Flexion creases of the digits.

The amount of fat in the superficial fascia is more in females and children. The fat being a bad conductor of heat, the females and children feel less cold. Further, it is the main factor responsible for the smooth external contours of the females.

Special fat deposits at certain sites in women form their secondary sexual characteristics. These sites are:

1. Gluteal and lumbar region
2. Front of thigh
3. Anterior abdominal wall below the navel (umbilicus)
4. Breasts
5. Post-deltoid region
6. Cervical thoracic region.

The superficial fascia acts as a distributing layer, in which the blood vessels, lymphatics and nerves can travel before entering the dermis.

N.B.

The subcutaneous fascia in the lower animal contains a thin sheet of muscle called *panniculus carnosus*. Its fibres are inserted into the skin. The twitch of its fibres prompts the insects to go away or fly off.

In humans, the panniculus carnosus is represented by:

- muscles of facial expression (skeletal muscles)
- platysma in the neck (skeletal muscle)
- subareolar muscle of the breast (smooth muscle)
- palmaris brevis (skeletal muscle)
- dartos in the scrotal wall (smooth muscle)
- corrugator cutis ani (smooth muscle)

Functions of superficial fascia

The functions of superficial fascia are as follows:

1. Forms an insulating layer deep into the skin
2. Responsible for smooth external contours of females and children
3. Allows mobility of the skin on the underlying structures
4. Provides easy passage to nerve, vessels and lymphatics
5. Acts as a cushion at certain sites (due to excessive accumulation of fat, e.g. buttocks).

Clinical correlation

- **Subcutaneous injections:** Subcutaneous injections are painful due to the presence of pain receptors in them. Drugs administered by this route are absorbed slowly because subcutaneous tissue has a poor blood supply. Only small doses (0.5–1 mL) of water-soluble drugs are given subcutaneously. For example, insulin injections in diabetic persons are given subcutaneously in small doses for slow release over a long duration.

  Sites of subcutaneous injections: The ideal sites for subcutaneous injections are:

  (a) Posterior aspect of the arm
  (b) Anterior aspect of the forearm
  (c) Anterior abdominal wall
  (d) Anterior aspect of the thigh.

Deep fascia

The deep fascia is a tough, inelastic membrane of fibrous tissue which encloses the body deep to subcutaneous tissue, like a tight sleeve (Fig. 5.10). It keeps the soft tissues in place and maintains the shape of the body. The deep fascia is best marked in the limbs and neck. In the limbs, it sends septa (intermuscular septa) between the groups of muscles to attach to the

periosteum of the bone. These septa enable a group of muscles to contract individually and slide freely over the adjacent muscle groups.

In the neck, it forms three layers:

1. **General investing layer**, which encloses the structures of the neck like a collar
2. **Pretracheal fascia**, which passes in front of the trachea
3. **Prevertebral fascia**, in front of the cervical part of the vertebral column. Thus, the neck is divided into two compartments: the visceral compartment and the musculoskeletal compartment.

Axiom. Wherever the deep fascia encounters the bone, it does not cross, but rather attaches itself to it for the simple reason that both are derived from the mesoderm.

Modifications of deep fascia AN4.4

The modifications of deep fascia are as follows:

1. **Retinacula.** At certain sites, deep fascia thickens to form thick bands to retain the tendon of long muscles in place and prevent their bowstringing during the action of these muscles. These bands are called **retinacula**, viz. flexor and extensor retinacula around wrist and ankle joints.
2. **Aponeurosis.** In palms and soles, it thickens to form palmar and plantar aponeurosis to protect the underlying structures. In the true sense, aponeurosis is a thick, wide sheet of fibrous tissue that provides attachment to muscles. The palmar and plantar aponeuroses represent the degenerated tendons of palmaris longus and plantaris muscles, respectively.
3. **Fibrous sheaths.** At certain sites, deep fascia condenses to form a sheath around neurovascular bundles to protect them from damage, viz.
   (a) *Carotid sheath* enclosing the common carotid artery, internal jugular vein and vagus nerve
   (b) *Axillary sheath* enclosing axillary artery and axillary vein (deep fascia is dense around the artery and rather loose around the veins to allow the veins to distend)

4. **Fibrous capsules.** At some sites, it splits to enclose certain glands to form their capsule, viz. parotid gland, submandibular gland, thyroid gland etc. to provide support to the enclosed structure.
5. **Interosseous membranes.** In the forearm and leg, the deep fascia is modified to form interosseous membranes to join adjacent bones.
6. **Intermuscular septa.** In the limbs, the deep fascia sends fibrous septa from its deep surface to help form the compartments of the muscles.
7. **Fibrous flexor sheaths.** On the flexor surfaces of fingers and toes, the deep fascia thickens to form the fibrous flexor sheath around the long flexor tendons. These sheaths prevent the tendons from bowing out of position.
8. **Ligaments.** The ligaments of joints are considered as localized thickened bands of the deep fascia to provide stability.
9. **Fascial sheath.** It forms a sheath around certain muscles, viz. psoas sheath to provide protection.

Clinical correlation

- Since deep fascia defines fascial planes between the muscles, these planes form potential pathways for infection to spread.
- Pus tends to force its way along the lines of least resistance provided by the planes of the deep fascia.
- Pus can track down through the fascial sleeves formed by deep fascia around the blood vessels and muscles, e.g. pus from the root of the neck can track down into the arm through the axillary sheath.
- Pus from the tubercular thoracic spine can track down in the inguinal region through psoas sheath.
- Surgeons can operate along the fascial planes with minimal injury to the adjoining structures.
- Deep fascia is least marked, i.e. scarcely demonstrable in the region of the anterior abdominal wall and is considered to be absent.

Sites where deep fascia is absent

The deep fascia is absent at the following sites:

1. Face
2. Breast
3. Anterior abdominal wall
4. Penis and scrotum
5. Ischiorectal fossa.

Nerve supply of deep fascia

The deep fascia is very sensitive. Its nerve supply is derived from:

1. Nerves supplying overlapping skin.
2. Nerves supplying enclosed muscles.

Functions of deep fascia

The functions of deep fascia are as follows:

1. Keeps the underlying structures in position and preserves the characteristic surface contour, viz. limbs, neck
2. Provides extra surface for muscular attachments
3. Facilitates venous and lymphatic drainage
4. Binds bones, viz. interosseous membranes
5. Retains the long tendons in place to prevent their bowstringing and also serves as pulleys during their actions.

Golden Facts to Remember

• **Largest organ in the body (area-wise)**	Skin
• **Largest sensory organ in the body**	Skin
• **Thickest skin in the body**	Palms of hands, soles of feet
• **Thinnest skin in the body**	Glans penis, eyelids, eardrum
• **Commonest site of skin cancer**	Face
• **Commonest congenital disorder**	Mole

of the skin	
• Mole (melanocytic naevus)	Melanocytes clustered in high densities
• Most common skin cancer	Basal cell carcinoma
• Largest modified gland of the skin	Mammary gland (modified sweat gland) in female
• Fingerprints were first used in criminal investigations by	Henry Faulds in 1880
• Exoskeleton in humans is represented by	Hair and nails
• Largest sensory receptors of the skin	Pacinian corpuscles
• Longest coarse hair in the body	Hair on scalp
• Smallest coarse hair in the body	Eyelashes of the lower eyelid
• Naked apes	Humans
• Most common type of hair in the body	Definitive or vellus hair
• Sites with the maximum number of sweat glands	Forehead, palms, soles
• Site with maximum number of sebaceous gland	Scalp
• Nails with the fastest growth	Nails of the middle finger of the hand
• Sites with abundant fat in the superficial fascia	Breasts, buttocks, flanks, anterior abdominal wall (below the umbilicus)
• Sites where fat is absent in superficial fascia	Eyelids, penis, scrotum
• Most common tumour arising from the subcutaneous tissue	Lipoma

• **Ideal sites for subcutaneous injections**	Posterior aspect of the arm, anterior aspect of the forearm, anterior abdominal wall, anterior aspect of the thigh
• **Toughest deep fascia in the body**	Temporal fascia, fascia lata
• **Sites where the deep fascia is absent**	Face, external genitalia
• **Thinnest deep fascia in the body**	The fascia of Gallaudet (deep fascia on the anterior abdominal wall)

Multiple choice questions

1. **All of the following statements are true regarding skin *except* that it:**
   (a) Forms the dynamic interphase between the body and the external environment
   (b) Is the largest organ in the body
   (c) Develops from both ectoderm and mesoderm
   (d) Forms about 27% of body weight in adult
2. **Epidermal layer not present in thin skin is:**
   (a) Stratum granulosum
   (b) Stratum spinosum
   (c) Stratum lucidum
   (d) Stratum corneum
3. **All of the following contribute to skin colour *except*:**
   (a) Dermal papillae
   (b) Melanin
   (c) Carotene
   (d) Haemoglobin
4. **Regarding cleavage (Langer) lines, all of the following statements are true *except*:**
   (a) They are caused by the pull of elastic and collagen fibres in the dermis
   (b) Their direction is vertical in the chest and abdomen
   (c) Incisions made parallel to these lines heal quickly and produce hairline scar
   (d) Incisions made across these lines heal poorly and produce wide

thick scar

5. **All of the following statements regarding apocrine sweat glands are true *except*:**
   (a) Are not functional until puberty
   (b) Are found in axillary and pubic regions
   (c) Discharge their secretion always on the skin surface
   (d) Discharge their secretion into the pilosebaceous canal/hair follicle
6. **Regarding dermis, all of the following statements are true *except*:**
   (a) It develops from surface ectoderm
   (b) It consists of a superficial papillary layer and a deep reticular layer
   (c) Reticular layer is used for making leather from domestic animals
   (d) It contains sweat glands, sebaceous glands, hair follicles and arrector pili muscles
7. **In which kind of burn is healing slow and leads to scarring:**
   (a) First-degree burn
   (b) Second-degree burn
   (c) Third-degree burn
   (d) None of the above
8. **Fat is absent in superficial fascia of all of the following, except:**
   (a) Eyelids
   (b) Penis
   (c) Anterior abdominal wall below umbilicus
   (d) External ear/pinna
9. **All of the following muscles are present in the superficial fascia *except*:**
   (a) Muscles of facial expression
   (b) Platysma
   (c) Pectoralis major
   (d) Corrugator cutis ani
10. **All of the following are modifications of deep fascia *except*:**
    (a) Axillary sheath
    (b) Pretracheal fascia
    (c) Retinacula
    (d) Platysma

Answers

1. *d*, **2.** *c*, **3.** *a*, **4.** *b*, **5.** *c*, **6.** *a*, **7.** *c*, **8.** *c*, **9.** *c*, **10.** *d*

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*Lunule: L. *Lunula* = small moon.

**Hyponychium: Gk. *Hypo* = under; *onyx* = nail.

Chapter 6: Skeleton: Bones and cartilages

Specific learning objectives

After studying this chapter, the student should be able to:

- Enumerate the types of skeleton and list the bones forming each type.
- Define bone and list the functions of the bone.
- Enumerate different types of cells in the bone.
- Classify the bones according to their shape and give an example of each.
- Describe the composition of bone and bone marrow. **AN 1.2**
- Enumerate the special features of a sesamoid bones. **AN2.3**
- Outline the parts of a growing long bone and discuss its arterial supply.
- Enumerate the laws of ossification. **AN 2.2**
- Describe intramembranous and intracartilaginous ossification.
- Describe parts, blood and nerve supply of a long bone. **AN 2.1**
- Compare and contrast the structure of compact and spongy bones. Write a note on osteon.
- Describe various types of cartilages with their structure and distribution in the body. **AN 2.4**
- Describe the growth of the bone and cartilage.
- Discuss remodelling of bone and its clinical significance.

- Correctly solve the Multiple Choice questions given at the end of the chapter.

The skeleton of the body is composed of bones and cartilages. Both bones and cartilages are made up of a specialized connective tissue called skeletal (**sclerous**) **tissue**, which can bear weight without bending and has considerable tensile strength.

The skeletal tissue consists of the same components (e.g. cells, matrix) as in a general connective tissue, but physically differs from it as its matrix is solidified.

The functions of the skeletal system are as follows:

1. Forms a rigid framework of the body.
2. Provides protection to the viscera (viz. brain, heart, lungs, etc.) of the body from external injury.
3. Provides leverage for the body movements.

Types of the skeleton

For the convenience of study, the skeleton is divided into two types (Fig. 6.1):

1. Axial skeleton
2. Appendicular skeleton.

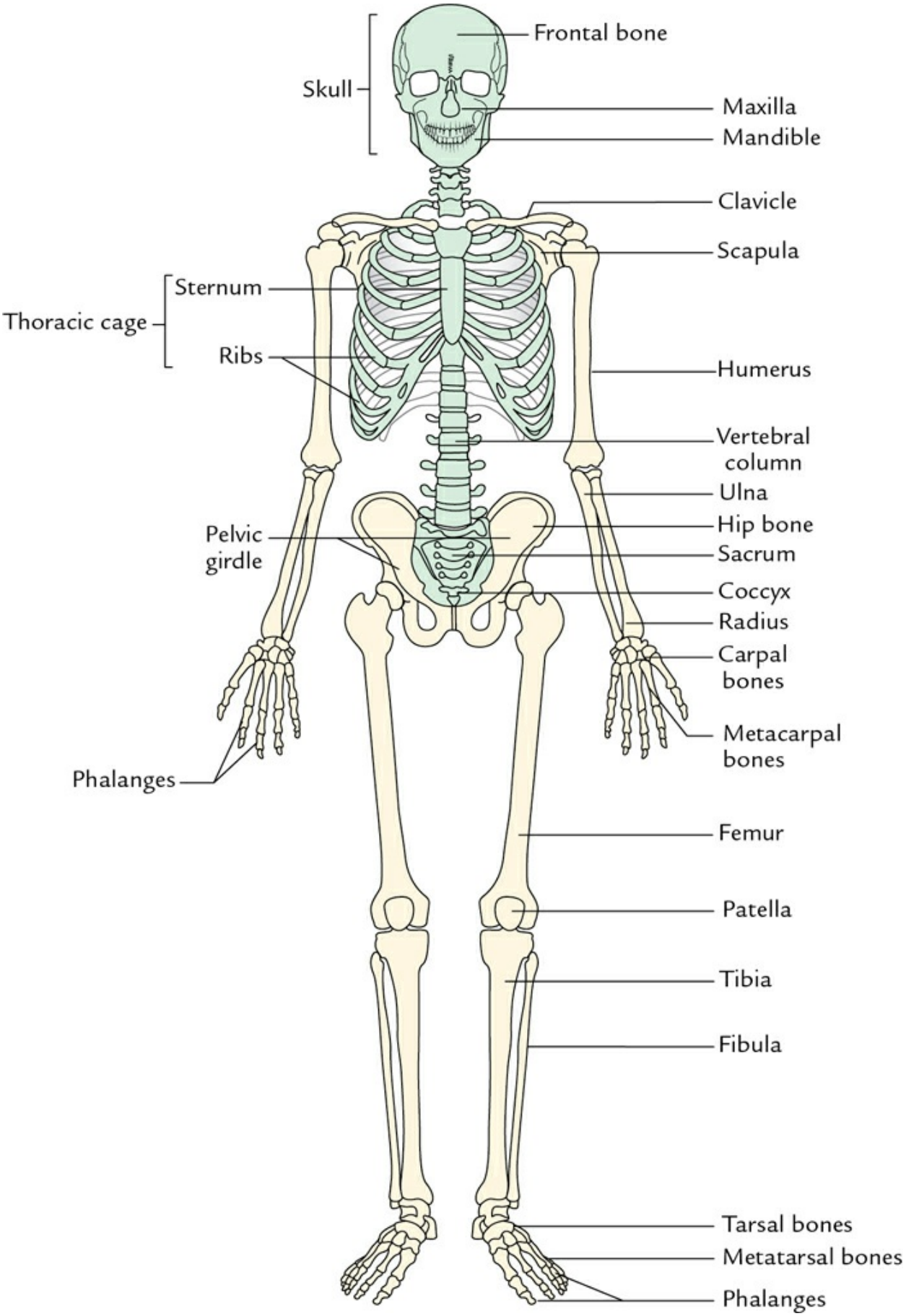


FIG. 6.1 ■ Skeleton: axial skeleton (green colour) and appendicular skeleton (light

brown colour).

Axial skeleton

The axial skeleton consists of bones and cartilages that lie close to the central axis of the body. It includes the skull, auditory ossicles, hyoid bone, vertebral column, and ribcage:

1. **Skull**: It consists of two sets of bones—the cranial bones that form the cranium or braincase and the facial bones.
2. **Auditory ossicles**: These are the three small bones present in each middle ear cavity of skull. They are bones within the bone.
3. **Hyoid bone**: It is located above the larynx and below the lower jaw.
4. **Vertebral column (backbone)**: This consists of 33 vertebrae: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal; however, sacral vertebrae fuse to form the **sacrum** and coccygeal vertebrae fuse to form **coccyx**, thus vertebral column consists of 24 individual or movable bones (vertebrae).
5. **Ribcage**: It forms the bony and cartilaginous framework of the thorax. The bone forming the ribcage includes 12 pairs of ribs with associated costal cartilages and sternum (breast bone).

Appendicular skeleton

The appendicular skeleton is bilaterally symmetrical and comprises the bones of the upper and lower extremities (or limbs) and bony girdles that anchor these extremities with the axial skeleton. Thus, it includes bones of the pectoral girdle, upper limb, pelvic girdle and lower limb (Fig. 6.1).

1. **Pectoral girdle**: It consists of paired scapulae and clavicles. It is not a complete girdle as it is attached only anteriorly.
2. **Bones of the upper limb**: Each upper limb contains the humerus within the arm (brachium); the radius and ulna within the forearm (antebrachium); the carpal bones, the metacarpal bones and the phalanges within the hand.
3. **Pelvic girdle**: It consists of two hip bones. It is a complete girdle as it is united anteriorly with symphysis pubis and posteriorly with the sacrum of the vertebral column.

4. **Bones of the lower limb**: Each lower limb contains the femur within the thigh; the tibia and fibula within the leg; the tarsal bones, the metatarsal bones and the phalanges within the foot.

The bones forming the axial and appendicular skeleton are listed in Table 6.1 and shown in Figure 6.1.

TABLE 6.1

Number of bones present in the axial and appendicular skeleton

Type of skeleton	Number of bones	
AXIAL SKELETON		
(a) *Skull and vertebral column*		80
Cranial bones	8	
Facial bones	14	
Hyoid	1	
Ear ossicles (3 in each ear)	6	
Vertebral bones	26	
(b) *Ribcage*		
Sternum	1	
Ribs	24	
APPENDICULAR SKELETON		
(a) *Pectoral (shoulder) girdle*		126
Clavicle	2	
Scapula	2	
(b) *Upper limbs*		
Humerus	2	
Ulna	2	
Radius	2	
Carpals	16	
Metacarpals	10	
Phalanges	28	
(c) *Pelvic (hip) girdle*		
Hip bone	2	
(d) *Lower limbs*		
Femur	2	
Fibula	2	

Tibia	2	
Patella	2	
Tarsals	14	
Metatarsals	10	
Phalanges	28	
Total bones of the body		**206**

Bones

The bones are made up of specialized scleral connective tissue. They are the hard structures, which form the rigid framework of the body.

Structurally, bone is a highly vascular mineralized connective tissue consisting of cells and dense intercellular organic matrix impregnated with inorganic salts. The organic material mainly consists of collagen fibres and forms one-third of the bone. It provides resilience to the bone. The inorganic material mainly consists of calcium phosphate and traces of other salts. It provides hardness and rigidity to the bone and makes it radiopaque in X-ray films.

The bone is not an inert material as often thought of by some students but it is a living structure. It is supplied by blood vessels, lymph vessels and nerves. It has the power of regeneration and repair. In fact, bones have greater regenerative power than any other tissues of the body, *except* blood.

The bones are subject to diseases like any other tissue of the body.

Clinical correlation

Bone health: The bones undergo atrophy, that is become thinner and weaker if not used, for example, bones of a paralyzed limb atrophy; on the other hand, they hypertrophy, that is become thicker and stronger if subjected to support increased weight. Therefore, regular exercise is essential to maintain the health of the bones.

N.B.

- The skeletal system of an adult human is composed of approximately 206 bones.

- At birth, the skeleton consists of approximately 270 bones (in adults, the number of bones decreases due to the gradual fusion of separate bones).

Functions of bones

The following are the functions of bones:

1. Form a rigid framework of the body to give it a shape and support.
2. Provide surface for attachment of muscles, tendons, ligaments, etc.
3. Serve as levers for muscles to bring about movement.
4. Protect certain viscera, for example, the brain, spinal cord, heart, lungs, liver, bladder, etc.
5. Contain marrow which is a factory of blood cells, for example, white blood cells, red blood cells and platelets.
6. Storehouse of calcium and phosphorus, about 95% of the phosphorus within the body is deposited in the bones and the teeth.
7. Some bones around the nose contain large cavities filled with air (paranasal air sinuses which affect the timber of the voice).

Microscopic structure of bones AN1.2

The bone is a specialized connective tissue and consists of the following three components:

1. Cells
2. Ground substance
3. Fibres.

The ground substance and fibres together form the intercellular substance or matrix which gets mineralized.

Cells

The bone cells are of three types: osteoblasts, osteocytes and osteoclasts.

Osteoblasts

1. The osteoblasts are derived from pluripotent **osteoprogenitor cells** located in mesenchyme, periosteum and endosteum.
2. They secrete **osteoid**, which is an unmineralized matrix, consisting of proteoglycans, glycoproteins and type I collagen fibres.
   (a) For mineralization to occur, the osteoblasts secrete **osteocalcin** and **alkaline phosphatase** which release calcium and phosphate radicals from substances containing them.
   (b) In addition, osteoblasts release **matrix vesicles** (membrane-bound vesicles), which concentrate calcium and phosphate and are the **most important factors necessary for mineralization to occur.**
3. They undergo mitosis.
4. They are the precursor cells of the osteocytes.

N.B.

The blood alkaline phosphatase level can be monitored clinically to assess osteogenesis during bone repair.

Osteocytes

1. The osteocytes are derived from osteoblasts. Once an osteoblast becomes surrounded by the matrix, it becomes an **osteocyte**.
2. The osteocytes are flattened cells with numerous cytoplasmic processes. They are located in spaces within a matrix called **lacunae** and **canaliculi**, respectively. The cytoplasmic processes of neighbouring cells communicate by **gap junctions**.
3. The osteocytes unlike osteoblasts do not undergo mitosis.
4. The canaliculi radiate from each lacuna and permit the diffusion of nutritive material (Fig. 6.2). Thus, cells remain alive in the calcified matrix and maintain the bone through their balanced osteogenic and osteoclastic activity. They secrete alkaline phosphatase to maintain calcification. When bone cells die, the matrix is decalcified.

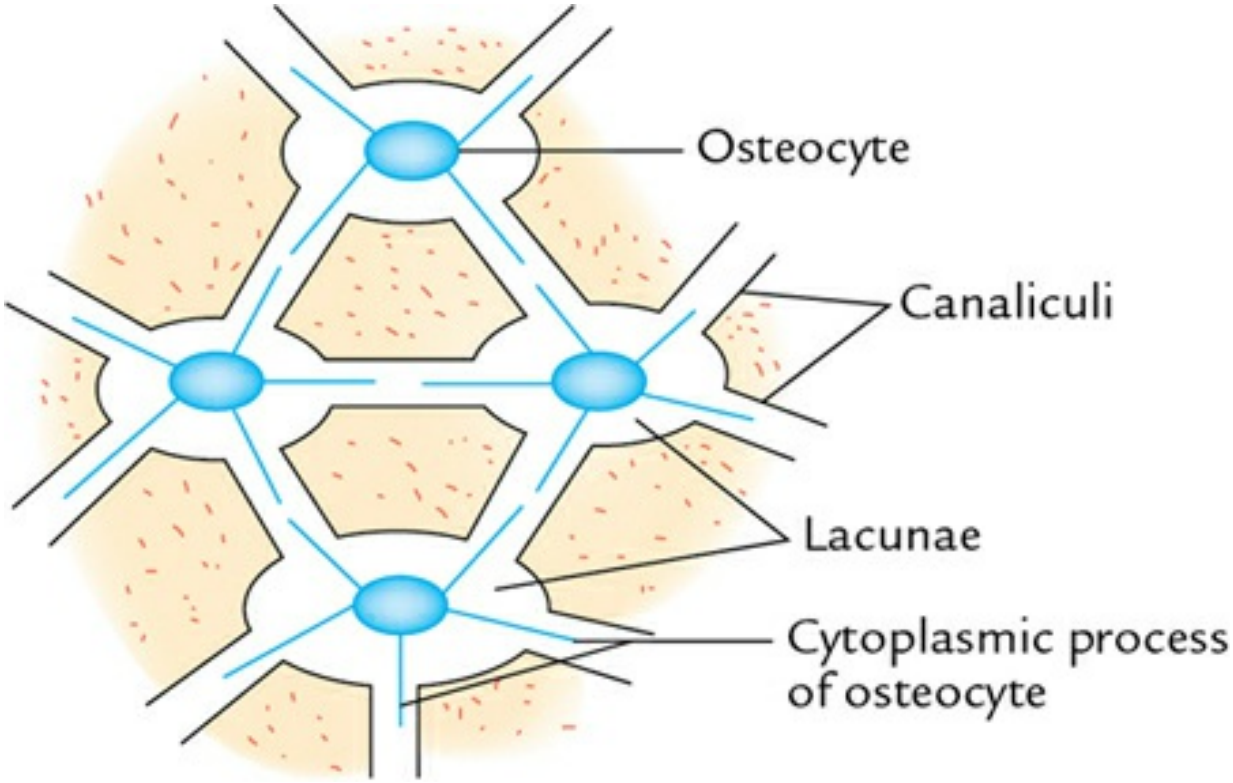


FIG. 6.2 ■ Osteocytes, lacunae and canaliculi.

Osteoclasts

1. The osteoclasts are derived from the fusion of uncommitted cells of red bone marrow that are related to a type of white blood cell called **monocyte** similar to the formation of *giant cells* by the fusion of macrophages.
2. They are large cells with multiple nuclei.
3. They help in the resorption of the bone and play an important role in bone remodelling.
4. They reside in shallow depressions of the bone called **Howship's lacunae**.
5. They do not undergo mitosis.

Ground substance

It consists of the following components:

1. **Proteoglycans** contain a side chain of glycosaminoglycans (GAGs), which includes: *chondroitin sulphate, keratan sulphate, dermatan sulphate*

and hyaluronan specially first two.

2. **Glycoproteins**, such as *osteonectin* and *osteocalcin* (a calcium-binding protein).
3. **A mineral component** that includes *hydroxyapatite* (calcium phosphate crystals), *citrate ions* and *bicarbonate ions*. Mineral component mainly consists of hydroxyapatite crystals of calcium phosphate ($Ca_{10}[PO_4]_6[OH]_2$), and contributes to the hardness/rigidity of bone.
4. **Water (tissue fluid),** which contributes to a low degree of bone hydration (7%).

Fibres

They are type I collagen fibres and provide tensile strength to the bone.

Classification of bones

The bones are usually classified in three ways:

(a) According to the shape
(b) According to the structure (structural classification)
(c) According to the development (developmental classification).

Classification according to the shape AN2.1

A. Depending on the size, shape, etc., the bones are classified into the following types (Fig. 6.3):

1. Long bones
2. Short bones
3. Flat bones
4. Irregular bones
5. Pneumatic bones
6. Sesamoid bones
7. Accessory bones.
8. Heterotopic bones.

1. **Long bones** are those in which length exceeds the breadth and thickness. The long bones are of two types: typical and miniature/short.
   (a) **Typical long bones**: They have the following features:

Consist of three parts: one elongated tubular shaft (diaphysis) and two expanded ends (epiphyses).
Contain medullary cavity filled with bone marrow.
Ossify in the cartilage.
Lie vertically in the body.
Are weight-bearing.
Are found in limbs and act as levers for muscles.
Examples of typical long bones are the humerus, radius, ulna, femur, tibia and fibula.

N.B.

The *clavicle* is the only long bone that lies horizontally, ossifies mainly in membrane and does not contain any medullary cavity.

(b) **Miniature/short long bones**: These are much shorter in length as compared to typical long bones with epiphysis present at one end only.
Examples of miniature long bones are metacarpals, metatarsals and phalanges. All the metacarpals and metatarsals have epiphysis at their distal end except the first metacarpal and first metatarsal which have epiphysis at their proximal end.

2. **Short bones** are small in size and usually cuboidal in shape, presenting six surfaces. These bones are found in the wrist (carpal bones) and foot (tarsal bones).

N.B.

All the short bones ossify in cartilage after birth except the talus, calcaneus and cuboid which start ossifying before birth.

3. **Flat bones** are flat and shallow plate-like bones. They form boundaries of certain body cavity, for example, the cranium, thoracic cavity. Examples of flat bones include: (a) bones forming cranial vault (frontal, parietal, occipital, etc.) and (b) bones forming thoracic cages (scapulae, ribs, sternum, etc.).
4. **Irregular bones** are highly irregular in shape, viz. hip bone, vertebrae, bones forming the base of the skull.
5. **Pneumatic bones** are a variety of irregular bones which contain air-filled cavities or cavities within them. These bones are mainly located

around the nasal cavity, viz. maxilla, frontal, sphenoid and ethmoid bones. The air-filled cavities in these bones are called **paranasal air sinuses**.

The paranasal air sinuses not only make the skull light but also add resonance to the voice. They also act as air conditioning chambers for the inspired air.

6. **Sesamoid bones (Arab *sesame* = seed)** are seed-like bony nodules that develop in certain muscle tendons where they rub against convex bony surfaces during the movements of the joint. The rubbing surface of the sesamoid bone is covered with articular cartilage.

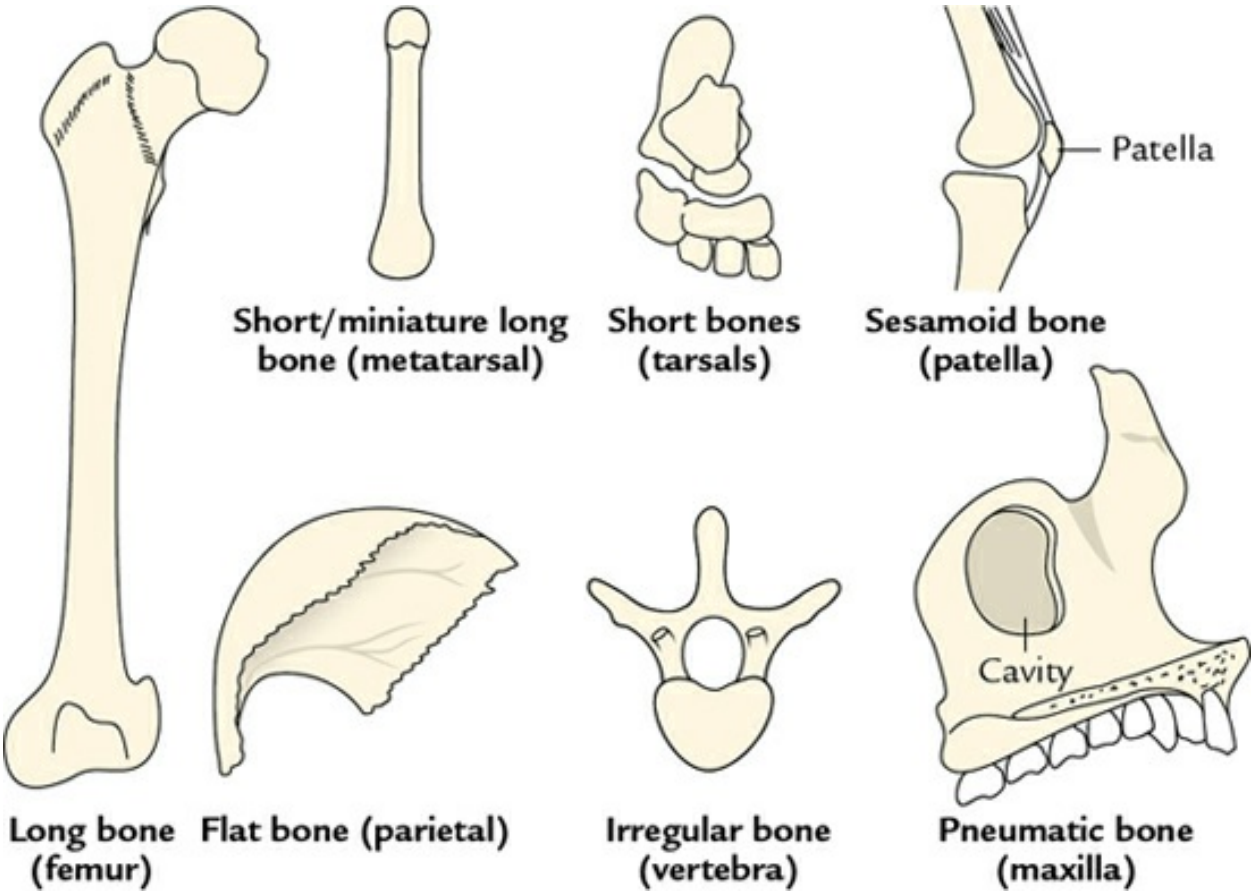


FIG. 6.3 ■ Types of bones-depending on their shapes.

Sites of sesamoid bones **AN2.3**

1. ***Patella*** in the tendon of quadriceps femoris in front of the knee joint.
2. ***Fabella*** in the lateral head of gastrocnemius behind the knee joint.
3. ***Two sesamoid bones below the head of the first metatarsal*** bone in the tendon of flexor hallucis brevis.

4. ***One sesamoid bone in the tendon of peroneus longus*** where it binds around the cuboid bone.
5. ***Pisiform*** in the tendon of the flexor carpi ulnaris.
6. ***One sesamoid bone on the ulnar side of the head of 1st metacarpal bone*** in the tendon of *adductor pollicis*.
7. Sometimes a sesamoid bone is found on the radial side of the head of the 1st metacarpal in the tendon of flexor *pollicis brevis*.

Functions of the sesamoid bones

1. Act as pulleys for muscle contraction.
2. Alter the direction of the pull of the muscle.
3. Minimize the friction of the tendon against the bone to prevent its attrition.

Characteristics of sesamoid bones

1. Develop in the tendons of the muscles.
2. Are devoid of periosteum.
3. Ossify after birth usually by multiple centres.
4. Lack the Haversian system.

N.B.

- *Patella* is the *largest sesamoid bone* in the body and the cartilage covering, its articular surface is the *thickest articular cartilage* in the body.
- *Sesamoid bones* are not classified as true bones as they are not covered by periosteum.

7. **Accessory bones** These bones are generally not present in the body. If present they do not cause any harm, sometimes clinicians confuse them with fractured bones.

Accessory bones may be formed due to:

1. Appearance of extra ossification centres in skull sutures, viz. **sutural or wormian bones**.

2. Nonfusion of an epiphysis. The examples are:
   (a) *Os trigonum*: the posterior tubercle of the talus that fails to fuse with the rest of the bone.
   (b) *Os vesalianum*: the styloid process of the 5th metatarsal that fails to fuse with the rest of the bone.
   (c) *Patella cubiti*: occasionally, the centre of ossification for the olecranon process of ulna fails to fuse to the proximal end of the shaft.

N.B.

8. Heterotopic bones sometimes formed in soft tissues where they are not normally found, for example, *rider's bone* in the tendon of the adductor longus muscle of the thigh.

B. Structural classification

Microscopic classification

Macroscopically (i.e. as seen on naked eye examination of a section of a long/flat bone), the architecture of bone may be compact (dense) or cancellous (spongy).

Most bones of the body have a basic structure of an outer region of compact bone and an inner region of spongy (cancellous) bone. For example:

1. In long bones, the shaft consists of compact bone forming a cylinder that surrounds a central cavity called the **medullary cavity**. The ends of long bones consist of cancellous bone surrounded by a thin layer of compact bone.
2. In flat bones of the skull, the cancellous bone is sandwiched between the plates of compact bone. The spongy part is called **diploe** and the outer and inner plates of compact bone are called inner and outer **tables**.

N.B.

All the bones of the body consist of both compact and spongy bones *except* the inferior nasal concha which consists of only spongy bone.

Microscopic classification

Compact (dense) bone

The texture of compact bone is dense, ivory-like with no visible spaces on naked eye examination. The compact bone consists of: (a) lamellae of collagenous sheets and (b) haversian systems or osteons (Fig. 6.4).

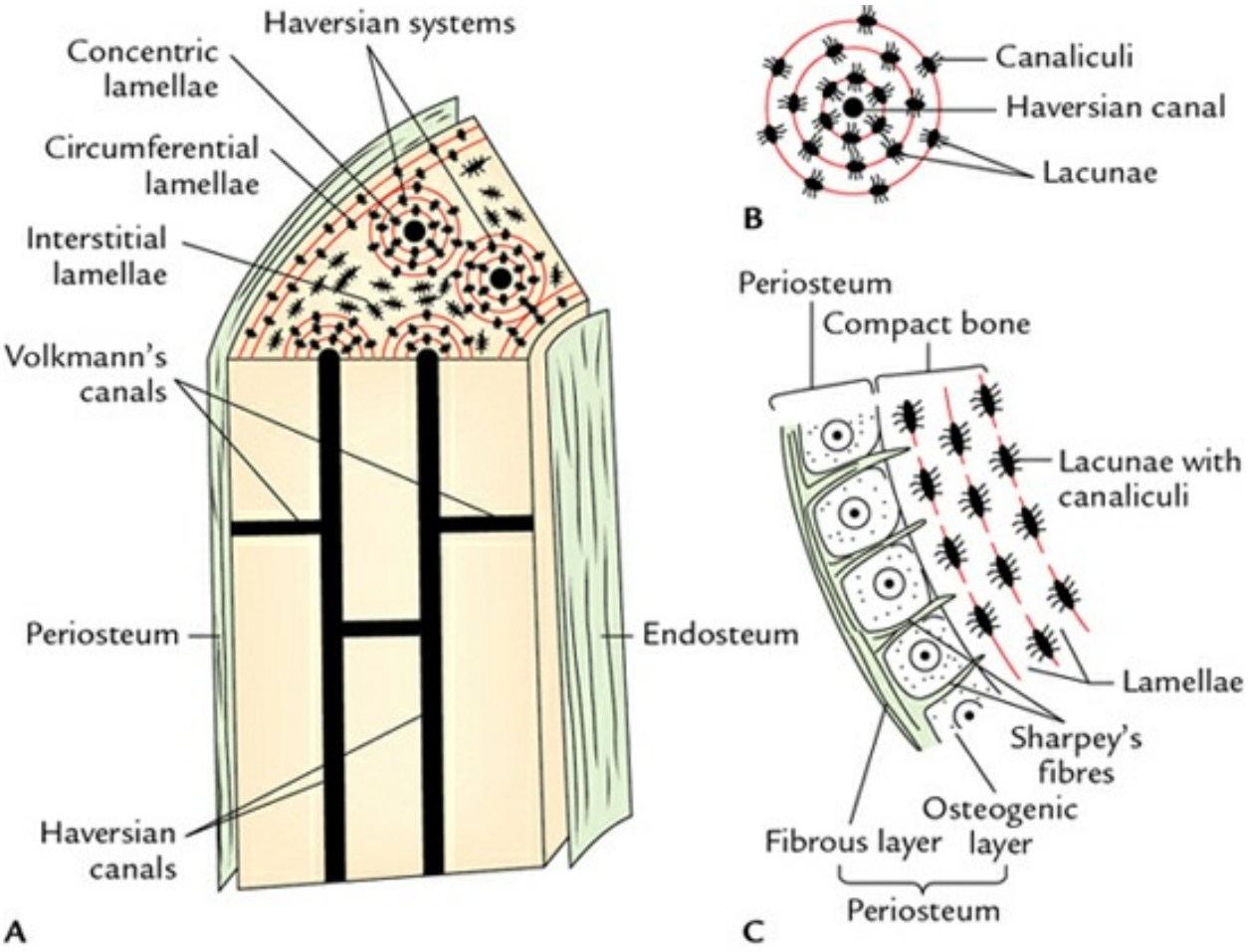


FIG. 6.4 ■ Structure of compact bone: **(A)** Haversian systems and lamellae; **(B)** an osteon and **(C)** periosteum and outer circumferential lamellae of a compact bone.

Lamellae

The compact bone consists of three types of bony lamellae:

1. **Concentric lamellae** which surround the Haversian canal.
2. **Interstitial lamellae** lie between the osteons. The **interstitial lamellae** are the remnants of old outer circumferential lamellae or old

Haversian systems.
3. **Circumferential lamellae** are flat plates that extend around the bone.

Haversian system (osteon)

The osteon (Haversian system) is the structural and functional unit of the compact bone. It consists of a **Haversian canal** (or central canal), surrounded by **concentric lamellae of bone**.

The Haversian canal runs parallel to the long axis of the bone and contains blood vessels, nerves and loose connective tissue.

The concentric lamellae, 4–20 in number, form rings around the Haversian canal. The osteocytes are located between the lamellar rings in lacunae.

The lacunae communicate with one another in between and across the lamellae, and with the central canal by numerous radiating **canaliculi**.

Haversian canals are lined by endosteum and communicate with each other, with the medullary cavity and with the surface of bone by numerous **Volkmann's canals**. The Volkmann's canals run perpendicular to the long axis of the bone.

The blood vessels from the periosteum or endosteum enter the bone through Volkmann's canals.

The Haversian canals receive blood vessels from Volkmann's canals.

The osteocytes receive nutrients and eliminate waste products through the canal system.

Cancellous (spongy) bone

The cancellous bone is a meshwork of bony spicules. It consists of interconnecting rods and plates of bone called **trabeculae**, enclosing large spaces filled with **red bone marrow.** The trabeculae:

1. consist of superimposed lamellae and do not form the **Haversian system** because they get nutrition from the blood vessels of tissues around them.
2. have a layer of osteoblasts on their surfaces.
3. are oriented along the lines of stress.

The differences between the compact and spongy bone are given in Table

6.2.

TABLE 6.2

Differences between compact and spongy bones

Feature	Compact bone	Spongy bone
Density	Dense like an ivory	Porous like a sponge
Haversian systems	Present	Absent
Arrangement of bony lamellae	Regular	Irregular
Location in bone	Outer region	Inner region
Bone marrow	Absent	Present
Amount in the body by weight	75%	25%

Wolff's Law (Trajectory theory of Wolff, 1892): According to this law, bone formation (osteogenesis) is directly proportional to stress and strain. The tensile force favours bone formation, whereas compressive force favours bone resorption. This theory, however, no longer holds good because now it is noticed that both tensile and compressive forces can stimulate bone formation in appropriate conditions.

The **architecture of cancellous bone** is often interpreted in terms of Wolff's law. Thus, the arrangement of bony lamellae is governed by the lines of maximal stress (Fig. 6.5):

1. **Pressure lamellae** are arranged parallel to the line of weight transmission.
2. **Tension lamellae** are arranged at right angles to the pressure lamellae.

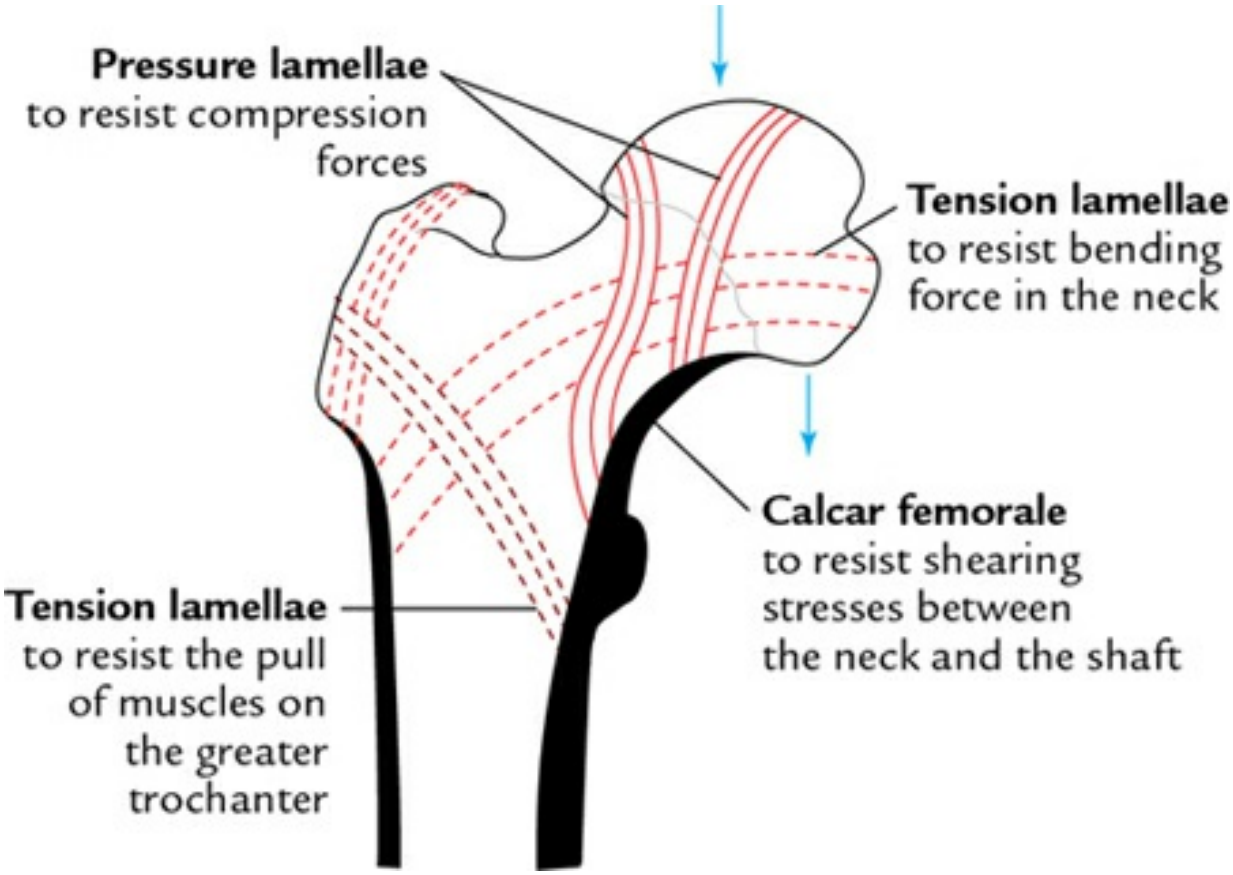


FIG. 6.5 ■ Diagrammatic sagittal section of the upper end of the femur showing pressure and tension lamellae, and calcar femorale.

N.B.

The compact arrangement of pressure lamellae form *bony buttresses to provide additional support,* viz. *calcar femorale* (Fig. 6.5).

Clinical correlation

The trabeculae are oriented along the line of stress within a bone. If the direction of weight-bearing stress is changed slightly, for example, because of a fracture that heals improperly, the trabecular pattern realigns with new lines of stress. For this reason, the patient often complains of pain at the fracture site in later life.

Microscopically, bones are of two types:

1. Woven
2. Lamellar.

This classification is based on how the different components of the matrix are arranged.

Woven bone

The collagen fascicles and bone crystals within a woven bone are arranged randomly forming a network resembling the warp and weft of woven fabric and hence the name 'woven bone'. Examples of woven bone are **young foetal bones** (most immature bone), **callus** at fracture repair sites.

Lamellar bone

In lamellar bone, the mineralized matrix is arranged in thin layers (lamellae). The lamellae are arranged in two different patterns:

1. In a number of concentric cylindrical units (Haversian system), for example, compact bone.
2. In a number of branching and anastomosing curved plates, for example, spongy bone.

N.B.

All the adult bones are lamellar bones.

C. Developmental classification

According to the process of bone development (ossification), the bones are of the following three types:

1. **Membranous bones** (membrane bones), developed by membranous ossification.
2. **Cartilaginous bones** (cartilage bones), developed by endochondral ossification.
3. **Membrano-cartilaginous bones**, developed by both membranous and endochondral ossification.

For details see the development of bones on page 74.

The examples of bones according to their development are enumerated in Table 6.3.

TABLE 6.3

Examples of bones according to their development

Types of bones	Examples
Membranous	Bones of the cranial vault Facial bones
Cartilaginous	Bones of limbs Bones of the base of the skull Bones of the vertebral column (vertebrae) Bones of thoracic cage (ribs, sternum)
Membrano-cartilaginous	Mandible Clavicle Occipital bone Temporal bone Sphenoid bone

Parts of a typical long bone AN2.1

A typical long bone consists of three parts: a shaft (or body) upper end and lower end (Fig. 6.6).

1. The **shaft** is an elongated part between the two expanded ends. It is made of an outer thick shell of compact bone (cortex) enclosing a cavity called a **medullary cavity**, thus providing maximum strength with minimal material and weight.
   The medullary cavity is filled with yellow bone marrow (remember that at birth it is filled with red bone marrow and is involved in active haemopoiesis).
2. The two **ends—upper and lower** are knobby (expanded) and largely made up of cancellous bone covered by a thin shell of a compact bone. The ends of a long bone are covered by an articular hyaline cartilage and take part in the formation of joints.

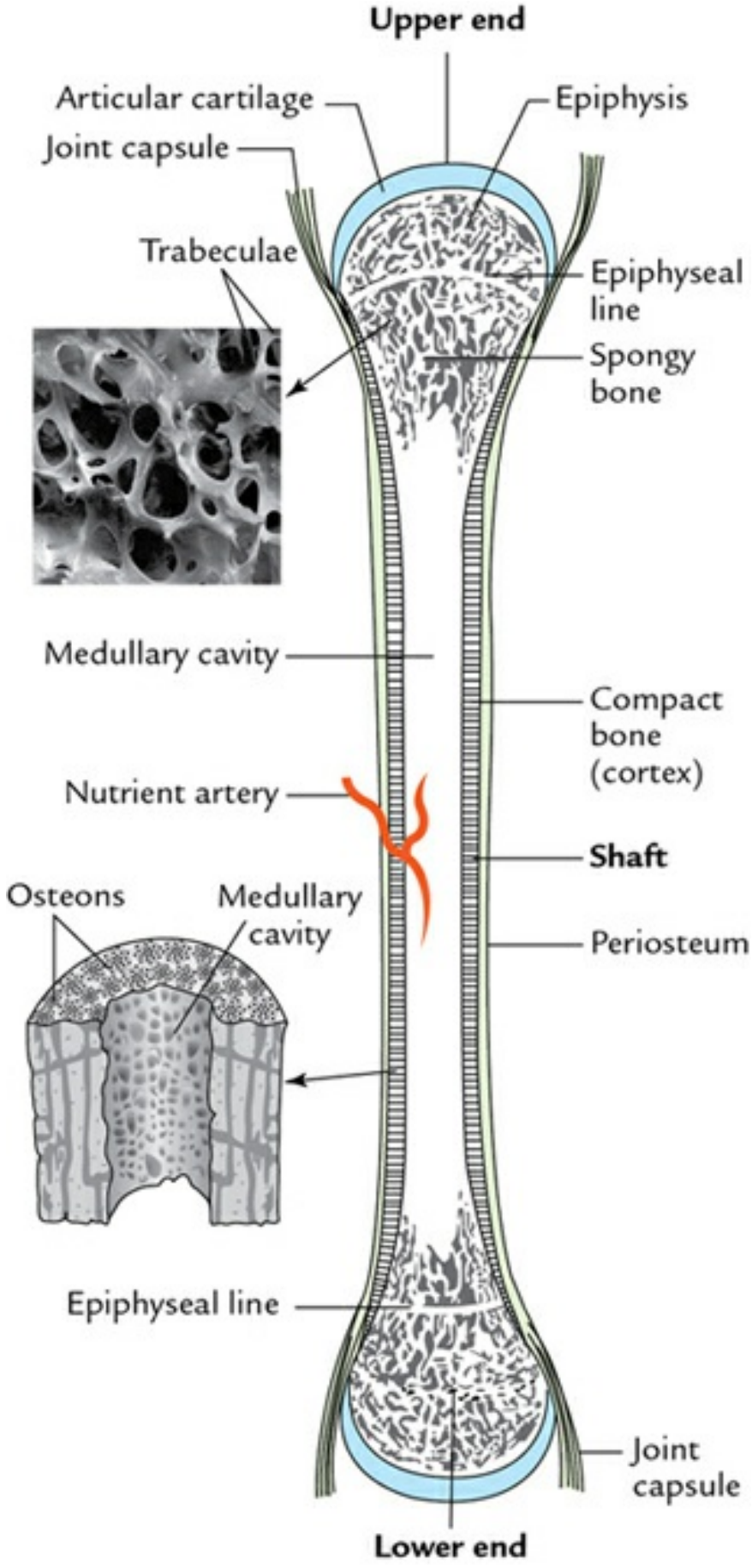

Upper end
Articular cartilage
Epiphysis
Joint capsule
Trabeculae
Epiphyseal line
Spongy bone
Medullary cavity
Compact bone (cortex)
Nutrient artery
Shaft
Osteons
Medullary cavity
Periosteum
Epiphyseal line
Joint capsule
Lower end

FIG. 6.6 ■ Parts and gross structure of a typical long bone. The insets show details of spongy (above) and compact (below) bones.

Blood supply of long bone AN 2.1

The long bone is supplied by three separate sources:

- A nutrient artery
- Periosteal vessels
- Epiphyseal vessels.

For details see page 72-73 Fig 6.10

Nerve supply of long bone AN 2.1

The nerve fibres enter the bone through its nutrient foramen and pass through the nutrient canal, harvesian canal and Volkman's canal to finally enter into the bone marrow.

Periosteum and endosteum

The outer surfaces of all the bones are covered by a thick fibrous membrane called *periosteum*, whereas their inner surfaces are lined by a thin fibrous membrane called *endosteum*. Both periosteum and endosteum contain osteoprogenitor cells, osteoblasts and osteoclasts which are essential for the formation, remodelling and repair of bone.

The **periosteum** (Figs. 6.4 and 6.6) is a thick fibrous membrane covering the entire surface of bone *except* at the areas covered by articular cartilage. At the articular margin, the periosteum is continuous with the joint capsule.

It is made up of two layers:

1. Outer dense fibrous layer.
2. Inner cellular layer which is osteogenic in nature.

The periosteum is united to the underlying bone by extrinsic collagen fibres, the **Sharpey's fibres**. These are coarse collagenous fibres from the inner layer which extend inward to penetrate the bone matrix (outer cortical

bone tissue) like spikes of a shoe, thus bolting the periosteum to the bone.

Functions of periosteum

1. Protects and maintains the shape of the bone.
2. Nourishes the outer part of the underlying cortex by abundant periosteal arteries.
3. Provides attachment to ligaments, tendons, muscles and intermuscular septa.
4. Provides regenerative capability to the bone.

The **endosteum** is the cellular membrane that lines the medullary cavity of the shaft. The osteoblasts and osteoprogenitor cells within the endosteum play an important role in bone remodelling and repair.

The **nutrient foramen** is usually present near the middle of the shaft for the entry of the nutrient artery.

Clinical correlation

Clinical significance of periosteum:

(a) The periosteum is important in the repair of fractures. It has a unique capability of forming new bone; hence, bone stripped of its periosteum will not survive.

(b) The periosteum is very sensitive to pain, particularly to tearing and tension. Therefore, drilling into the bone without anaesthesia is very painful. For the same reason, during intramuscular injection, if the needle penetrates the periosteum, severe pain is felt by the patient.

Bone marrow

The bone marrow is a soft, loose, vascular tissue consisting of a delicate network of reticular fibres and various types of cells. It is the main site of haemopoiesis.

It is present in the medullary cavity of the long bones and in the cavities of the spongy bone.

Types of bone marrows

Two types of bone marrows are described according to their appearance on gross examination.

1. Red bone marrow
2. Yellow bone marrow.

Red bone marrow

It is vascular and appears red in colour due to the presence of red blood cells. It consists of a network of fine reticular fibres containing blood-forming cells, showing all stages of development: immature (nucleated) and mature (non-nucleated) red blood cells, myeloblasts, myelocytes, granulocytes, megakaryocytes, etc. At birth, it is present in all the bones at all sites and is an important site of haemopoiesis, but as age advances the marrow in the medullary cavity of long bones is gradually replaced by yellow marrow.

Hence in adults, the red marrow is found in the cancellous bone. The sites (Fig. 6.7) are as follows:

1. Ends of long bones
2. Sternum
3. Ribs
4. Skull bones
5. Iliac crests of hip bones
6. Vertebrae.

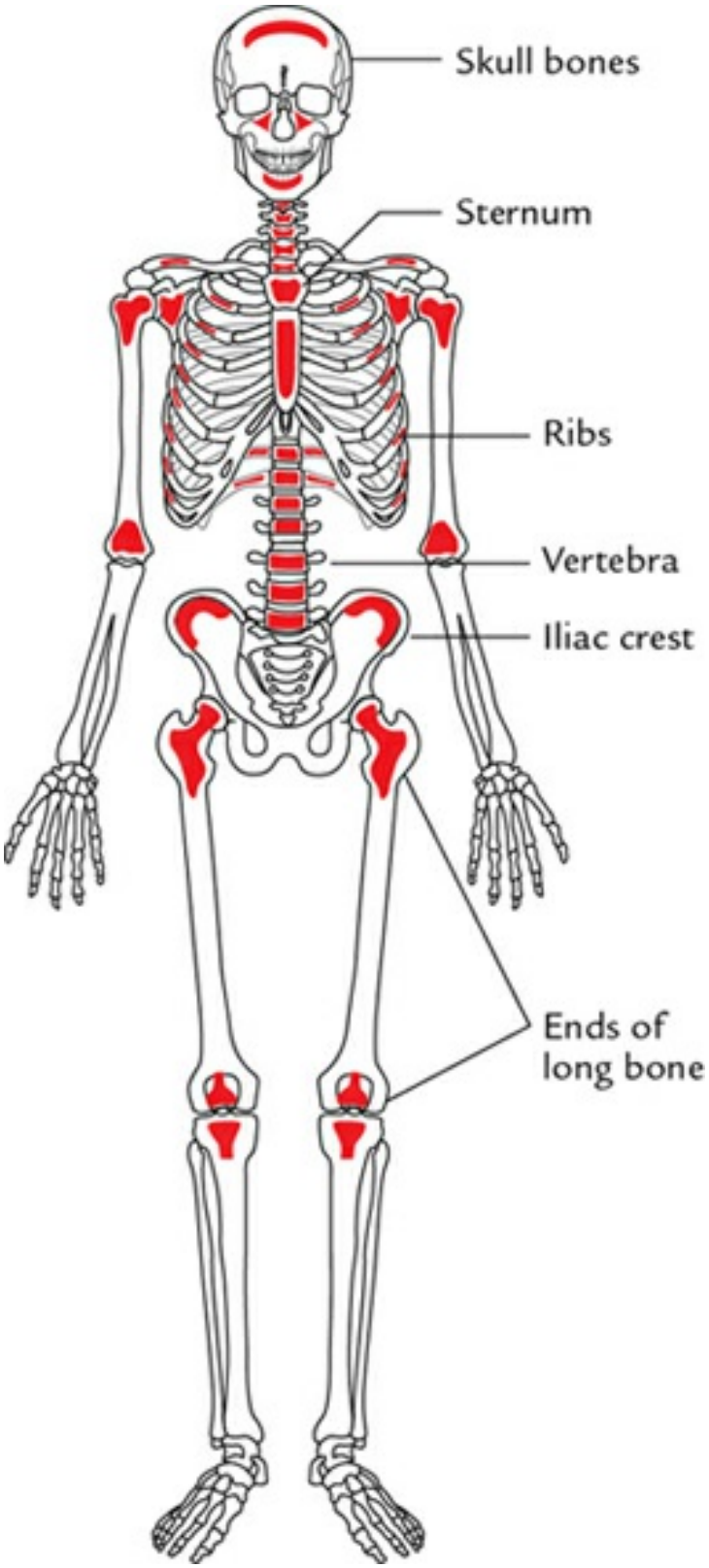


FIG. 6.7 ■ Sites of red bone marrow.

Clinical correlation

Bone marrow aspiration: It is often performed by clinicians for diagnostic

purposes. The sites commonly used for bone marrow aspiration are: the *sternum*, *anterior* and *posterior iliac spines of hip bones*, ribs, lumbar spinous processes and upper end of the tibia.

(a) *In the adult*, the *common sites of bone marrow aspiration* are the manubrium of the sternum and spinous processes of lumbar vertebrae.
(b) In the children, common sites of bone marrow aspiration are posterior parts of the iliac crests of hip bones.

Yellow bone marrow

It mainly consists of adipose tissue. However, few haemopoietic elements may be found in it. Under certain conditions, such as severe bleeding or hypoxia, yellow bone marrow converts back into the red bone marrow.

N.B.

In old age, sometimes the red marrow in the skull bones degenerates to produce jelly-like material (gelatinous mass). It is known as *gelatinous marrow*.

Parts of growing (young) long bone

A typical long bone develops from a preformed model of hyaline cartilage in three parts: two ends and an intervening shaft. The two ends are formed by secondary centres of ossification and the shaft is formed by the primary centre of ossification. Before the ossification is complete, the following parts can be defined in the young long bone (Fig. 6.8):

1. Epiphyses
2. Epiphyseal plates
3. Metaphyses
4. Diaphysis.

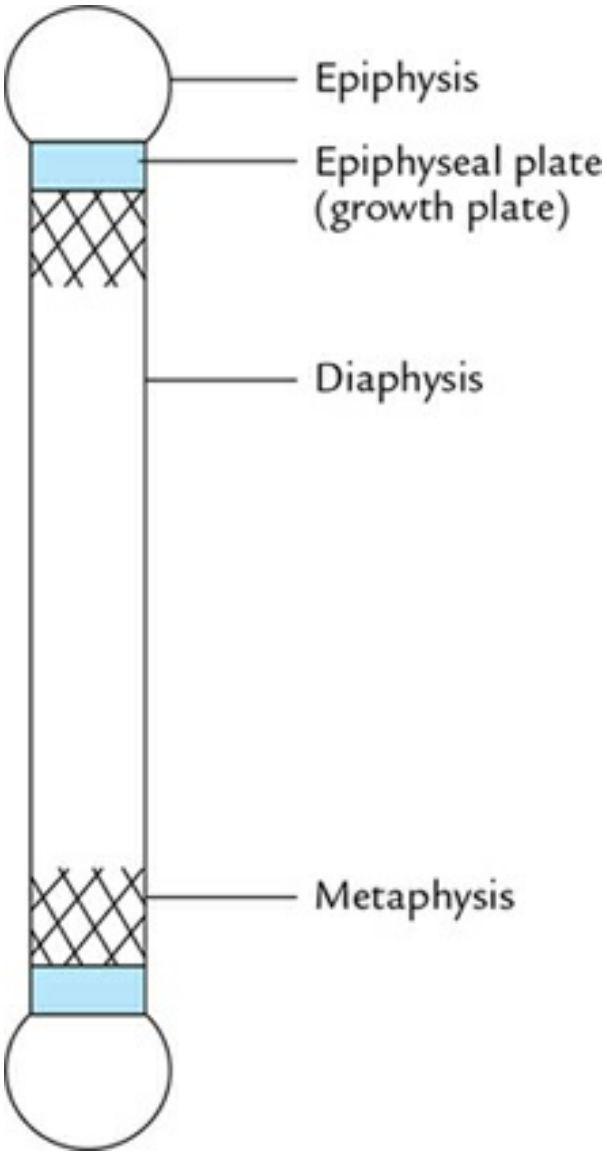


FIG. 6.8 ■ Parts of a growing long bone.

Epiphyses

These are ends of long bones that ossify from secondary centres.

Types of epiphyses

The epiphyses are of the following four types (Fig. 6.9):

1. **Pressure epiphysis (Fig 6.9A):** It is covered by articular cartilage and takes part in the transmission of body weight, for example, head of femur, humerus, lower end of radius, etc.
2. **Traction epiphysis (Fig 6.9A)**
   (a) It is produced by a pull of the muscle or muscles, for example,

greater and lesser trochanters of the femur, greater and lesser tubercles of the humerus.

(b) It is always nonarticular and provides attachment to the muscle or muscles.

(c) It always ossifies later than the pressure epiphysis.

3. **Aberrant epiphysis (Fig 6.9B):** It is an epiphysis that appears at the unusual end of a short long bone, for example, epiphysis at the head of the first metacarpal. Remember, normally epiphysis appears at the base of the first metacarpal bone.
4. **Atavistic epiphysis (Fig 6.9C, D):** It is an independent bone in lower mammals, which in man gets fused to the nearest bone to receive nutrition from the host bone. It grows like a parasite, for example, in the coracoid process of the scapula, the posterior tubercle of the talus which is also known as *os trigonum*.

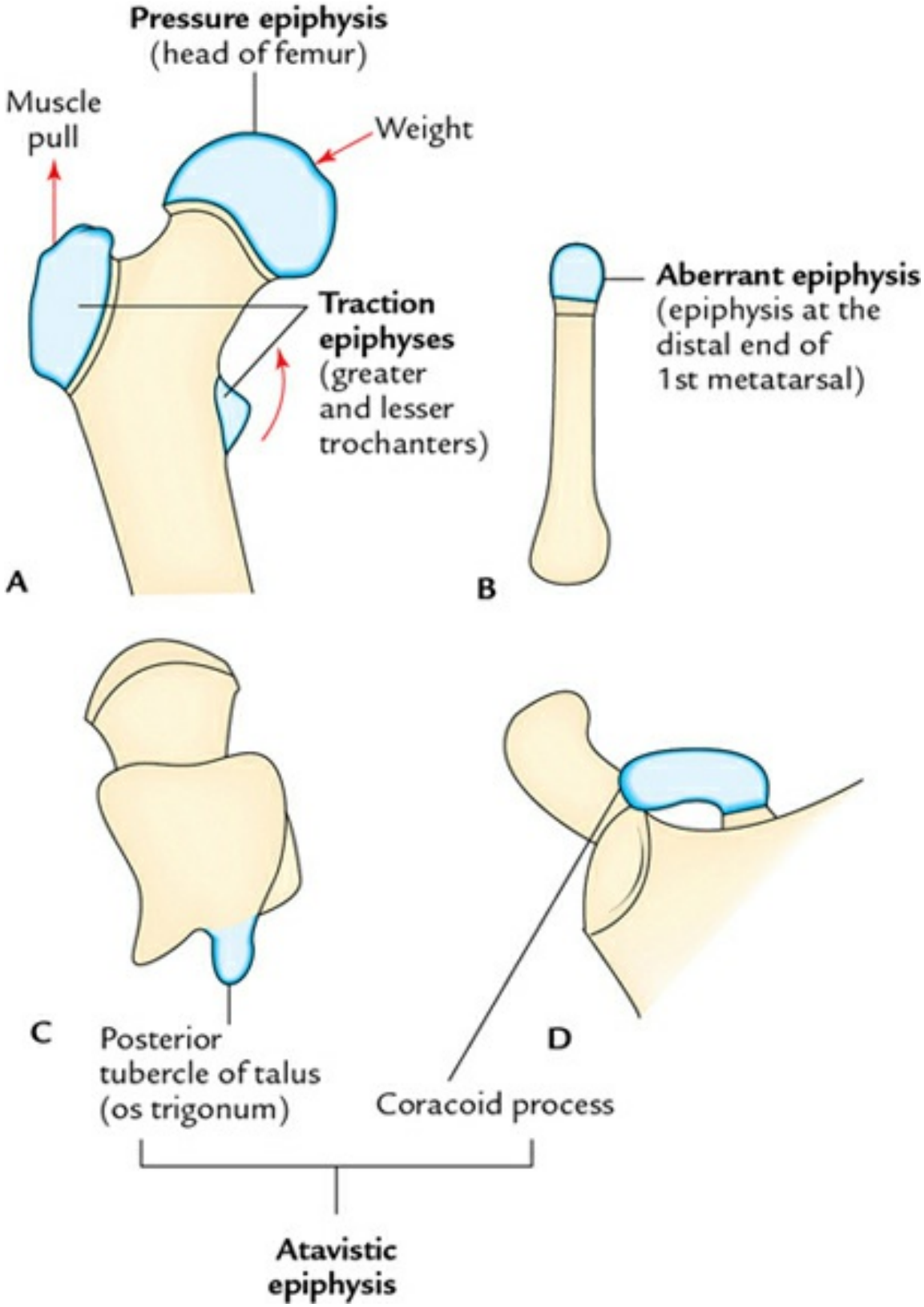


FIG. 6.9 ■ Types of epiphyses: **(A)** pressure and traction epiphyses; **(B)** aberrant epiphysis; **(C)** and **(D)** atavistic epiphysis.

Epiphyseal (growth) plate

It is a plate of hyaline cartilage which intervenes between the epiphysis and diaphysis of a growing long bone. The proliferation of cells in the epiphyseal cartilage is responsible for the growth in length of a long bone (for details see pages 79). After the fusion of epiphysis with diaphysis, the bone can no longer grow in length. The epiphyseal plate/cartilage is nourished by both epiphyseal and metaphyseal arteries.

N.B.

The fusion between epiphysis and diaphysis occurs 2 or 3 years earlier in females; hence, they are shorter in height than males.

Metaphysis

The end of diaphysis toward the epiphyseal cartilage is called metaphysis. It is the most actively growing area of a long bone. Before the fusion of epiphysis, the metaphysis is profusely supplied by blood from nutrient, periosteal and juxta-epiphyseal arteries. These are end arteries and form hairpin-like bends. Therefore, metaphysis is the common site of osteomyelitis in children for bacteria and emboli are easily trapped in the hairpin bends leading to infarction. After the epiphyseal fusion, the communications are established between the epiphyseal and metaphyseal arteries, as a result, metaphysis contains no more end arteries. For this reason, osteomyelitis in this region is rare in adults.

Diaphysis

It is the elongated part of bone between the metaphyses. It develops from the primary ossification centre.

Blood supply of bones AN2.1

1. **Blood supply of a growing long bone**: It is supplied by the following four sets of arteries: nutrient artery, periosteal arteries, metaphyseal arteries and epiphyseal arteries (Fig. 6.10).
   (a) *Nutrient artery*: It enters the middle of the shaft through a nutrient foramen, runs obliquely through the cortex, and then divides into ascending and descending branches in the medullary

cavity. Each branch then subdivides into several smaller parallel vessels which enter the metaphysis and form **hairpin loops**. These loops anastomose with epiphyseal, metaphyseal (juxta-epiphyseal) and periosteal arteries. Therefore, the metaphysis is the most vascular zone of the long bone.

The nutrient artery supplies the medullary cavity containing bone marrow and the inner two-thirds of the outer shell of compact bone of diaphysis and metaphysis.

N.B.

- The oblique direction of a nutrient foramen in the shaft is opposite to the growing end of the long bone.
- The nutrient artery is tortuous before entering the nutrient foramen so that it is not affected during the movements of the bone.
- The nutrient artery of the tibia is the largest nutrient artery of the body.

(b) *Periosteal arteries*: They are numerous and ramify beneath the periosteum. They enter the bone through Volkmann's canals to supply the outer one-third of the cortex. The periosteal vessels are especially numerous beneath the muscular and ligamentous attachments.

(c) *Metaphyseal (juxta-epiphyseal) arteries*: They are derived from neighbouring arteries and enter the metaphysis directly along with the attachment of the joint capsule.

(d) *Epiphyseal arteries*: They are derived from arterial anastomosis around the joint (*circulus vasculosus*). They enter the epiphysis either directly or after piercing the epiphyseal cartilage.

2. **Blood supply to short long bones**: To an extent, this supply is similar to that of a long bone *except* that:

(a) The nutrient artery enters the middle of the shaft and immediately divides to form a plexus.

(b) The periosteal vessels supply the major part of the bone in adults and replace the nutrient vessels.

Clinical correlation

- **Osteomyelitis:** It is an infection of the bone and commonly occurs in children. In typical growing long bones, infection occurs in the metaphyseal regions firstly because they are richly supplied with blood and secondly because the blood supply in the metaphyses is through end arteries forming *hairpin bends*. Therefore, the bacteria and emboli are easily trapped in these hairpin bends, leading to infarction (necrosis) of bone, resulting in a clinical condition called *osteomyelitis*. In short long bones, the infection begins in the middle of the shaft because the nutrient artery enters the middle of the shaft and immediately divides to form the plexus.
- The blood supply of bone is so rich that the passing of a metal pin cannot interrupt the blood supply sufficiently to kill the bone.

3. **Blood supply of a vertebra**: It is supplied by three sets of vessels:
   (a) One or more large but short vessels enter the body from its posterior aspect through the *basivertebral foramen*.
   (b) A set of small vessels pierce the anterolateral surface of the body.
   (c) A set of long vessels pierce the root of the transverse processes and supply the vertebral arch and transverse and spinous processes.
4. **Blood supply of a rib**: It is supplied by two sets of vessels:
   (a) The nutrient artery which enters it just behind the tubercle.
   (b) The periosteal arteries.

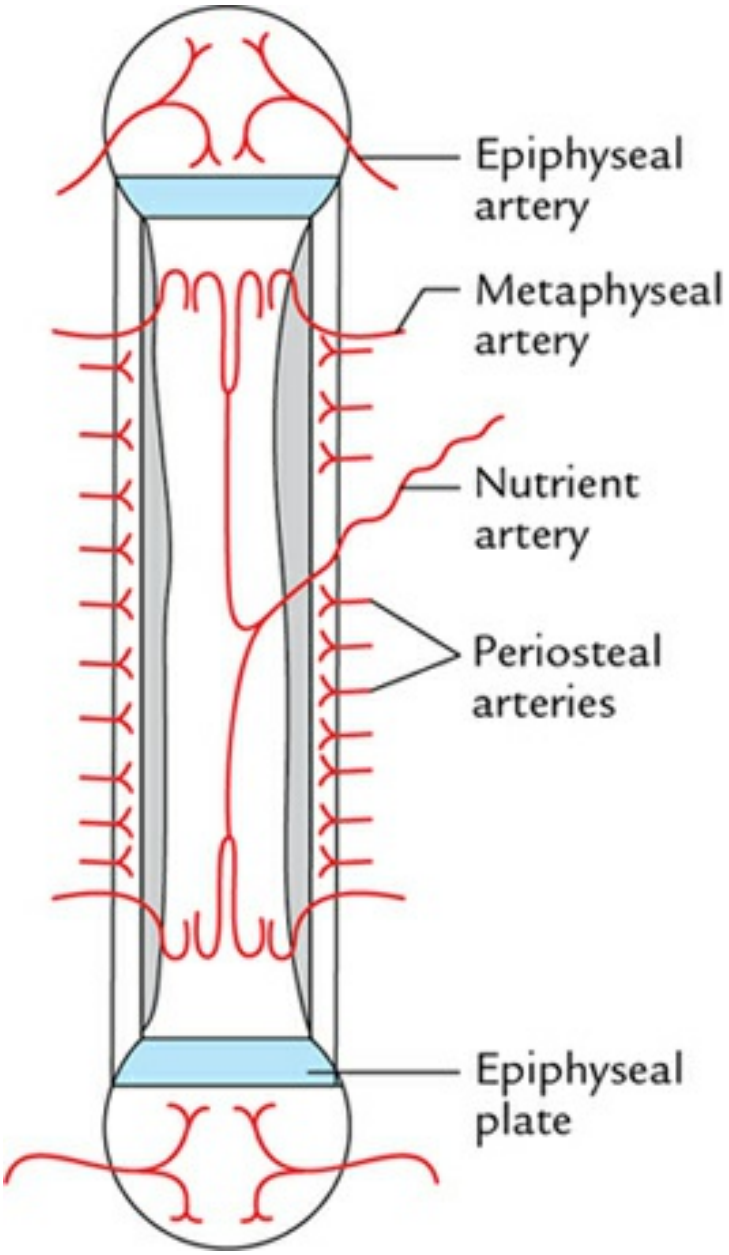


FIG. 6.10 ■ Blood supply to a growing long bone.

N.B.

- The veins are numerous in cancellous bones; for example, in the vertebrae, they join to form a large *basivertebral vein*. In the compact bone, they accompany the arteries in the Volkmann's canals.
- There are no lymphatics in the bone; however, some lymph vessels do accompany the periosteal blood vessels and drain into the regional lymph nodes.

Clinical correlation

Fracture of bone

The fracture is a break in the continuity of the bone. It is the most common type of bone injury. Fracture mostly occurs due to trauma (**traumatic fractures**); however, they may occur spontaneously due to disease that weakens the bone (**spontaneous** or **pathological fractures**).

Classification of fractures

A fracture may be simple or compound.

1. **Simple or closed fracture**: the fractured bone is not exposed to the exterior through the skin.
2. **Compound fracture**: the fractured bone is exposed to the exterior through an opening in the skin.

The fractures can also be classified on the basis of fracture line/lines as under:

1. **Transverse fracture**, when the fracture line is perpendicular to the shaft of the bone.
2. **Oblique fracture**, when the fracture line is on an angle through the bone.
3. **Spiral fracture**, when fracture line is spirally placed
4. **Comminuted fracture**, when the bone breaks into several pieces.

When a bone fractures, the treatment involves realigning the broken ends and then immobilizing them until the fracture is healed (repaired).

Repair of a fractured bone

It involves the following steps:

1. When bone is fractured, the blood collects and coagulates to form **fracture haematoma** in and around the fracture site.
2. After 2 or 3 days, new blood capillaries and uncommitted cells (fibroblasts, macrophages) from the surrounding tissue invade the haematoma to form **granulation tissue**.
3. After 1 week, some of the uncommitted cells differentiate into fibroblasts, which produce a fibrous network between fractured ends.

The other cells differentiate into chondroblasts, which produce islets of fibrocartilage in the fibrous network forming a **fibrocartilage callus (temporary callus)**.

4. The **osteoprogenitor cells** in the periosteum and endosteum around the fracture site proliferate and differentiate into the bone-forming cells, the **osteoblasts**, which invade the temporary callus and lay down the woven bone (primary bone tissue or osteoid) which unites the extremities of the fractured bone. It is called **bony callus**.
5. The **primary bone tissue** of the callus is gradually replaced by a **secondary bone** (mature bone).
6. **Remodelling** takes place and restores the original bone structure.

Figure 6.11 depicts the repair of a fractured bone.

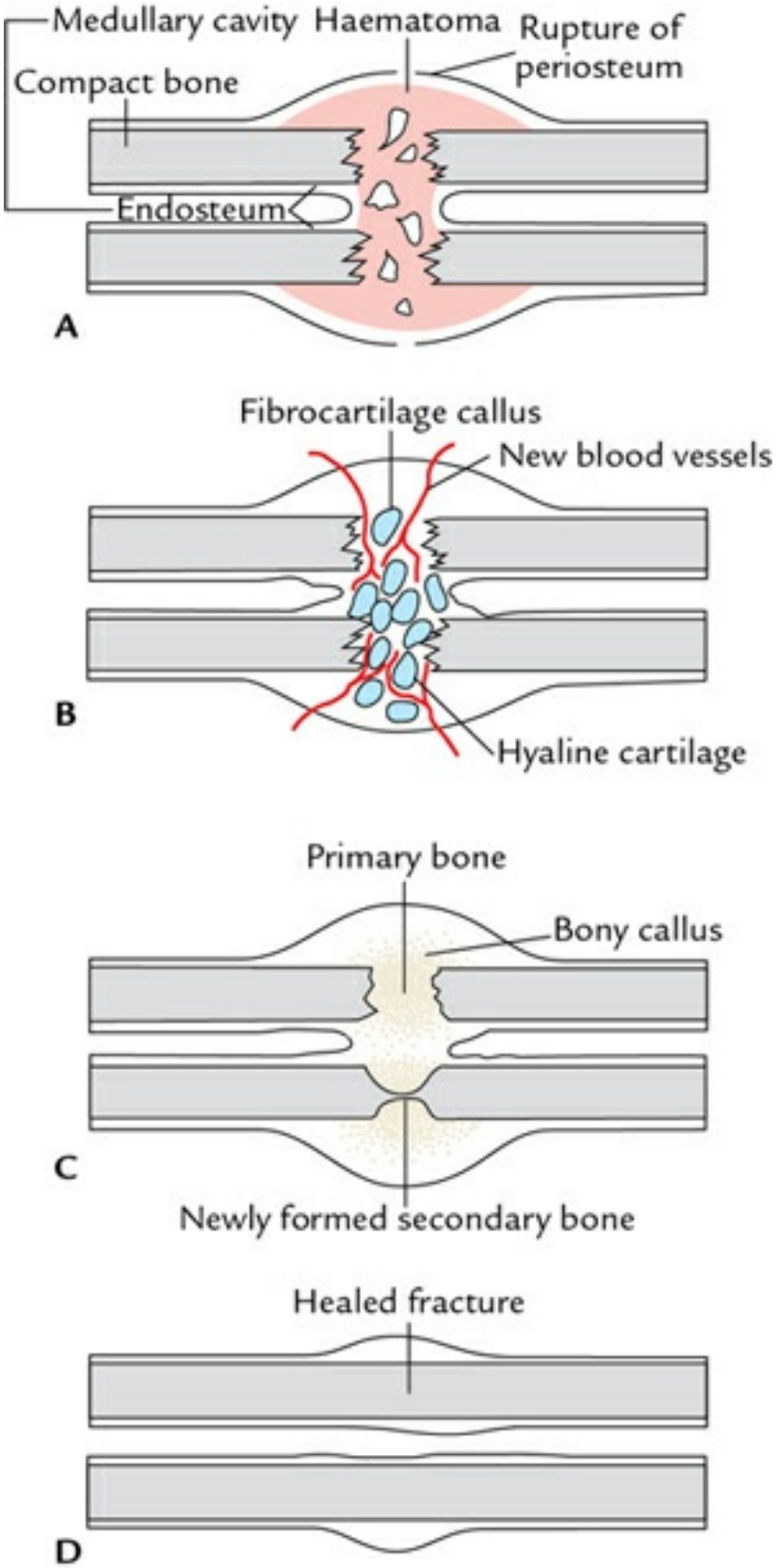


FIG. 6.11 ■ Repair of a fractured bone: **(A)** bone fracture with the formation of haematoma; **(B)** formation of fibrocartilage callus; **(C)** formation of bony callus and **(D)** healed fracture.

Development/ossification of bones

All the bones develop from mesenchyme by a process called ossification.

As stated, it is the process of bone formation.

Laws of ossification AN 2.2

These are:

- The *primary centes of ossification* is single and appears before birth (exception, carpal bones)
- *The secondary centres of ossification* appear after birth (exception, lower end of the femur)
- *The centre of ossification* which appears first, fuse last (exception, lower end of fibula).

Types of ossification

There are two types of ossifications:

1. Intramembranous ossification.
2. Intracartilaginous (endochondral) ossification.

In intramembrane ossification, mesenchymal models of bones undergo ossification, while in intracartilaginous ossification, cartilaginous models of bones undergo ossification. The details are as under:

Intramembranous ossification

It involves the following steps:

Step 1: Mesenchymal tissue condenses to form a membranous sheet—mesenchymal *model*. Osteoprogenitor cells located in this sheet differentiate into osteoblasts. The sites where the osteoblasts first appear are called ossification centres.

Step 2: Osteoblasts secrete an organic substance (ground substance and collagen fibres) in the intercellular spaces to form osteoid tissue or bone matrix.

Step 3: Under the influence of alkaline phosphatase secreted by

osteoblasts, the osteoid tissue is mineralized with calcium salts to become bone. The osteoblasts now become trapped in a mineralized matrix and are called *osteocytes*.

The intramembranous ossification is shown in Figure 6.12. Bones formed by the intramembranous ossification include *flat bones of the skull*, viz. frontal, parietal, occipital, *clavicle*, etc.

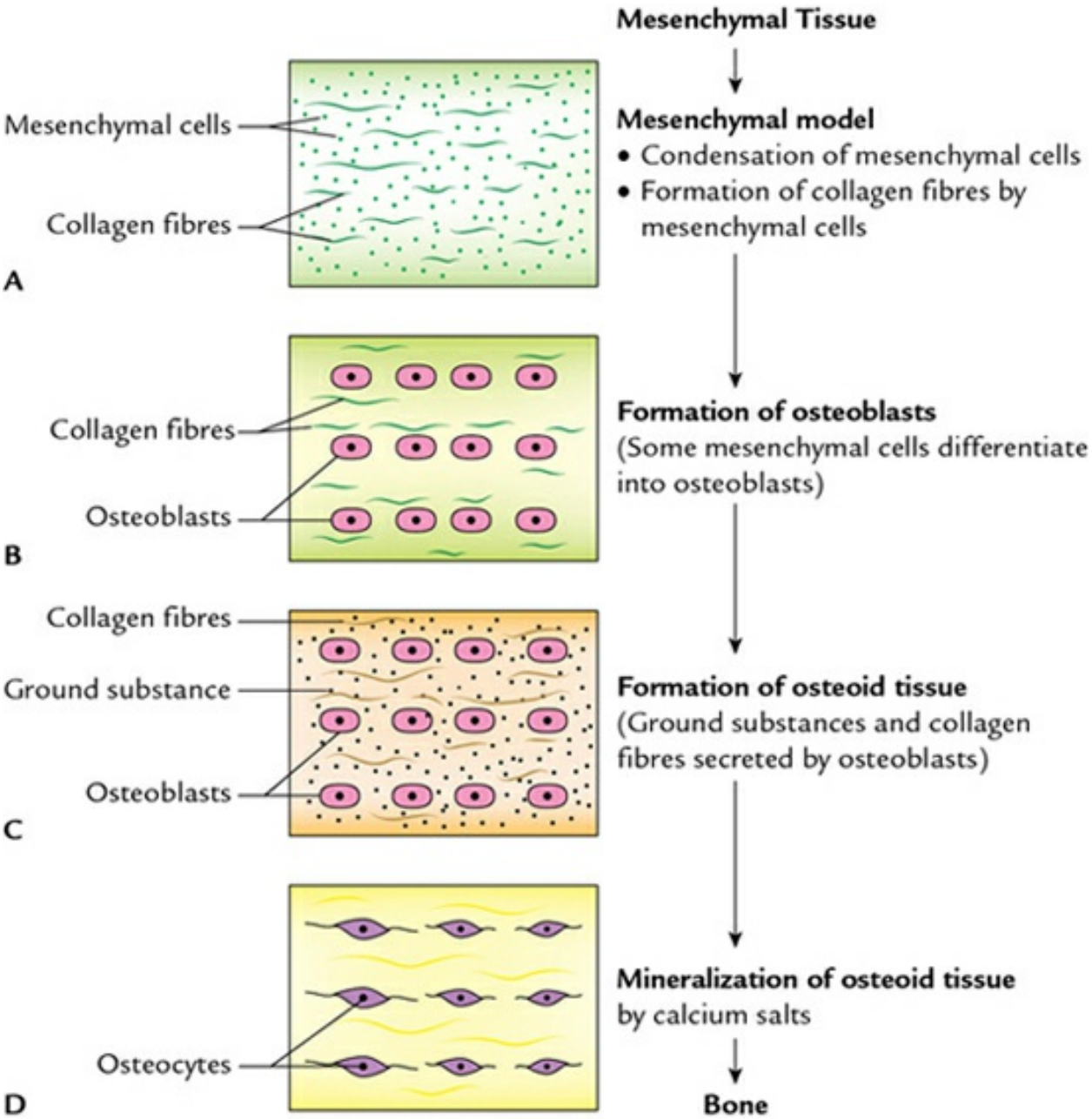


FIG. 6.12 ■ Steps of intramembranous ossification. (Source: Fig. 8.1, Page 85, Textbook of Clinical Embryology , Vishram Singh. Copyright Elsevier 2017, All rights reserved.)

Clinical correlation

Cleidocranial dysostosis: It is a congenital condition presenting the following features:

(a) Complete or partial absence of clavicles.
(b) Defective development of cranial vault with large fontanelles and delayed closing of the sutures. This condition occurs due to defective intramembranous ossification.

Intracartilaginous (endochondral) ossification

The intracartilaginous ossification is more complicated, but clinically more important because all the long bones of limbs (and many others) are ossified by this process.

It involves the following six steps (Fig. 6.13):

Step 1: The cartilage cells (chondroblasts) of the cartilaginous model enlarge and the matrix surrounding them is calcified under the influence of alkaline phosphatase secreted by cartilage cells.
Step 2: The cartilage cells die and disappear leaving behind empty spaces called *primary areolae*.
Step 3: The cells on the surface of the periosteum differentiate into osteoblasts which enter at the site of ossification along with blood vessels (*periosteal bud*).
Step 4: The most of calcified matrix is absorbed forming large empty spaces called *secondary areolae*, leaving behind only thin bars of a calcified matrix.
Step 5: The new bone (osteoid) is laid down on the surface of calcified bars of the matrix.
Step 6: The mineralization of osteoid.

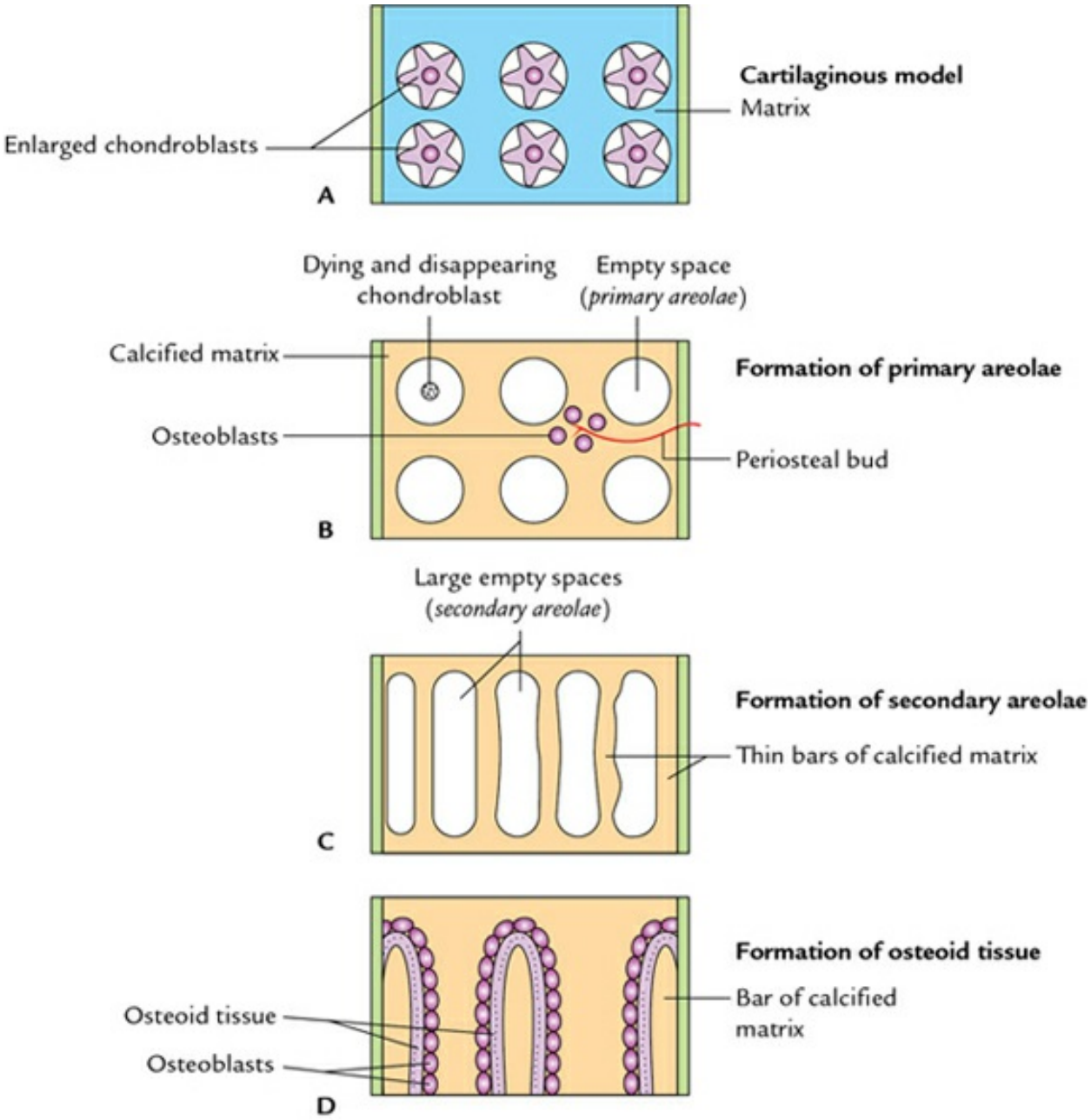


FIG. 6.13 ■ Steps of intracartilaginous ossification (**A-D**). (Source: Fig. 8.2, Page 86, Textbook of Clinical Embryology , Vishram Singh. Copyright Elsevier 2017, All rights reserved.)

Ossification of a long bone

The following is a simplified account of the intracartilaginous ossification of a long bone (Fig. 6.14).

Step 1: First the bone is laid down as a hyaline cartilaginous model surrounded by perichondrium.

Step 2: A **primary centre of ossification** then appears in the centre of the shaft and this spreads toward the ends to form the diaphysis.
Step 3: At the same time, the periosteum lays down a **collar of bone** (periosteal collar) around the circumference of the shaft.
Step 4: Later, one or more **secondary centres of ossification** develop at each end of the cartilaginous model and form the epiphysis.
Step 5: The **epiphyseal cartilage** separating epiphysis from diaphysis and articular cartilage at each end of bone remains cartilaginous.
Step 6: The epiphyseal plate of cartilage continues to produce new cartilage and thus enables the bone to grow in length. For this reason, the epiphyseal plate of cartilage is also called the **growth plate**. Once the growth in length is completed, remaining epiphyseal cartilage ceases to proliferate and becomes ossified leaving only an epiphyseal scar called the **epiphyseal line**.

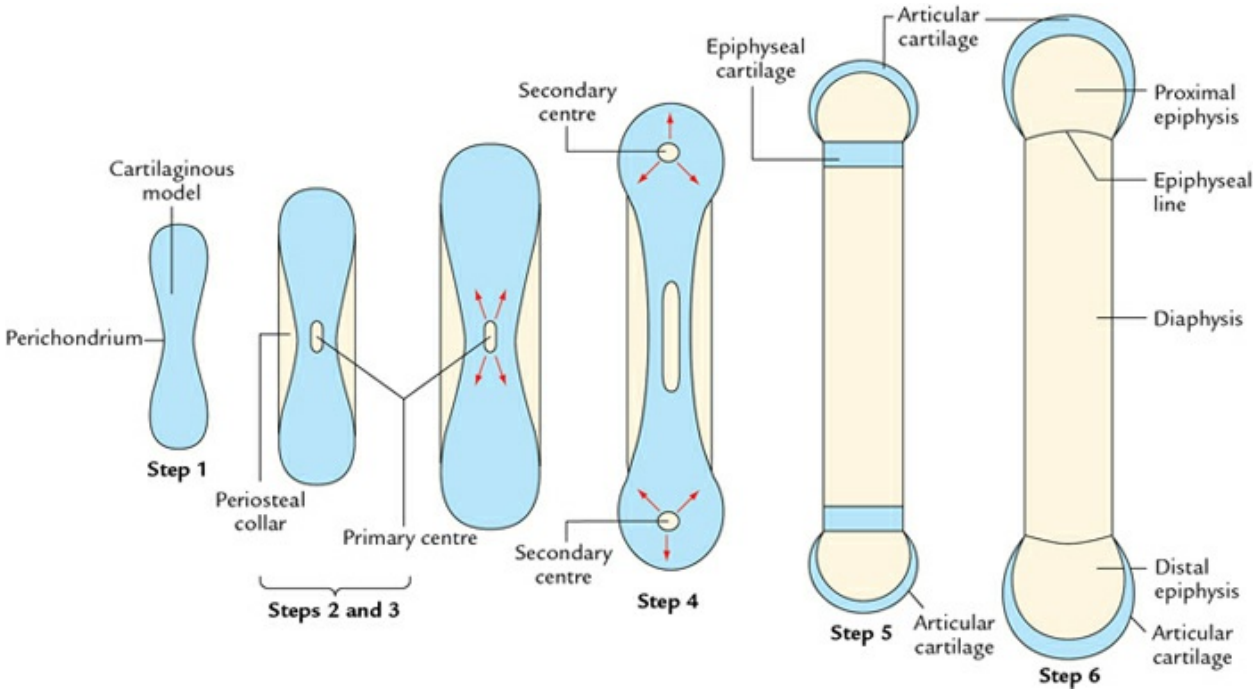


FIG. 6.14 ■ Ossification of a long bone.

Ossification centres

These are sites where bone formation begins. The ossification centres are generally classified into two types: primary and secondary.

1. **Primary centres of ossification**, appear before birth (usually between

7th to 12th week) with some exceptions (viz. primary centres of tarsal and carpal bones appear after birth except those of talus, calcaneum and cuboid).

2. **Secondary centres of ossification**, appear as a rule after birth (usually from the time of birth to 5 years of age).

A primary centre forms diaphysis, and the secondary centre form epiphyses. The fusion of epiphysis with the diaphysis starts at puberty and is usually complete by the age of 25 years, therefore after the age of 25 years, no more bone growth can take place.

In general, the appearance of secondary centres and fusion of epiphyses occur about 1 year earlier in females than in males.

N.B.

All the secondary centres appear after birth except the one at the lower end of the femur which appears in the 9th month of intrauterine life and sometimes at the upper end of the tibia and humerus.

Clinical correlation

- **Clinical significance of the visibility of centre of ossification in the distal end of the femur in radiograph of newborn child found dead:** It is of great medicolegal importance because it indicates that the child was full-term (Fig. 6.15). In radiograph of newborns, the shaft of long bone presents a white (radiopaque) shadow, whereas ends and joints cast a black (radiolucent) shadow. This is because at birth the shaft of the cartilaginous model is ossified, that is bony, but the ends are still unossified, which is cartilaginous.
- On the other hand in radiograph of growing children, the shaft and epiphyses cast a white (radiopaque) shadow but the epiphyseal plate between the epiphysis and diaphysis casts a black (radiolucent) shadow.
- **Achondroplasia (dwarfism):** It is a congenital condition with the following clinical features:
  - The individual is abnormally short (dwarf).
  - Disproportionately shorter limbs than the trunk.
  - Dorsal kyphosis and lumbar lordosis.

This condition occurs due to defective endochondral ossification.

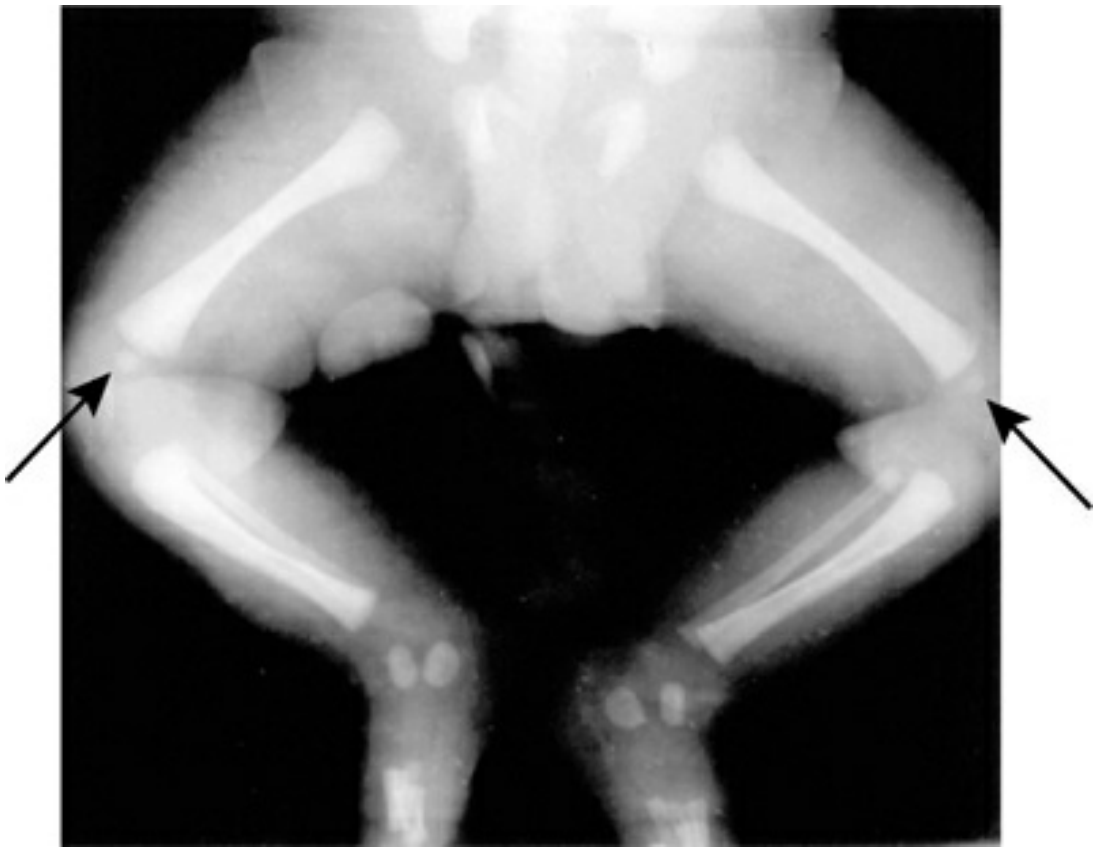


FIG. 6.15 ■ Radiograph of a full-term child showing the secondary centre of ossification at the distal end of the long bone (arrow). (Source: Fig. 7.1, Page 147, Textbook of Forensic Medicine and Toxicology , 5th Edition, Krishan Vij, Copyright Elsevier 2011. All rights reserved.)

Growing end of the long bone

In most of the long bones, the two epiphyses do not fuse simultaneously. The epiphysis at one end always fuses a few years before than at the other end.

The end at which fusion occurs later is called the **growing end** and this is also the end at which the secondary centre of ossification appears first.

The growing end is always located opposite the direction of the nutrient foramen.

The direction of the nutrient foramen is easily remembered by a '*dictum*' that says, '**To the elbow, I go and from knee, I flee**'.

In the milking cow position, the direction of nutrient foramina is always downward (Fig. 6.16).

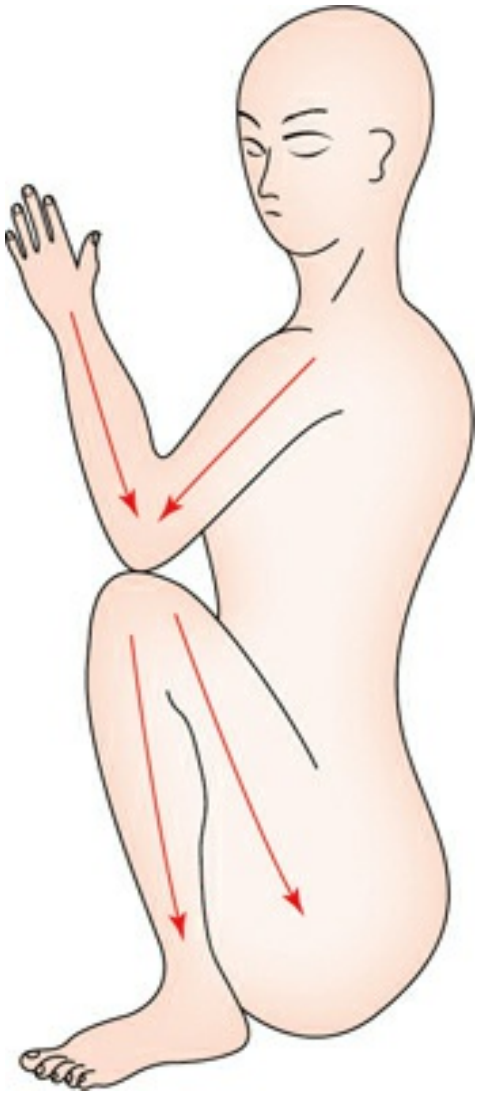


FIG. 6.16 ■ The direction of nutrient foramina (red arrows) as seen in milking cow position.

Thus in the upper limb, the shoulder end of the humerus and wrist ends of the ulna and radius are growing ends, whereas, in the lower limb, the knee ends of the femur, tibia and fibula are growing ends.

N.B.

- The nutrient foramen in the shaft of all long bones is always directed opposite to the growing end *except* that in the shaft of the fibula which is directed toward the growing end.
- The direction of the nutrient artery is opposite to the direction of the growing end of the long bone.

Law of union of epiphyses (law of ossification AN2.2

According to this law, the epiphyseal centre (secondary centre of ossification) which appears first unites last and the epiphyseal centre which appears later unites first *except* in the case of the fibula where the epiphyseal centre for the lower end appears first and also unites first. On the other hand, the epiphyseal centre for the upper end appears late and also unites late (Fig. 6.17). Thus, fibula is the only long bone which violates the law of the union of epiphyses.

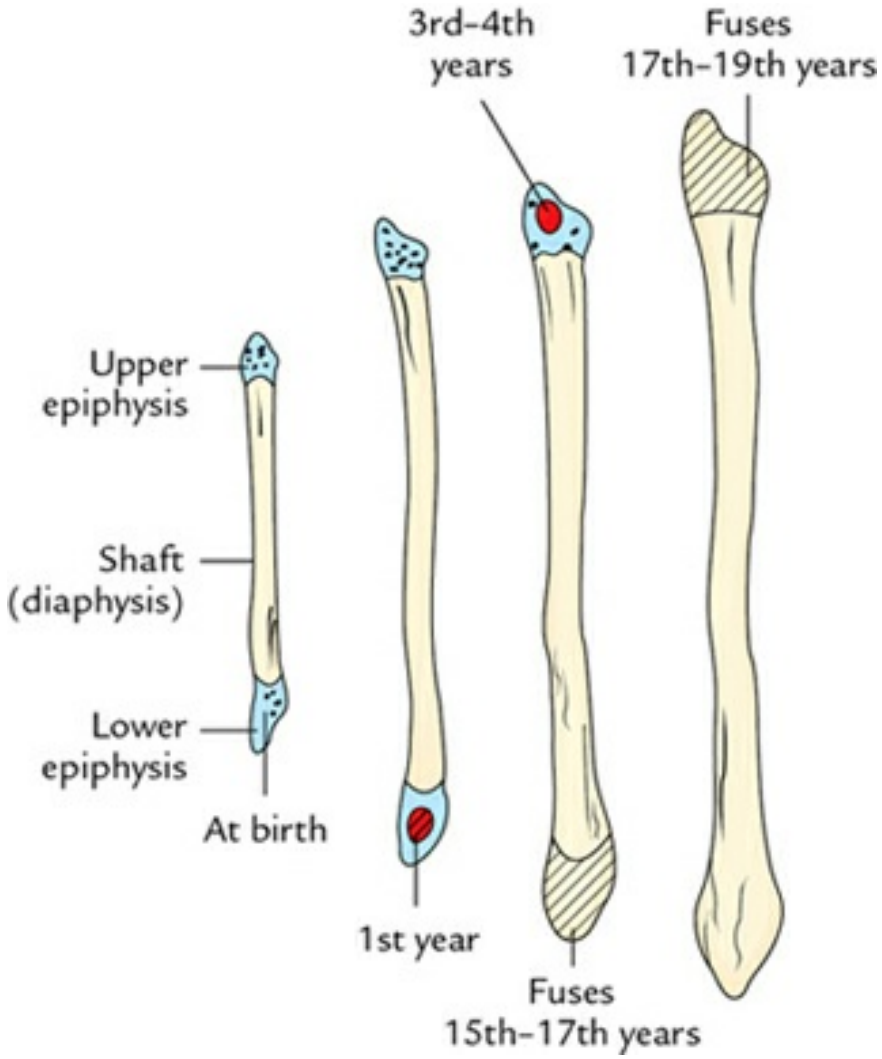


FIG. 6.17 ■ Violation of the law of union of epiphyses by the fibula.

Growth of a long bone

The growth of long bone after birth occurs by two methods:

1. Appositional growth
2. Endochondral growth.

N.B.

The bones cannot grow by an interstitial growth like tendons, ligaments and cartilage.

Appositional growth

The appositional growth refers to the addition, that is, growth at the periphery of the bones resulting in an increase in the diameter of the long bones.

In appositional growth, the osteoblasts on the surface of bones proliferate. The superficial osteoblasts produced from these divisions remain as such or divide again. The deep osteoblasts resulting from these divisions produce bone matrix, and when they are surrounded by matrix, they become **osteocytes**. Consequently, a new layer of bone is deposited on the surface of the bone.

In cancellous bone, appositional growth adds bone matrix to the outer surface of trabeculae.

Endochondral growth

The endochondral growth is responsible for the increase in the length of long bones.

The endochondral growth occurs due to the multiplication of the cells of the epiphyseal plate of cartilage.

The surface of the epiphyseal plate facing toward the epiphysis gives rise to new cartilage which pushes the epiphysis away from the diaphysis.

The amount of new cartilage produced is equal to the amount of cartilage replaced by spongy bone toward the metaphyseal surface of the epiphyseal plate leading to an increase in the length of the diaphysis. The thickness of the epiphyseal plate remains almost the same. The details are as under:

The epiphyseal plate is organized into four zones (Fig. 6.18); from superficial to deep these are:

1. Zone of resting cartilage

2. Zone of proliferation
3. Zone of hypertrophy
4. Zone of calcification.

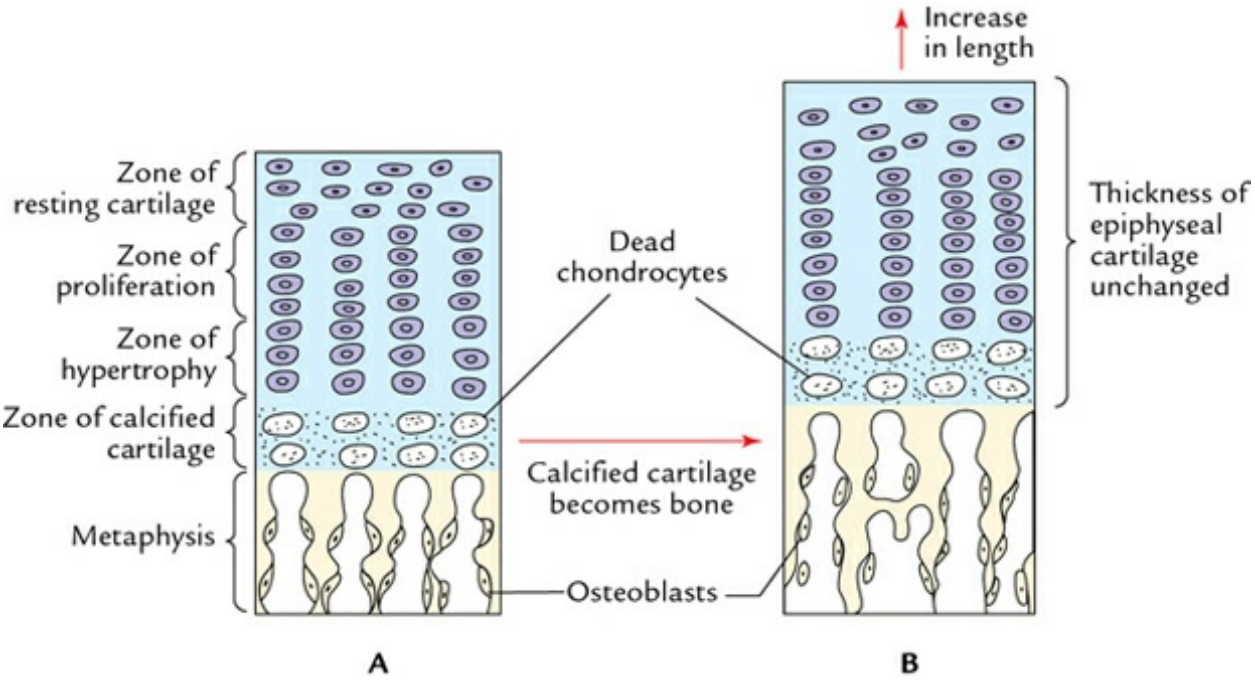


FIG. 6.18 ■ Growth of bone—lengthwise: **(A)** four zones of epiphyseal cartilage and **(B)** conversion of calcified cartilage into bone.

The **zone of resting cartilage** is nearest to the epiphysis and contains randomly arranged chondrocytes that do not divide rapidly.

In the **zone of proliferation**, the chondrocytes proliferate and form longitudinal columns of young cartilage cells resembling stacks of plates or coins.

In the **zone of hypertrophy**, the chondrocytes mature and hypertrophy. They secrete alkaline phosphatase.

Thus, a maturation gradient exists in each column of chondrocytes. The cells near the zone of resting cartilage are younger and actively proliferating, whereas cells progressively near the diaphysis are older and are undergoing hypertrophy.

The **zone of calcification** is very thin. It consists of a matrix mineralized with calcium carbonate. When the hypertrophied chondrocytes die, the blood vessels from diaphysis grow into this area. The connective tissue surrounding the blood vessels contains osteoblasts from the endosteum. The

osteoblasts line up on the surface of the calcified cartilage and deposit bone.

Clinical correlation

Growth in height: The epiphyseal (growth) plates of long bones of upper and lower limbs are responsible for the growth in height of an individual. Once the epiphyses unite with diaphyses, the growth in height stops.

The sex hormones stimulate the ossification of epiphyseal plates leading to the union of the epiphysis with diaphysis. In females, oestrogen causes early closure of epiphyses with diaphysis as compared to that of testosterone. Consequently, females usually do not reach the same height as males.

The damage to the epiphyseal plate at the growing end of long bones of limbs of growing children will lead to the shortening of the limb because the damage of the epiphyseal plate interferes with the elongation of that bone.

Remodelling of bone

The bone does not grow by multiplication of its cells or by an increase in its intercellular material (i.e. interstitial growth), hence its shape cannot be maintained.

The bone grows by deposition of new bone by osteoblasts on its ends and on its surface in a random fashion. Therefore, to maintain its shape, the unwanted bone is removed by osteoclasts. This process of bone removal is called **remodelling**.

Surface remodelling

As the bone grows in length, there occurs subperiosteal bone deposition in the shaft while subperiosteal bone resorption occurs in the conical region towards the end. Thus diverging regions are straightened to become the part of the shaft (Fig. 6.19).

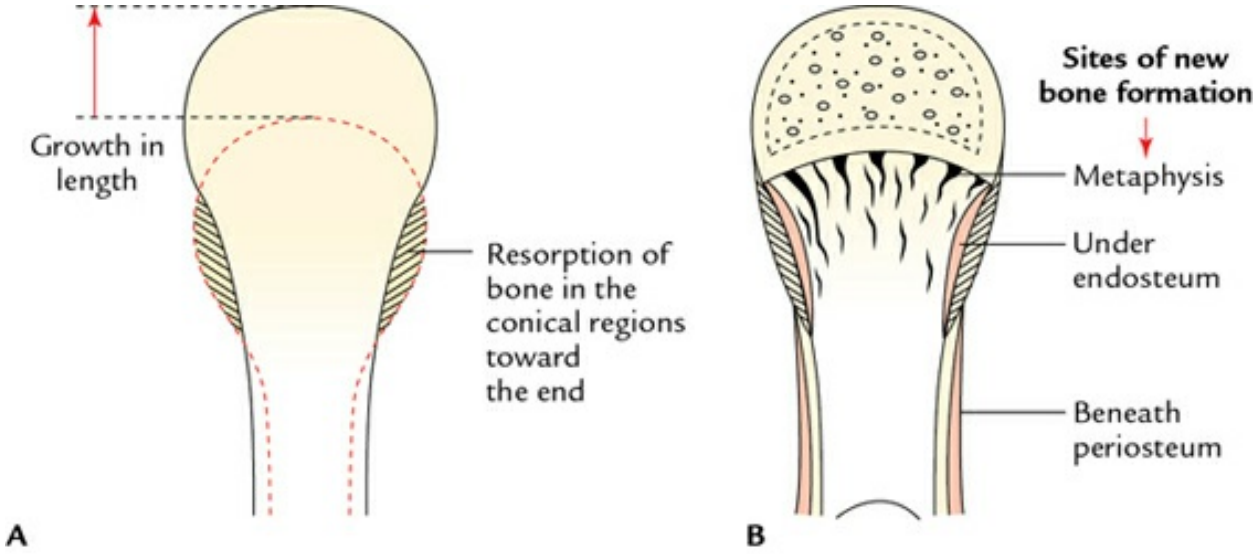


FIG. 6.19 ■ Remodelling of bone: **(A)** as the long bone grows, the sites once occupied by expanded ends become part of a slender shaft and **(B)** sites of new bone deposition (black areas).

Internal remodelling

As the bone grows in diameter by deposition of new layers of bone deep to the periosteum, the periosteal bone becomes thicker and thicker which is neither necessary nor desirable. Hence as the bone is laid down outside the shaft, it is removed from inside by osteoclasts. Consequently, the shaft grows in diameter, and at the same time, its wall does not become too thick.

The osteoclasts also remove trabeculae in the centre of bone that was formed by endochondral ossification. This leads to the formation of **marrow cavity**.

N.B.

Remodelling of developing bone is done by: (a) deposition of bone by osteoblasts and (b) selective absorption of bone by osteoclasts.

Clinical correlation

Paget's disease: Normally the bone is continuously removed and repaired (replaced) by a new bone throughout life. In *Paget's disease* (osteitis deformans) which occurs in later life, there is uncontrolled osteoclast activity causing widespread bone resorption which is followed by hectic osteoblastic activity producing woven bone (osteoid) that fills the erosion but the repair stops at the osteoid stage. As a result, the healthy mature

bone is gradually replaced by thick, bulky, weak osteoid bone. Consequently, in individuals suffering from Paget's disease, the bones are thick and bent, especially the femora, tibiae and spine. The skull is enlarged and thick, the spine is bent forward (kyphosis).

Factors affecting the growth of bones

1. Nutritional factors:
   (a) Vitamin A coordinates the activity of osteoblasts and osteoclasts. The deficiency of vitamin A slows down the activity of osteoclasts. Consequently, the size of spinal and cranial foramina is reduced, with eventual compression of nerve roots. On the other hand, high concentration of vitamin A causes rarefaction and resorption of bone.
   (b) Vitamin C is essential for the synthesis of the organic intercellular matrix (i.e. collagenous fibres and ground substance) by osteoblasts. The deficiency of vitamin A leads to defective development of growing ends of the bone. It also leads to rupture of capillaries producing painful subperiosteal haematoma.
   (c) Vitamin D is essential for the absorption of calcium and phosphate from the intestine. The deficiency of vitamin D leads to defective mineralization (calcification) of osteoid tissue. As a result, children suffer from **rickets** (characterized by bowing of legs, knobby metaphyseal regions); and adults suffer from **osteomalacia** (i.e. softening of the bones).
2. **Hormonal factors**: The hormones play a very important role in bone growth. The hormones which are essential for the proper development and growth of bone include pituitary hormones, thyroid hormones, parathyroid hormones and sex hormones. Their defective secretion can cause a number of skeletal defects.
3. **Genetic factors**: A clinical condition **chondrodystrophia foetalis** occurs due to defective autosomal dominant inheritance. In this condition, endochondral ossification fails to occur properly.
4. **Mechanical factors**: Tensile force helps in bone formation whereas compressive forces favour bone resorption. In practice, orthopaedic surgeons provide traction for quick healing of fractures.

Cartilages AN2.4

The cartilage is an avascular specialized scleral connective tissue, which provides rigidity and elasticity to the skeleton of the body. Hence it is found in those areas of the body, where both rigidity and elasticity are required. It consists of chondrocytes embedded in a gel-like matrix.

Phylogenetically, the cartilage tissue is older than bone tissue. Most of the bones in the intrauterine life are preformed in cartilage. The cartilages which are replaced by bones are called **temporary cartilages** and those that persist throughout life are called **permanent cartilages**.

Functions of a Cartilage

The following are the functions of the cartilage:

1. Provides rigidity and support to soft tissues.
2. Provides a smooth gliding surface for articulation.
3. Enables the development and growth of long bones.

N.B.

Both bone and cartilage are specialized connective tissue, but the basic difference between the two is that in the bone matrix it is mineralized while in cartilage it is not mineralized.

Structure

The cartilage has all common features of connective tissue, which include the following:

1. Cells
2. Fibres
3. Ground substance.

1. ***Cells***

   Cells of the cartilage are of the following three types:

   (a) **Chondrogenic cells**: found in the perichondrium, where they undergo mitosis and differentiate into chondroblasts.

   (b) **Chondroblasts**: young cartilage cells occupying small spaces (lacunae) and may undergo mitosis.

(c) **Chondrocytes**: mature cartilage cells which reside in lacunae. They form isogenous cell clustres surrounded by a territorial matrix.

2. ***Fibres***

Cartilage has the following two types of fibres:

(a) **Type I collagen fibres** in fibrocartilage.

(b) **Type II collagen fibres** in hyaline and elastic cartilages.

3. ***Ground substance***

It consists of:

(a) **Proteoglycans**, specifically chondroitin sulphate and keratan sulphate.

(b) **Glycoproteins**, viz. chondronectin and chondrocalcin (a calcium-binding protein).

(c) **Water (tissue fluid)** contributes to 75% hydration of the ground substance (high degree of hydration).

N.B.

There is no mineral (inorganic) component in the ground substance of cartilage because it is not mineralized.

Perichondrium

The cartilages are usually covered externally by a vascular connective tissue membrane called **perichondrium** (cf periosteum covering bones).

It is made up of two layers (Fig. 6.20):

(a) Outer fibrous layer

(b) Inner chondrogenic layer.

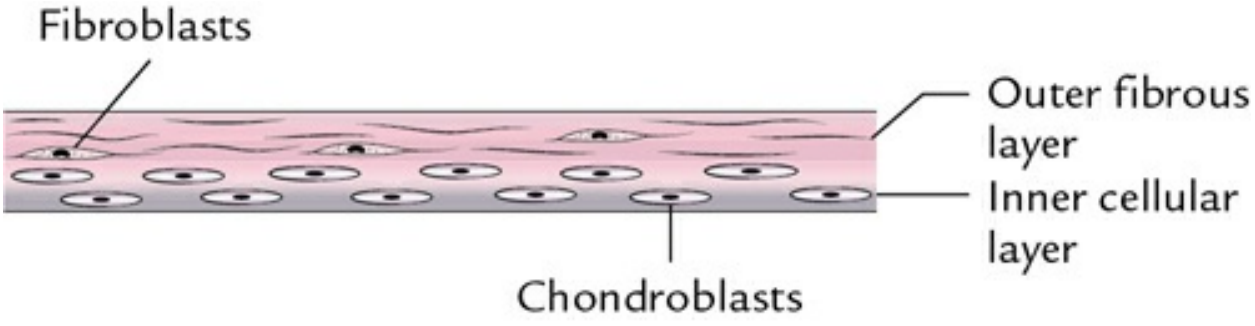


FIG. 6.20 ■ Structure of perichondrium.

Growth of cartilage

The cartilage grows by both appositional and interstitial methods.

1. **Appositional growth**: In this, layers of new cartilage are deposited at the surface beneath the perichondrium. The new cartilage is formed by chondroblasts derived from perichondrium. By appositional growth, the cartilage increases in width.
2. **Interstitial growth**: It occurs due to an increase in size and the number of existing cells and by an increase in the amount of intercellular matrix, due to proliferation of chondrocytes by mitosis in the centre of the cartilaginous model. By interstitial growth, the cartilage increases in length.

N.B.

Adult cartilage grows and repairs slowly, after a severe injury.

Characteristic features of cartilage

The characteristic features of cartilage are as follows:

1. It is **avascular** and receives its nutrition by diffusion through the ground substance from the nearest capillaries. Here thin **cartilage canals** provide nutrition to the deepest core of the cartilaginous mass.
2. It has no lymphatics.
3. It has **no nerves;** hence, it is insensitive.
4. It is usually surrounded by perichondrium, a highly vascular membrane of connective tissue.
5. It grows by appositional as well as by interstitial methods of growth.
6. **When cartilage calcifies, chondrocytes die** because they are deprived of nutrition by diffusion.

N.B.

The articular cartilages and fibrocartilages are devoid of the perichondrium.

Clinical correlation

- **Cartilage graft**: The cartilage has low antigenicity due to lack of lymphatics and isolation of chondrocytes in separate lacunae within the matrix, hence *homogenous transplantation of cartilage* is possible without rejection.
- **Cartilage repair**: Damaged cartilage shows limited *repair* (regeneration) with defects being slowly filled with scar tissue instead of cartilage. Thus, repair of cartilage takes a long time because it is avascular.

Types of cartilage AN2.4

The cartilages are classified into three types (Fig. 6.21):

1. Hyaline cartilage
2. Elastic cartilage
3. Fibrocartilage.

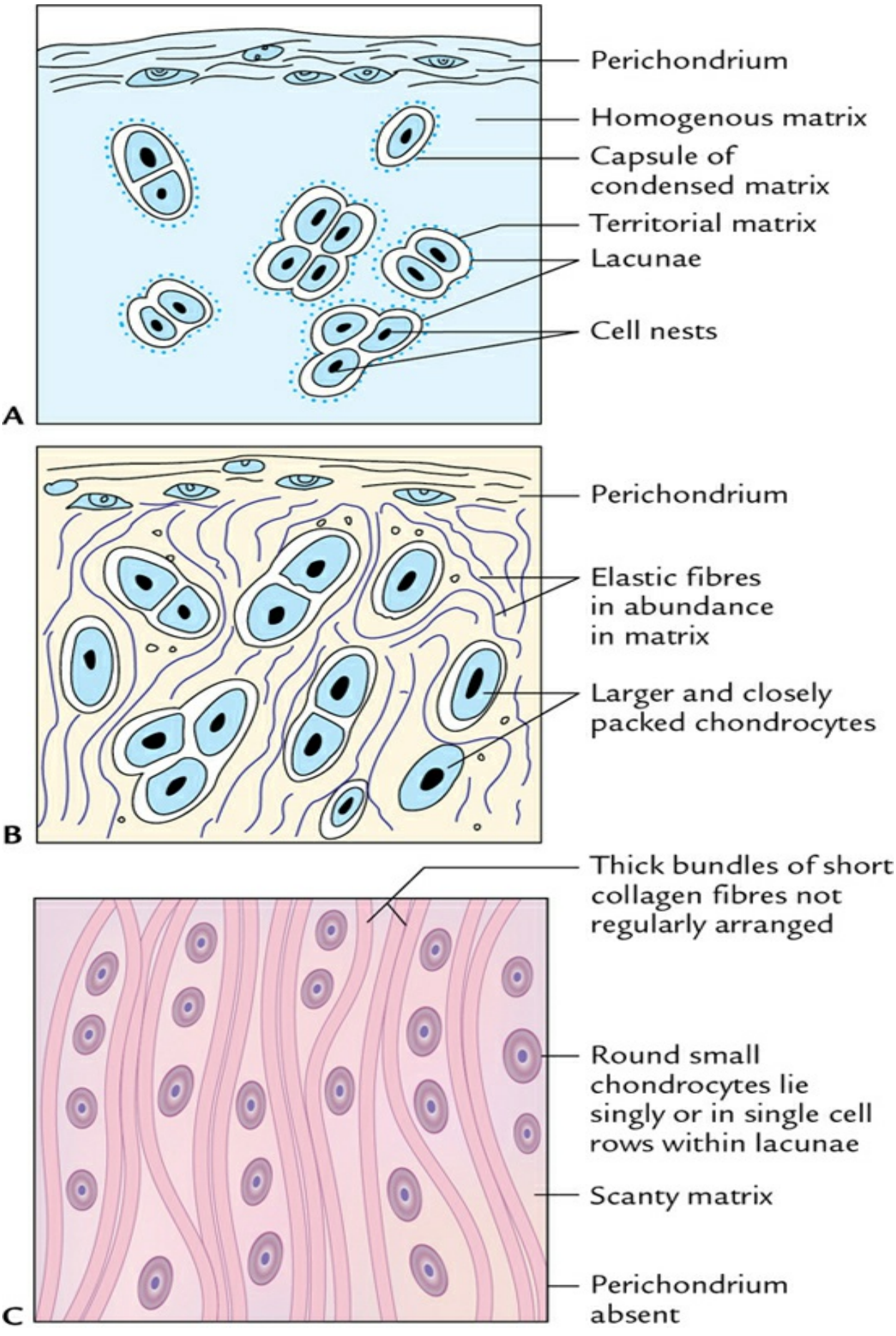

Perichondrium
Homogenous matrix
Capsule of condensed matrix
Territorial matrix
Lacunae
Cell nests
A
Perichondrium
Elastic fibres in abundance in matrix
Larger and closely packed chondrocytes
B
Thick bundles of short collagen fibres not regularly arranged
Round small chondrocytes lie singly or in single cell rows within lacunae
Scanty matrix
Perichondrium absent
C

FIG. 6.21 ■ Types of cartilage: **(A)** hyaline; **(B)** elastic and **(C)** fibrocartilage.

Hyaline cartilage (GK. Hyalos = Transparent stone)

It appears bluish-white and transparent because it contains very fine collagen fibres having the same refractive index as that of the ground substance.

- Chondrocytes are present in lacunae in groups of 3–4 cells called *isogenous group*
- The matrix around lacunae is darkly stained and called the *territorial matrix*.

It is the most widely distributed cartilage in the body (see Table 6.4). All the long bones in the body are preformed in hyaline cartilage.

TABLE 6.4

Sites of distribution of hyaline, elastic and fibrocartilages AN 2.4

Hyaline cartilage	Elastic cartilage	Fibrocartilage
• Articular cartilages of most of the joints	• Pinna of the external ear	• Intervertebral disc
• Thyroid cartilage	• Epiglottis	• Interpubic disc
• Cricoid cartilage	• Corniculate cartilage	• Menisci of knee joint
• Lower part of arytenoid cartilage	• Cuneiform cartilage	• Articular discs of temporomandibular, sterno-clavicular and inferior radio-ulnar joints
• Tracheal rings	• Apex of arytenoid cartilage	• Articular cartilages of temporomandibular, sterno-clavicular and acromio-clavicular joints

• Costal cartilages • Bronchial cartilage	• Auditory tubes • External auditory meatus	• Glenoid labrum, acetabular labrum, etc.
• Nasal cartilages		

N.B.

- All the hyaline cartilages are covered by perichondrium *except* articular cartilages.
- Nonarticular hyaline cartilage has a tendency to calcify and be replaced by bone.

Elastic cartilage

It is made up of numerous chondrocytes embedded in a matrix containing a rich network of yellow elastic fibres. Chondrocytes are large and lie in lacunae in groups of 2–3 cells. The sites of distribution of elastic cartilage include the pinna of the ear, epiglottis. The elastic cartilages are covered by perichondrium.

Fibrocartilage

It appears white and opaque due to the abundance of collagen fibres in it. The collagen fibres are arranged in bundles. The chondrocytes are few, small and scattered singly or arranged in rows. It is formed at sites subjected to great pressure like an intervertebral disc.

The distribution of the three types of cartilages in the body is enumerated in Table 6.4.

The key histological features of three types of cartilages (Fig. 6.21) are presented in Table 6.5.

TABLE 6.5

Salient histological features of three types of cartilages

Feature	Hyaline cartilage	Elastic cartilage	Fibrocartilage
Colour	Glossy bluish, transparent	Yellowish	White, opaque
Perichondrium	Present	Present	Absent
Chondrocytes	Smaller, less in numbers, present singly or in group of 3-4 cells inside lacunae	Larger, more numerous, present singly or in group of 2-3 cells inside lacunae	Few in number, scattered singly or arranged in single-cell rows
Matrix	Homogenous, basophilic, collagen fibres delicate and not visible	Rich in elastic fibres	Thick bundles of collagen fibres run parallel within a matrix but not very regularly arranged
Tendency to calcify	Common (in later life)	Less common	Absent

Clinical correlation

- **Osteoarthritis:** The articular cartilages of weight-bearing joints, viz. hip joint, knee joint etc. progressively become thinner and thinner and ultimately break, thus exposing the bone lying underneath the cartilage. As a result, bones of joint rub against each other (i.e. bone rubs against bone) during walking and undergo degeneration. Old age is the most common cause of osteoarthritis.
- Clinically it presents as pain during walking with a reduced range of movements.

N.B.

The knee joint being under most stress and strain is most commonly affected.

Golden Facts to Remember

• Total number of bones in the body	206
• Largest bone in the body	Femur
• Smallest bone in the body	Stapes
• Longest bone in the body	Femur
• Smallest long bone in the body	Malleus
• Most slender long bone in the body	Fibula
• Largest flat bone in the body	Hip bone
• Largest sesamoid bone in the body	Patella
• The most actively growing area of long bone	Metaphysis
• Most vascular area of a long bone	Metaphysis
• Most commonly fractured bone in the body	Clavicle in children and adults, radius in people over 50 years of age
• Largest nutrient artery in the body	Nutrient artery of tibia
• Commonest site of osteomyelitis in a long bone	Metaphysis
• All the long bones of the body lie vertically except	Clavicle which lies horizontally
• All the bones in the body are covered by periosteum except	Sesamoid bones and ear ossicles
• All the bones in the body are made up of both compact and spongy bones except	Inferior nasal concha which is made up of only spongy bone
• All the bones in the body form a joint/joints except	Hyoid bone
• The commonest site of bone marrow aspiration	Manubrium sternum in adults and the iliac crest in children
• First bone to ossify in the body	Clavicle
• Commonest congenital	Achondroplasia

anomaly due to defective endochondral ossification	(dwarfism)
• Commonest congenital anomaly due to defective membranous ossification	Cleidocranial dysostosis
• Most common site of accessory bones	Lambdoid suture of skull
• All the long bones in the body follow the law of ossification except	Fibula
• Most abundant cartilage in the body	Hyaline cartilage
• Most durable cartilage in the body	Fibrocartilage
• Largest yellow elastic cartilage in the body	Cartilage of the ear auricle
• Largest hyaline cartilage in the body	Thyroid cartilage of the larynx

Multiple choice questions

1. **Part of growing long bones commonly involved in osteomyelitis is:**
   (a) Epiphysis
   (b) Metaphysis
   (c) Diaphysis
   (d) Epiphyseal plate
2. **The scapula is an example of:**
   (a) Long bone
   (b) Flat bone
   (c) Irregular bone
   (d) Short bone
3. **All of the following bones are pneumatic bones *except*:**
   (a) Maxilla
   (b) Mandible
   (c) Frontal
   (d) Sphenoid
4. **Primary centre of ossification appears in:**

(a) Epiphysis
(b) Metaphysis
(c) Diaphysis
(d) Epiphyseal plate

5. **The secondary centre of ossification appears in:**
   (a) Epiphysis
   (b) Metaphysis
   (c) Diaphysis
   (d) Epiphyseal plate
6. **In adults, red bone marrow is found in all of the following sites *except*:**
   (a) Sternum
   (b) Ribs
   (c) Vertebrae
   (d) Medullary cavity of long bones
7. **In advanced age, gelatinous bone marrow may be found in:**
   (a) Hip bones
   (b) Skull bones
   (c) Scapula
   (d) Vertebrae
8. **All of the following bones ossify partly in membrane and partly in cartilage *except*:**
   (a) Temporal
   (b) Parietal
   (c) Mandible
   (d) Clavicle
9. **The coracoid process of the scapula is an example of:**
   (a) Traction epiphysis
   (b) Pressure epiphysis
   (c) Atavistic epiphysis
   (d) Aberrant epiphysis
10. **All of the following are examples of traction epiphysis *except*:**
    (a) Greater trochanter of femur
    (b) Greater tubercle of the humerus
    (c) Lesser tubercle of humerus
    (d) Coracoid process of scapula
11. **All of the following bones are examples of sesamoid bone *except*:**
    (a) Patella
    (b) Fabella

(c) Os trigonum
(d) Pisiform

12. **All of the following statements are true about hyaline cartilage *except that it***:
    (a) Covers articular surfaces of bones
    (b) Forms epiphyseal plates
    (c) Forms most of the laryngeal cartilages
    (d) Has abundant elastic fibres in its matrix
13. **All of the following are examples of white fibrocartilage *except*:**
    (a) Intervertebral discs
    (b) Articular cartilages of temporomandibular joint
    (c) Cartilage of pinna of the ear
    (d) Acetabular labrum
14. **All of the following statements are true regarding elastic cartilage *except* that it:**
    (a) Has abundant elastic fibres in its matrix
    (b) Is adapted to withstand tension and compression
    (c) Has a yellowish appearance
    (d) Is found in the external auditory canal
15. **All statements are true regarding hyaline cartilage *except* that it:**
    (a) Has a homogenous bluish-stained matrix
    (b) Has a clear glassy appearance
    (c) Forms cartilaginous model of most of the long bones
    (d) Forms menisci of knee joint

Answers

1. *b*, **2.** *c*, **3.** *b*, **4.** *c*, **5.** *a*, **6.** *d*, **7.** *b*, **8.** *b*, **9.** *c*, **10.** *d*, **11.** *c*, **12.** *d*, **13.** *c*, **14.** *b*, **15.** *d*

Chapter 7: Joints

Specific learning objectives

After studying this chapter, the student should be able to:

- Describe various joints with their subtypes and examples. **AN 2.5**
- Classify the joints according to their structure and function.
- State the different types of synovial joints and describe the characteristic features of a typical synovial joint.
- Outline different types of fibrous joints and describe their characteristic features.
- Describe the features of primary and secondary cartilaginous joints. Discuss the secondary cartilaginous joints in detail.
- Explain the concept of the nerve supply of joints and Hilton's law. **AN 2.6**
- Compare and contrast the features of rheumatoid arthritis and osteoarthritis.
- Classify levers and discuss the functional significance of each type.
- Describe the close-packed and loose-packed positions of major joints of the limbs.
- Discuss the factors maintaining the stability of the joint.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

In general usage, the term **joint** means a place where two things are joined together. In anatomical usage, a joint is a junction between two or more bones and cartilage. The long bones articulate by their ends, the flat bones by their margins and short or irregular bones by their surfaces. It is important for a medical student to know various synonyms which are commonly used in clinical medicine. The term **articulation** or **arthrosis** means a joint in Latin. The term **arthrology** (i.e. study of joints) or term **arthritis** (i.e. inflammation of a joint) are derived from the term *arthron* which means a joint in Greek. Basically, a joint is a device to permit movements; however, some joints are immovable. The *dislocation* is defined as the loss of contact (partial or complete) between two articulating bones.

Classification of joints AN2.5

The joints can be classified according to their structure and function i.e. mobility.

For the sake of convenience of presentation, functional classification is described first.

Functional classification

It is based upon the degree of mobility of the joint. They are of three types:

1. Immovable joints (synarthroses)
2. Slightly movable joints (amphiarthroses)
3. Freely movable joints (diarthroses).

Immovable joints (synarthroses) show no mobility, e.g. cranial sutures in adults, primary cartilaginous joints in growing children.

Slightly movable joints (amphiarthroses) show some degree of mobility, e.g. secondary cartilaginous joints, syndesmoses.

Freely movable joints (diarthroses) show maximum degree of mobility, e.g. synovial joints.

Structural classification

It is based upon the type of connecting tissue and the presence or absence of a joint cavity. The joints are classified into three types (Fig. 7.1):

1. Fibrous
2. Cartilaginous
3. Synovial.

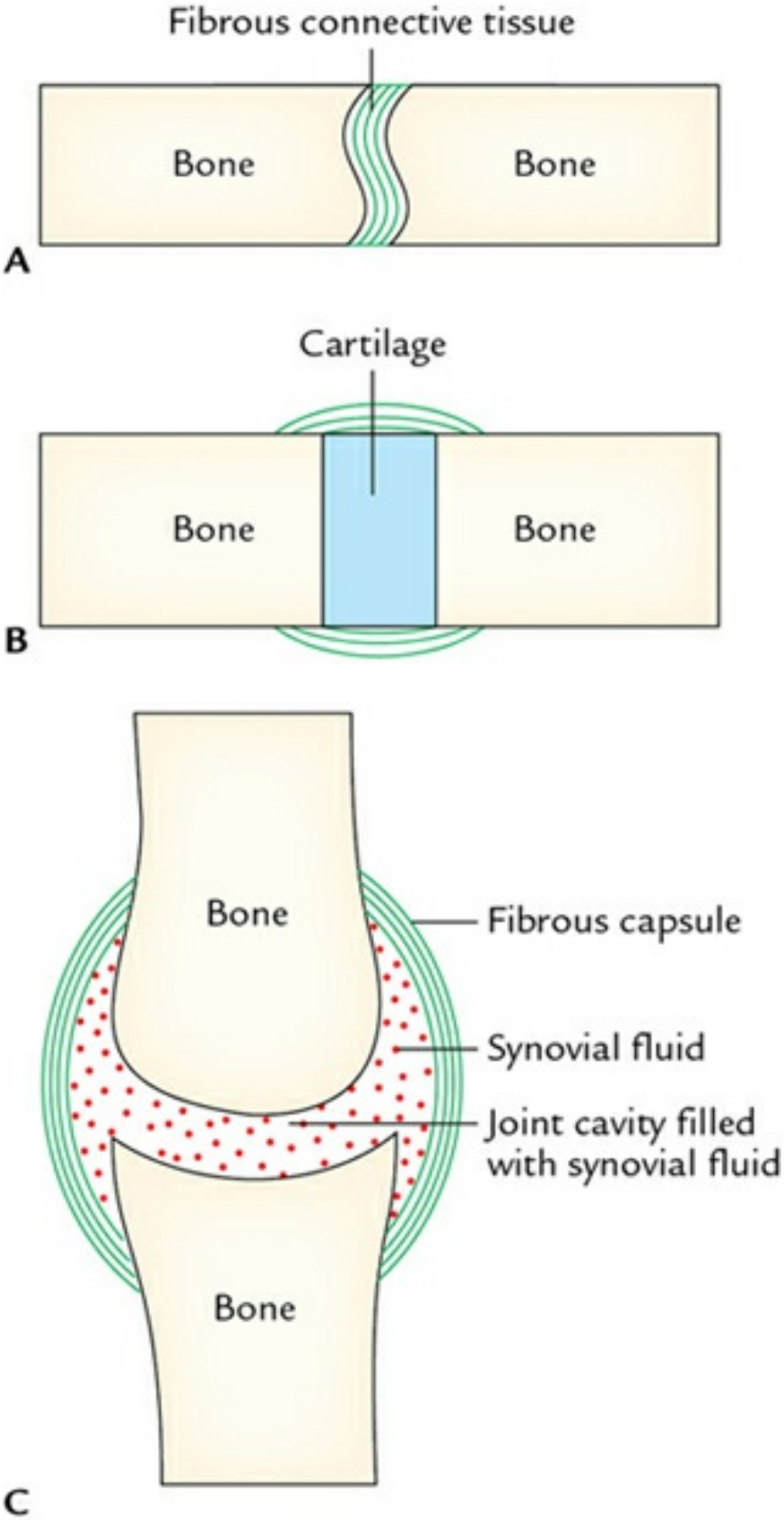


FIG. 7.1 ■ Types of joints: **(A)** fibrous, **(B)** cartilaginous and **(C)** synovial.

In clinical practice, the structural classification is most commonly

followed, hence will be discussed in detail.

Fibrous joints

Here the bones forming the joint are united by fibrous connective tissue. These joints are either immovable or permit only a slight degree of movement. A fibrous joint lacks a joint cavity.

The fibrous joints are of three types —sutures, syndesmoses and gomphoses.

1. **Sutures:** The articular surfaces are connected by a thin layer of connective tissue (sutural ligaments). These joints are confined to the skull (i.e. they are peculiar to the skull) and are immovable (Fig. 7.2). In growing children, they may permit little mobility.

   Depending upon the shape of the articular surfaces and margins of the articulating bones, these joints are further divided into the following subtypes (Fig. 7.3):

   (a) *Plane suture*: The articular surfaces of bones are plane and fairly smooth, e.g. median palatine suture, where the paired maxillary and palatine bones articulate to form the hard palate.

   (b) *Serrate or limbus suture*: The articular surfaces of the bones are reciprocally serrated and interlock with each other in a jigsaw fashion, e.g. sagittal suture.

   (c) *Denticulate suture*: The articulating margins of the bone possess teeth-like projections which interlock with each other like teeth of a saw, e.g. lambdoid suture.

   (d) *Squamous suture*: The articulating surfaces of the sutures are relatively flat and overlap each other, e.g. suture between temporal and parietal bones.

   (e) *Schindylesis (wedge* and *groove joint)*: It is a specialized suture where a ridge of one bone fits into the groove of the other bone, e.g. joint between the rostrum of the sphenoid bone and the cleft between the alae of vomer bone.

Clinical correlation

Synostosis: In the elderly, most of the sutures of the skull undergo

ossification leading to rigid bony union (*synostosis*). For this reason, the skull of the child is resilient to blows but not so in adults. In adults, it becomes rigid like an eggshell and frequently splinters following an impact. Thus, fractures of the skull are much more common in an adult than in a young child.

2. **Syndesmoses:** These are joints where two adjacent bones are linked together by a considerably greater amount of connective tissue than in sutures in the form of interosseous ligaments and membranes (Fig. 7.4), e.g. interosseous radioulnar joints, interosseous tibiofibular joints, inferior tibiofibular joints, joints between adjacent laminae of vertebrae (being connected by ligamenta flava), tympano-stapedial joints.

   A slight movement is permitted at these joints, viz. rotation of radius around ulna in movements of supination and pronation.
3. **Gomphoses (peg and socket joint):** These are specialized fibrous joints restricted to the fixation of teeth in alveolar sockets of the mandible and the maxillae. The root of the tooth is attached to the socket within the alveolus by a **periodontal ligament** (Fig. 7.5).

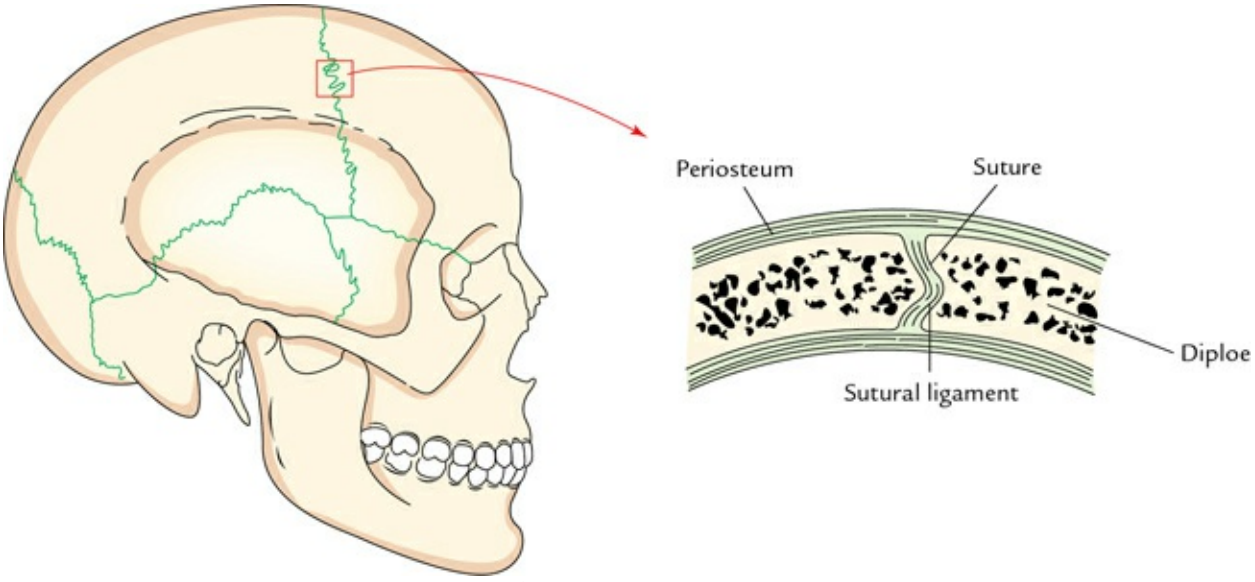


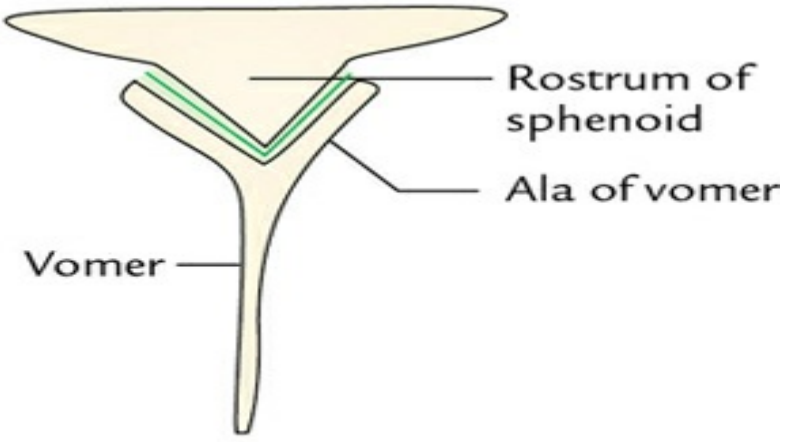
FIG. 7.2 ■ A suture.

Plane suture

Serrate suture

Denticulate suture

Squamous suture



Schindylesis

FIG. 7.3 ■ Subtypes of sutures.

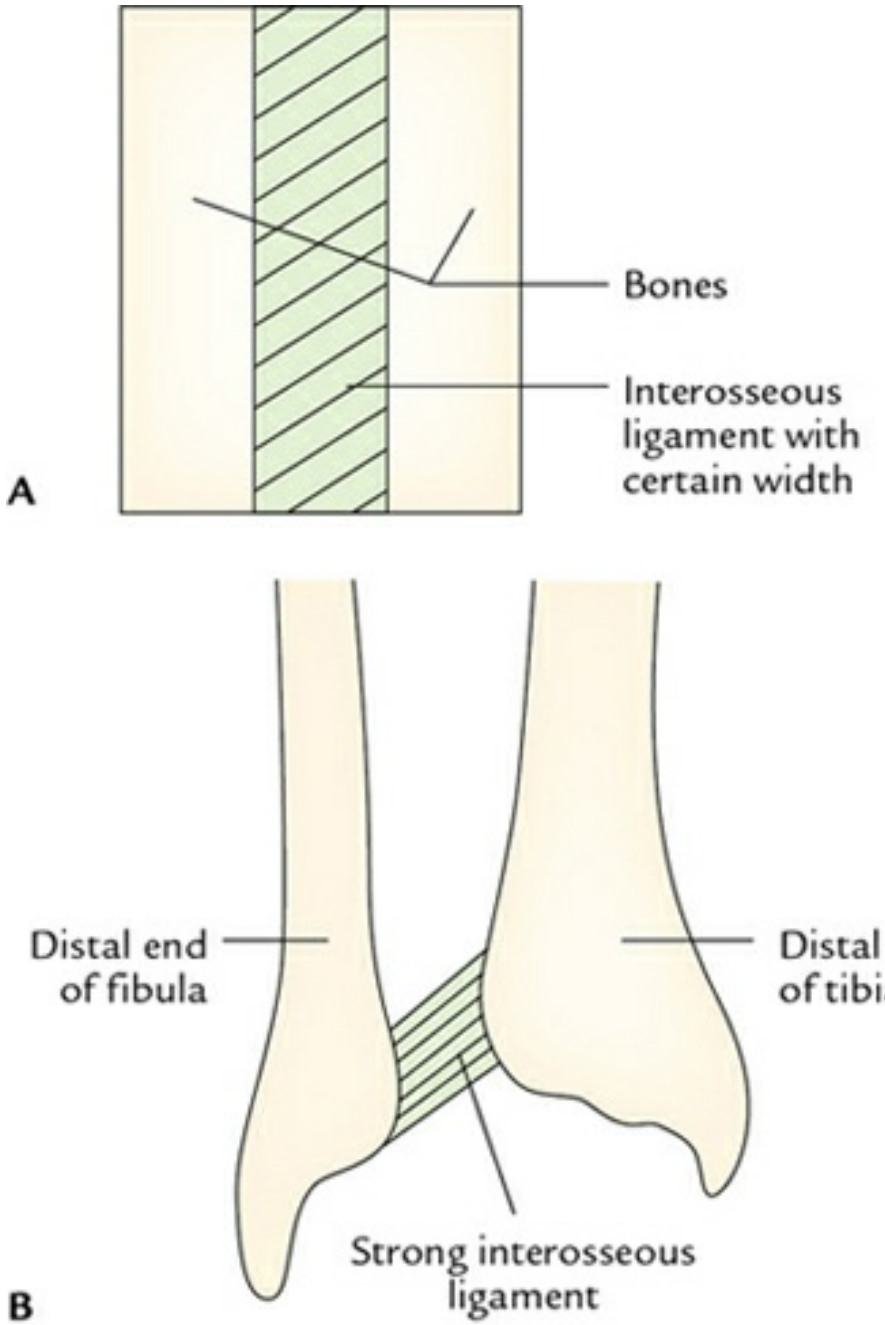


FIG. 7.4 ■ Syndesmosis: **(A)** schematic diagram and **(B)** inferior tibiofibular joint representing syndesmosis.

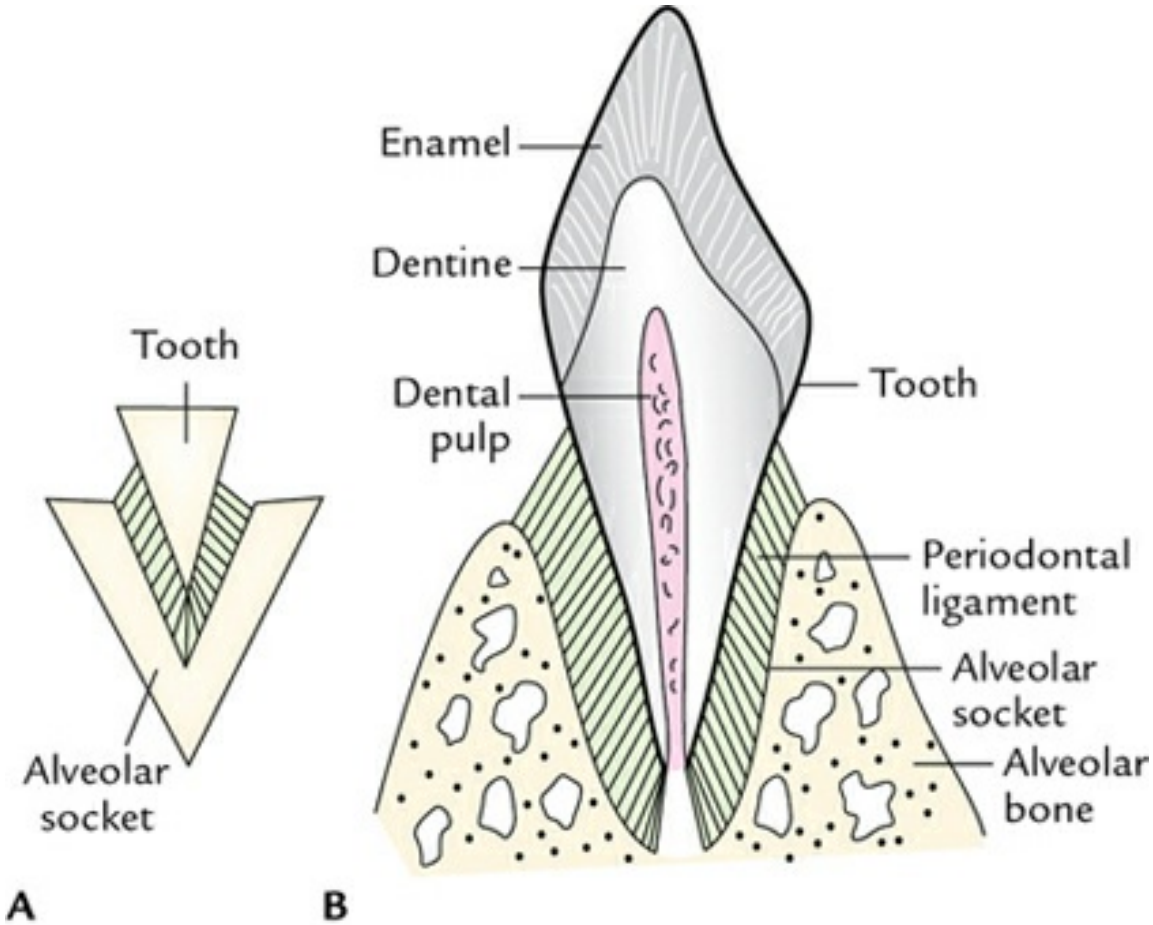


FIG. 7.5 ■ Gomphosis (peg and socket variety): **(A)** diagrammatic representation and **(B)** tooth in alveolar socket representing gomphosis.

Clinical correlation

Periodontitis: The gomphoses have clinical importance in dentistry because teeth become loose and may fall following inflammation and degeneration of the periodontal ligament, a clinical condition called *periodontitis*.

Cartilaginous joints

The cartilaginous joints are those joints in which the bones forming the joint are united by means of either hyaline cartilage or fibrocartilage. The cartilaginous joints also lack the joint cavity.

The cartilaginous joints are of two types: primary cartilaginous joints (**synchondroses)** and secondary cartilaginous joints (**symphyses**):

1. **Primary cartilaginous joints** (**synchondroses**) (Fig. 7.6): The bones or parts of the bones forming the joint are joined by a plate of hyaline cartilage, e.g.
   (a) Joint between epiphysis and diaphysis of growing long bone.
   (b) Joint between basisphenoid and basiocciput (spheno-occipital joint).
   (c) First costosternal joint.
   These joints are immovable and mostly temporary in nature. As the growth ceases they undergo synostosis (i.e. plate of hyaline cartilage is completely replaced by bone).

N.B.

All the primary cartilaginous joints are temporary i.e. undergo synostosis except the *first costosternal joint* which is permanent.

Clinical correlation

Clinical significance of the joints between the epiphysis and diaphysis of a growing long bone: It is of great clinical significance because:

(a) Piece of hyaline cartilage between the epiphysis and diaphysis allows the growth of long bone in length hence it is also called a growth plate and as growth is completed in height, these joints ossify.
(b) Growth plate is clearly seen as a radiolucent shadow between epiphysis and diaphysis in radiographs.
(c) Damage to the epiphyseal plate, particularly at the growing end, following fracture of a long bone in a child may lead to shortening of the limb.

2. **Secondary cartilaginous joints (symphyses):** In these joints, the articular surfaces of bones forming the joint are covered by thin plates of hyaline cartilage, which are connected by a disc or a pad of fibrocartilage (Fig. 7.7), e.g.
   (a) *Symphysis pubis*, between two pubic bones.
   (b) *Intervertebral discs*, between bodies of adjacent vertebrae.
   (c) *Manubriosternal joint*, between manubrium and body of sternum.
   (d) *Symphysis menti*, between two halves of the foetal mandible (not

true symphysis).

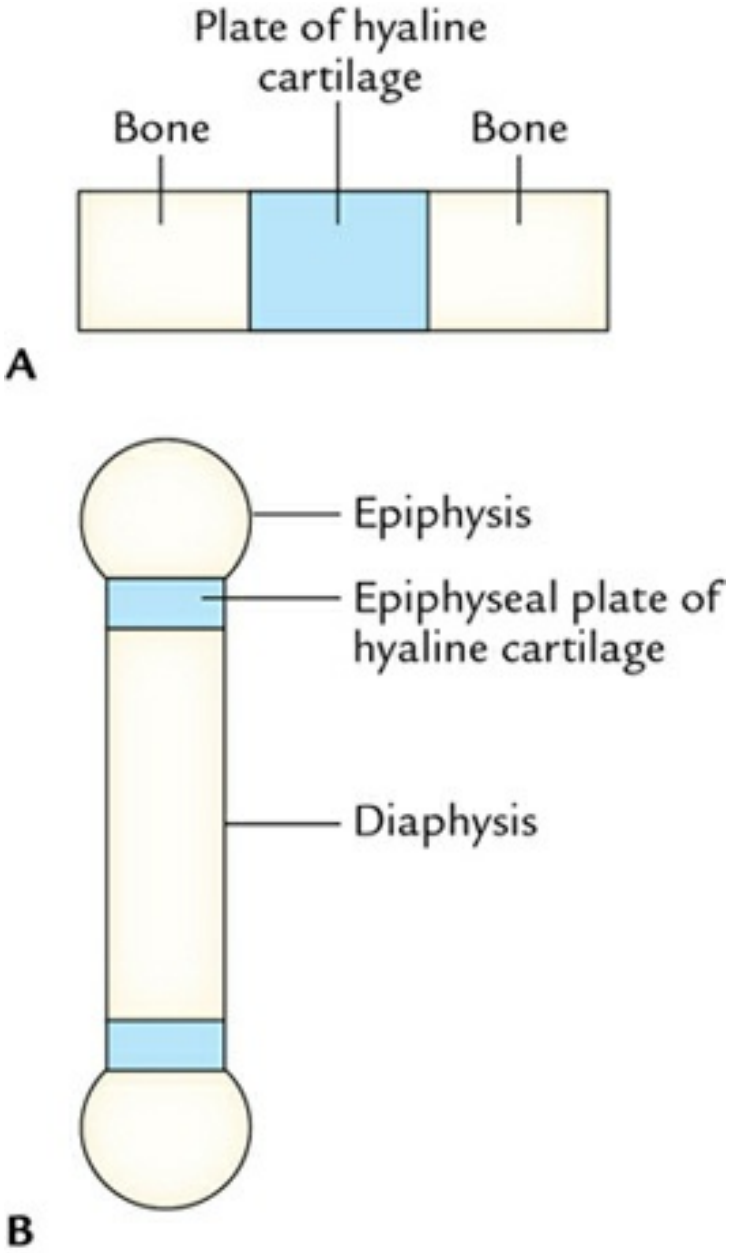


FIG. 7.6 ■ Primary cartilaginous joint (synchondrosis): **(A)** schematic diagram and **(B)** primary cartilaginous joint between epiphysis and diaphysis representing synchondrosis.

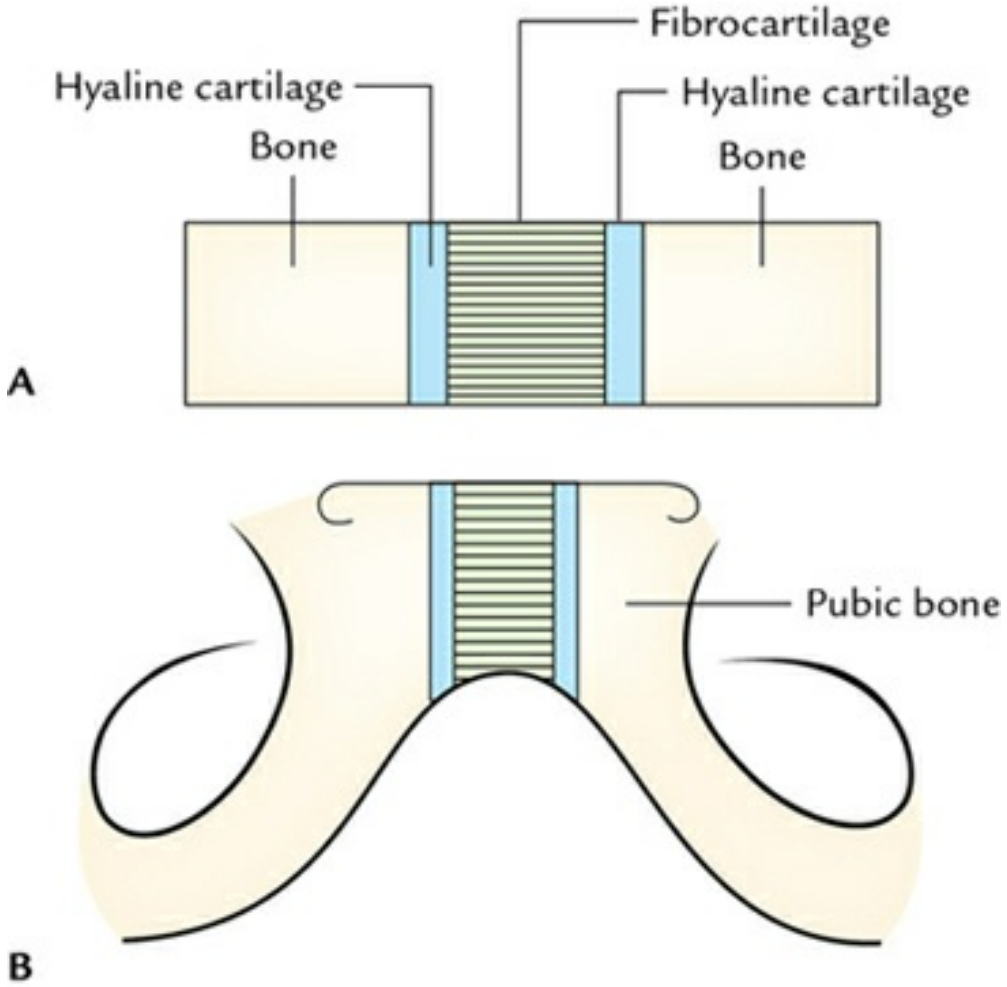


FIG. 7.7 ■ Secondary cartilaginous joint (symphysis): **(A)** schematic diagram and **(B)** pubic symphysis representing symphysis.

The differences between the primary and secondary cartilaginous joints are given in the Box 7.1.

Box 7.1

Differences between primary and secondary cartilaginous joints.

PRIMARY CARTILAGINOUS JOINT	SECONDARY CARTILAGINOUS JOINT
Bones are united together by hyaline cartilage	Bones are covered by hyaline cartilage and are united together by fibrocartilage
Immovable	Slightly movable

Temporary joint (disappear with age)	Permanent joint (do not disappear with age)
Rarely occurs in the midline	Always occur in the midline

N.B.

- Secondary cartilaginous joints typically occur in the midline.
- All the symphyses belong to the axial skeleton *except* the pubic symphysis which belongs to the appendicular skeleton.
- These joints permit limited movement due to the compressible pad of fibrocartilage.
- The term *symphysis menti* is a misnomer.

Synovial joints

Out of all the types of joints, the synovial joints are the most common and by far the most important clinically. Therefore, they have been described here in detail.

Synovial joints

These joints possess a cavity and the articular ends of bones forming the joint are enclosed in a **fibrous capsule**. As a result, they are separated by a narrow cavity, the **articular cavity** (or the joint cavity), which is filled with a fluid called **synovial fluid**. The synovial fluid is like egg albumin, hence the name synovial joint. *The synovial joints are the most evolved and freely movable joints*. They are often termed **diarthrodial joints**.

The characteristic features of synovial joints (Fig. 7.8) are as follows:

1. The articular surfaces are covered by a thin plate of hyaline cartilage.
2. The joint cavity is enveloped by an *articular capsule* which consists of an *outer fibrous capsule* and an *inner synovial membrane*.

3. The cavity of the joint is lined everywhere by synovial membrane *except* over the articular cartilages.
4. The cavity is filled with synovial fluid secreted by the synovial membrane which provides lubrication to the articular surfaces and nutrition to the articular cartilages.
5. Sometimes a joint cavity is incompletely or completely divided by an articular disc/meniscus.
6. Some additional structures are present within the joint cavity, e.g. (1) fat pads, (2) tendons, etc.

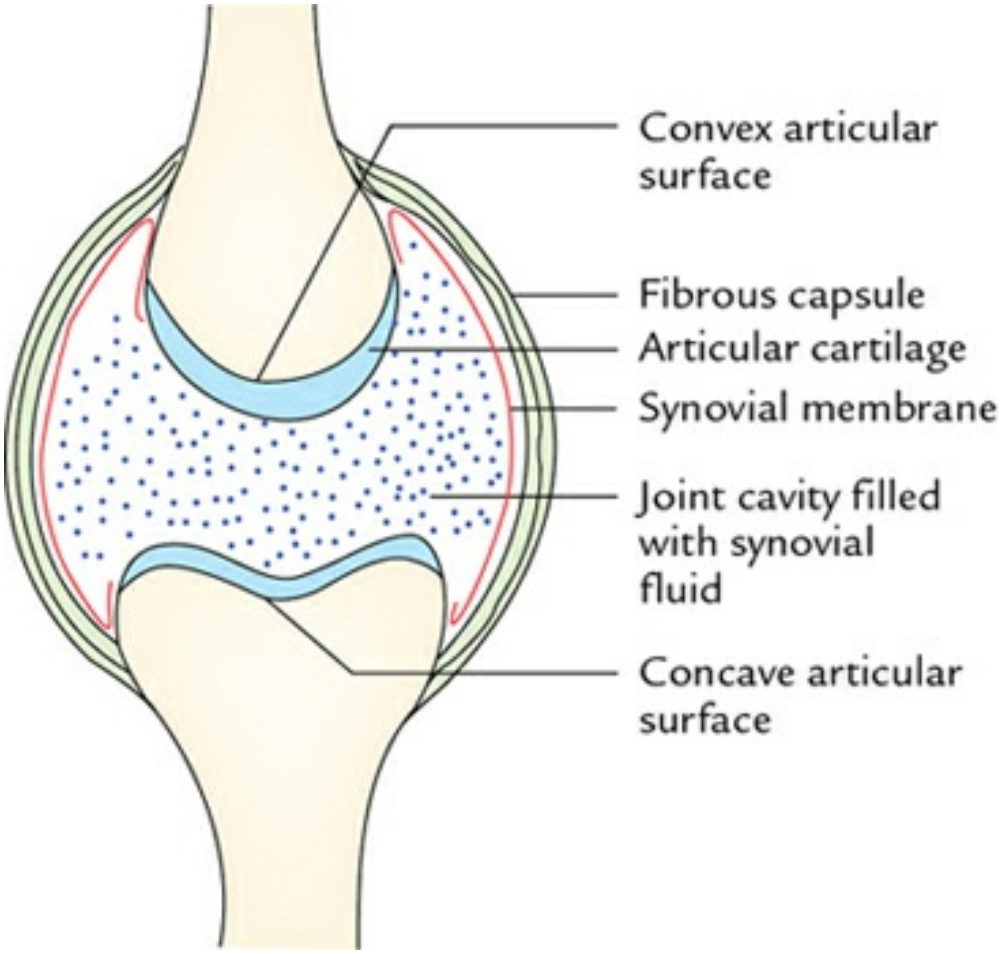


FIG. 7.8 ■ Diagrammatic representation of a typical synovial joint.

Components of synovial joints and their functional significance

The following are the components of synovial joints:

1. **Fibrous capsule:** It completely invests the joint like a sleeve and encloses a synovial cavity. It is attached by continuous lines to the bones forming the joint close to the articular cartilages. It consists of longitudinal and interlacing bundles of white connective tissue fibres. It is lined on its inner aspect by the synovial membrane. The fibrous capsule along with the synovial membrane together forms the **articular capsule**.

   Functions

   (a) The fibrous capsule stabilizes the joint in such a way that it permits movements but resists dislocation.

   (b) Numerous sensory nerve endings ramify on the capsule. The stimulation of these nerve endings produces reflex contraction of muscles acting on the joint in such a way that the joint is brought to a position of maximum comfort to protect the joint. This is known as the '**watch-dog**' action of the capsule.

2. **Ligaments:** These are thickened bands of collagen fibres. They are of two types: true ligaments and accessory ligaments (Fig. 7.9).

   (a) *True ligaments* are the local thickenings of parallel fibre bundles of capsular ligament, hence not separate from the capsular ligament, therefore they are also called **intrinsic ligaments**, e.g. medial and lateral collateral ligaments of knee joint.

   (b) *Accessory ligaments* are separate from the fibrous capsule and may be either extracapsular or intracapsular. The stylomandibular and spheno-mandibular are examples of extracapsular accessory ligaments and anterior and posterior cruciate ligaments of the knee joint are examples of intracapsular accessory ligaments.

   True ligaments permit the movements in one plane and prevent unwanted movements in other planes. In addition, they also stabilize the joint.

   Accessory ligaments provide additional reinforcement to the joint and limit the range of movements.

   A tear in the ligament is called *sprain.* It leads to swelling and pain in the joint.

3. **Synovial membrane:** It is a thin highly vascular membrane of connective tissue lining the inside of the fibrous capsule. It is reflected from the fibrous capsule onto the bone, which it covers right up to the articular cartilage. Note that articular cartilages are not covered by synovial membrane.

Functions

(a) The synovial membrane produces synovial fluid in sufficient quantity to keep the surfaces properly lubricated.

The synovial fluid is slippery like an egg-white. It is a dialysate of blood plasma plus mucin called hyaluronic acid. *The viscosity and lubricating properties of the synovial fluid are better than those of commercial lubricants*.

(b) The synovial membrane may form folds that contain fat pads (**haversian pads**). The haversian pads act as cushions and fill irregular spaces of the joints (also see fat-pads).

4. **Articular cartilage:** With few exceptions, the articular cartilage is made up of hyaline cartilage.

The cartilage consists of proteoglycan-hyaluronic acid aggregates. The hyaluronic acid retains water which resists compression. The cartilaginous articular surface has a low coefficient of friction.

Function

The articular cartilage provides smooth friction-free movements and resists compression forces.

N.B.

- The articular cartilages of all the synovial joints in the body are thin plates of hyaline cartilage *except* those of temporo-mandibular, sterno-clavicular and acromio-clavicular joints, which are thin plates of fibrocartilage, therefore these joints are called *atypical synovial joints*.
- Sometimes a noise (cracking sound) is produced in the joint when the articular surfaces are separated forcefully. The sound is produced due to the development of a vacuum within the joint due to the forceful separation of articular surfaces.

5. **Articular disc or meniscus:** The articular discs are pads of fibrocartilage interposed between the articular surfaces of some joints, e.g. temporo-mandibular, sterno-clavicular, acromio-clavicular, radio-ulnar and knee joints.

Functions

(a) Helps in lubrication of a joint by maintaining an interval between the articular surfaces.

(b) Divides the joint completely into two compartments.
(c) Acts as a ligament to modify certain joint movements.
(d) Prevents wear and tear of articular cartilages by providing a cushioning effect.

6. **Bursae:** These are pouch-like sacs of connective tissue filled with synovial fluid, found near certain synovial joints. They are commonly located between tendon and bone, between muscle and bone, between skin and bone and between tendon and skin.

   The bursae reduce the friction of one structure moving over the other.

   Function

   The function of bursae is to cushion certain muscles and facilitate the movement of tendons or muscles over bony or ligamentous surfaces.

   The **synovial tendon sheath** is a modified bursa that surrounds and lubricates the tendons of certain muscles, particularly those that cross the wrist and ankle joints.

7. **Fat-pads (haversian glands):** These are pads of fat placed between the synovial membrane and fibrous capsule or between synovial membrane and bone, e.g. acetabular fat of hip joint, infrapatellar fat-pad of knee joint. As fat is very pliant, the pads can accommodate themselves to changing conditions of the joint during different movements.

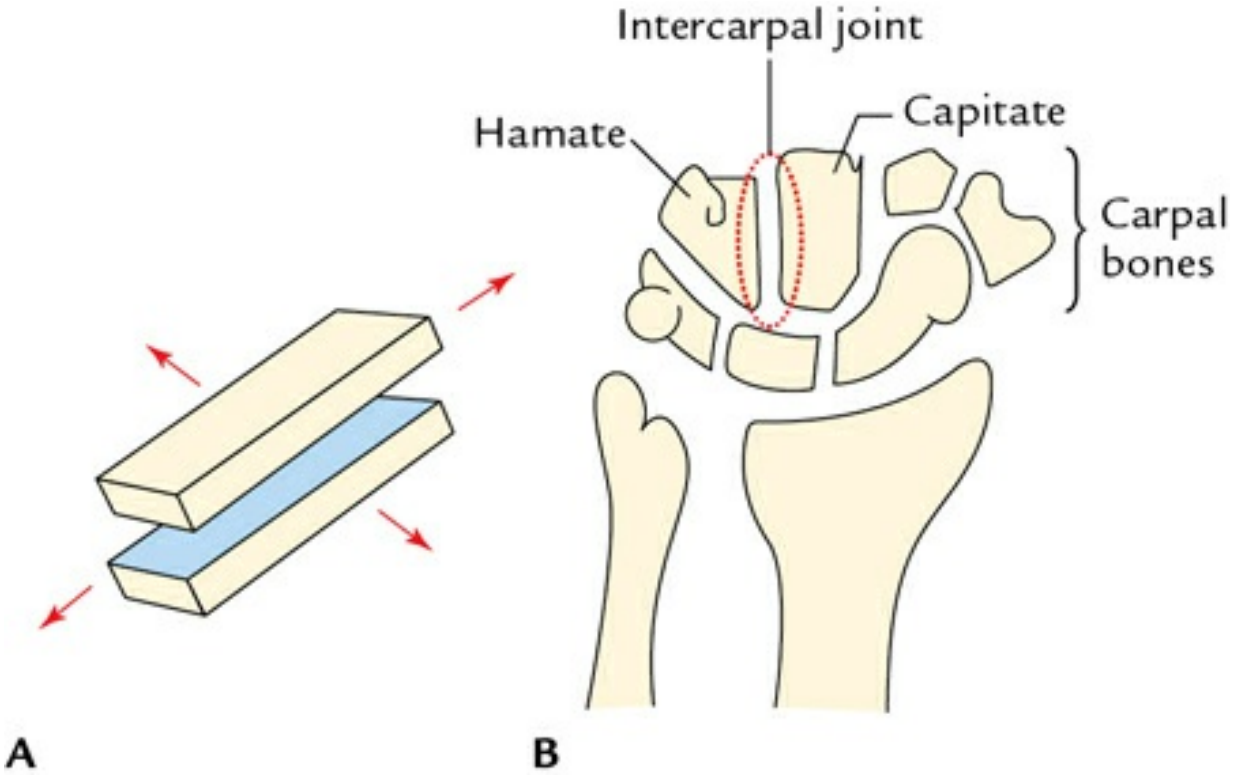


FIG. 7.9 ■ Plane (gliding) joint: **(A)** diagrammatic representation of the joint and **(B)** joint between capitate bone and hamate bone representing the plane joint.

Clinical correlation

The tissues involved in diseases of the synovial joints are hyaline cartilage, bone and synovial membrane.

- **Osteoarthritis:** Under normal conditions, the articular surfaces of bones of synovial joints do not come in contact with each other, because articular surfaces of bones are capped by articular cartilages and synovial fluid within the joints provides lubrication to these cartilages.
  If articular cartilages are damaged due to trauma or disease or if the synovial fluid is reduced, the articular bones come in contact with each other and undergo attrition. The bones begin to degenerate. There is abnormal bone repair and articular surfaces become uneven (misshapen) causing *osteoarthritis*. It affects large weight-bearing joints, e.g. hip and knee joints are most commonly involved in osteoarthritis. Sometimes there is the formation of *osteophytes*.
  Formation of osteophytes: The zone of articular bone at the junction of articular cartilage, synovial membrane and periosteum is highly vascular. It is endowed with immense proliferative power and hence

the site for the formation of osteophytes (pseudo bone formation) which leads to the lipping of articular margins.

- **Rheumatoid arthritis:** It is a chronic progressive inflammatory autoimmune disease involving the synovial membrane.
  This leads to hypertrophy and hyperplasia of synovial cells and fibrinous inflammatory effusion into the joint. If the disease progresses, it will cause erosion of articular cartilage and the growth of granulation tissue that separates the bones and distorts the shape of the joint. Rheumatoid arthritis commonly affects small joints of the hands and feet.
  Table 7.1 highlights the differences between osteoarthritis and rheumatoid arthritis.
- **Arthroplasty:** It is a surgical repair or replacement of joints. Recent advancement in soft tissue repair involves the use of artificial ligaments made up of carbon fibres coated with plastic (polylactic acid).

TABLE 7.1

Differences between osteoarthritis and rheumatoid arthritis

	Osteoarthritis	Rheumatoid arthritis
Nature of disease	Degenerative and inflammatory	Inflammatory and autoimmune
Tissue affected	Articular cartilage	Synovial membrane
Joints affected	Weight-bearing, e.g. hip, knee, joints of the cervical and lumbar spine	Small joints of hands and feet

Classification of synovial joints

According to the shape of articular surfaces

1. **Plane joints (Fig. 7.9):** The articular surfaces are nearly flat (plane). They permit gliding movements in various directions, i.e. side to side, back and forth movements with slight rotation. These are the simplest type of joint movements. The examples are:
   (a) Intercarpal joints
   (b) Intertarsal joints
   (c) Intermetatarsal
   (d) Intermetacarpal
   (e) Joints between the articular processes of adjacent vertebrae (zygapophyseal joints).
2. **Hinge or ginglymus joints (Fig. 7.10):** The articular surfaces are pulley shaped. Movements are permitted only in one plane around a transverse axis much like the hinge of the door. These joints have strong collateral ligaments to prevent other movements. The hinge joints are the most common type of synovial joints. The examples are:
   (a) *Elbow joint* (strictly speaking humero-ulnar joint)
   (b) Interphalangeal joints
   (c) Knee joint
   (d) Ankle joint.
3. **Pivot or trochoid joints (Fig. 7.11):** The articular surface of one bone is rounded and fits into the concavity of another bone. Further, the rounded part is surrounded by a ligamentous ring, i.e. a rod surrounded by a ring. The movement in a pivot joint has limited rotation around a central axis, i.e. either the rod rotates in an osteo-ligamentous ring, e.g. superior radio-ulnar joint or osseo-ligamentous ring rotates around the rod such as a median atlanto-axial joint. The superior radio-ulnar joint permits rotation of the forearm and the median atlanto-axial joint allows the rotational movements of the head.
4. **Condylar joints (Fig. 7.12):** The round articular surface of one bone fits into the socket-type articular surface of another bone. The end of bone bearing a round articular surface is called condyle. These joints permit movements in two directions (biaxial), i.e. up and down and side-to-side. The examples are:
   (a) Right and left temporo-mandibular joints
   (b) Knee joints.
5. **Ellipsoidal joints (Fig. 7.13):** The elliptical convex surface of one bone articulates with the elliptical concave surface of another bone. The movements are permitted in two directions (biaxial), i.e. flexion and

extension around a transverse axis and abduction and adduction around the anteroposterior axis. The combination of these movements produces **circumduction**. The examples are:

(a) Radio-carpal joint (wrist joint)
(b) Atlanto-occipital joints
(c) Metacarpo-phalangeal joints
(d) Metatarso-phalangeal joints.

6. **Saddle or sellar joints (Fig. 7.14):** The articular surfaces are reciprocally saddle-shaped, i.e. concavo-convex. This unique articulation is a modified condyloid joint that allows a wide range of movement. The examples are:
   (a) First carpo-metacarpal joint
   (b) Sterno-clavicular joint
   (c) Calcaneo-cuboid joint.
   (d) *Incudo-malleolar joint* (smallest saddle joint)
7. **Ball and socket or spheroidal joints (Fig. 7.15):** Rounded convex surface of one bone fits into the cup-like socket of another bone. The movements occur around an indefinite number of axes that have one common centre. This type of articulation provides the greatest range of movement of all the synovial joints. The movements include flexion, extension, adduction, abduction, medial rotation, lateral rotation and circumduction. The examples are:
   (a) *Hip joint* (largest ball and socket joint)
   (b) Shoulder joint
   (c) *Incudo-stapedial joint* (smallest ball and socket joint).
   The examples of various types of synovial joints (according to the shape of their articular surfaces) are summarized in Table 7.2.

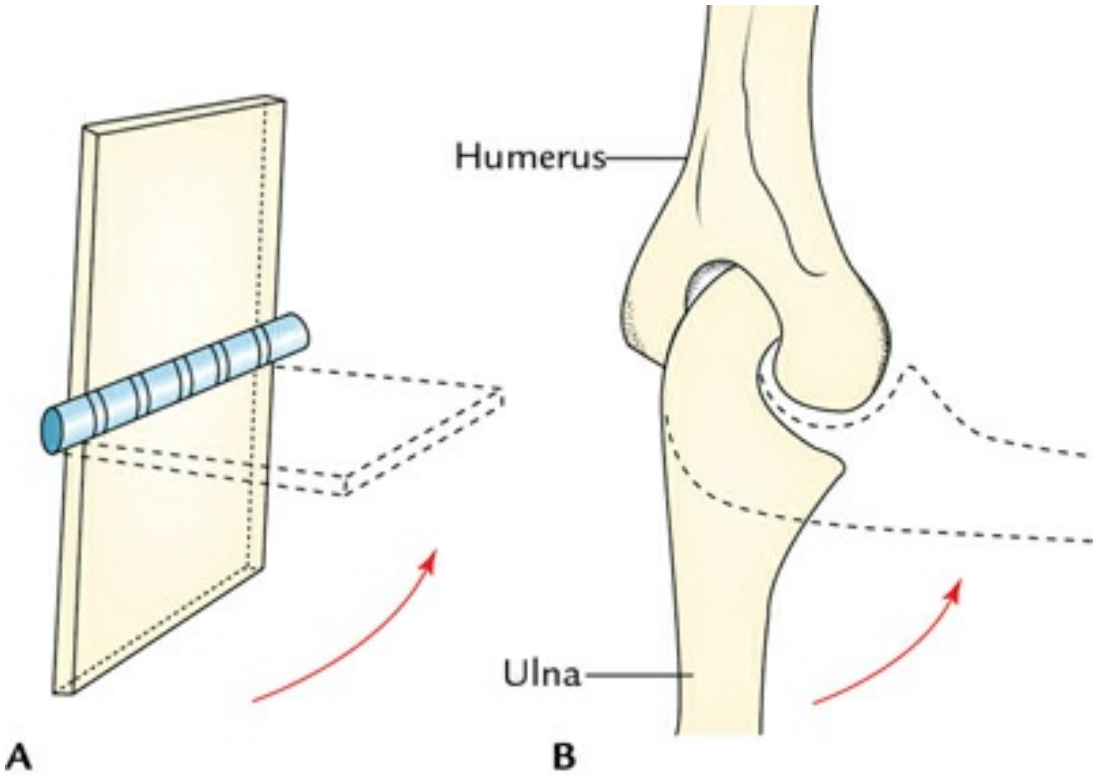


FIG. 7.10 ■ A hinge joint: **(A)** diagrammatic representation of the joint showing bending movement and **(B)** humero-ulnar joint representing a hinge joint.

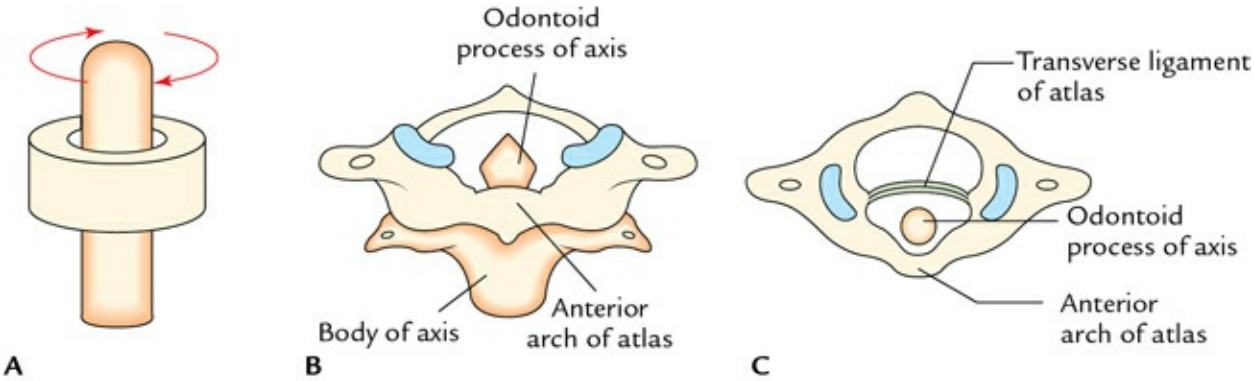


FIG. 7.11 ■ Pivot joint: **(A)** diagrammatic representation of the joint and (**B** and **C**) median atlanto-axial joint representing pivot joint.

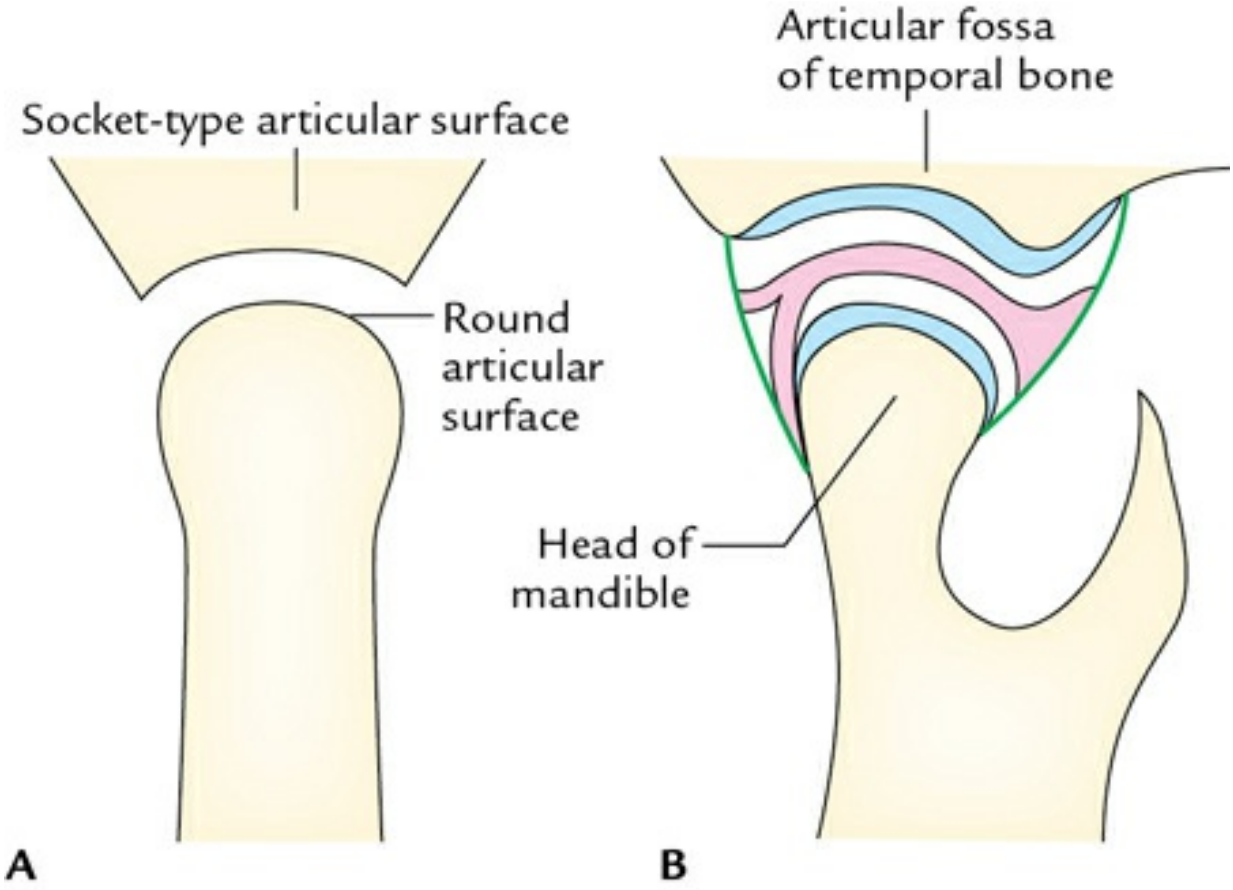


FIG. 7.12 ■ Condylar joint: **(A)** diagrammatic representation of the joint and **(B)** temporo-mandibular joint representing a condylar joint.

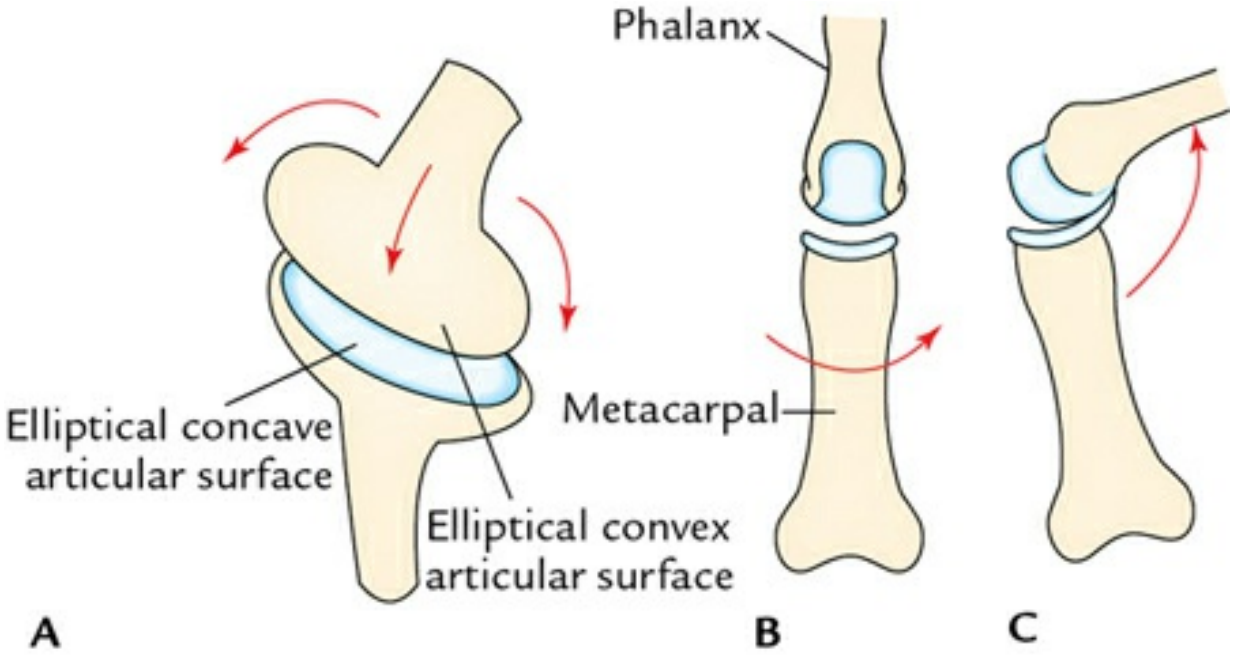


FIG. 7.13 ■ Ellipsoid joint: **(A)** diagrammatic representation of the joint and (**B** and **C**) metacarpo-phalangeal joint representing ellipsoid joint.

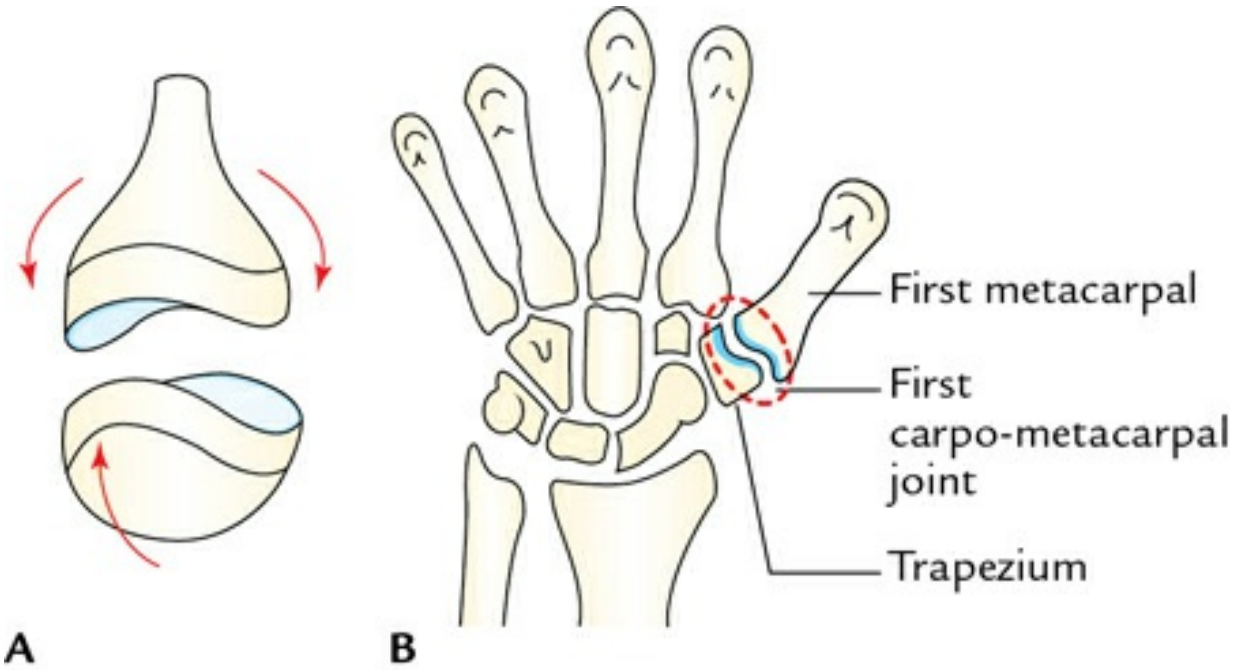


FIG. 7.14 ■ Saddle joint: **(A)** diagrammatic representation and **(B)** first carpo-metacarpal joint representing saddle joint.

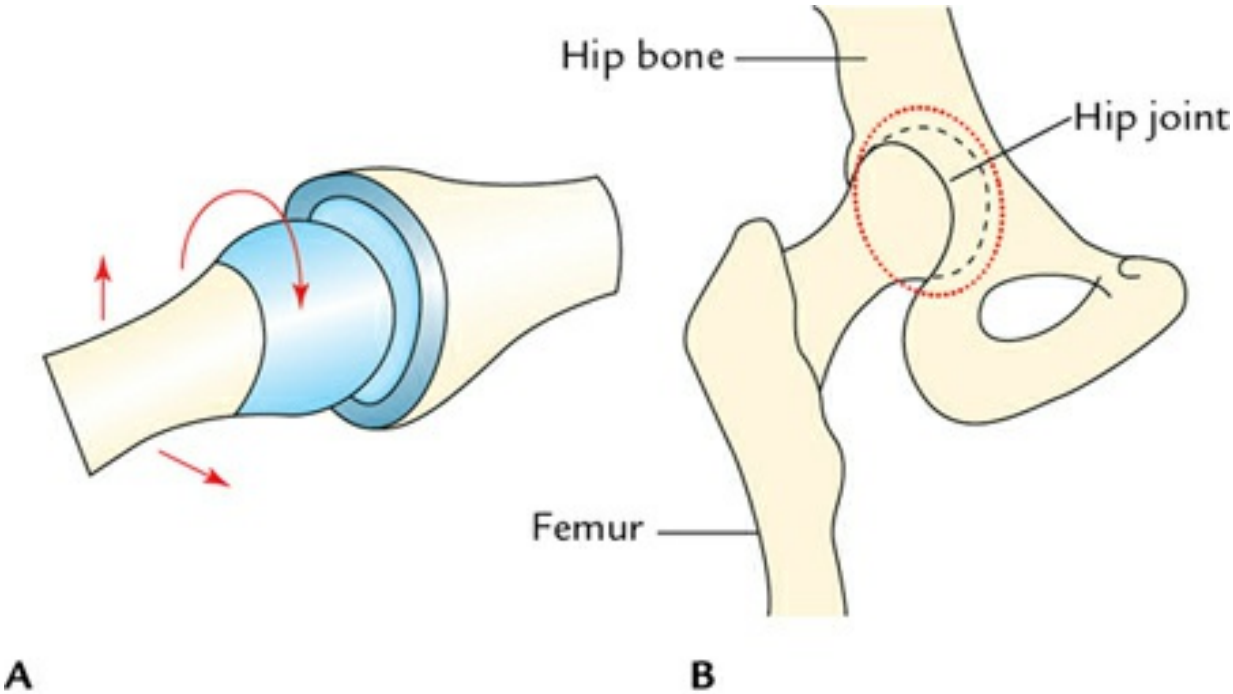


FIG. 7.15 ■ Ball and socket joint: **(A)** diagrammatic representation of the joint showing directions of possible movements and **(B)** hip joint representing ball and socket joint.

TABLE 7.2

Examples of various types of synovial joints according to the articular surfaces

Types of Synovial Joints						
Plane	**Hinge**	**Pivot**	**Condylar**	**Ellipsoidal**	**Saddle**	**Ball ar socket**
• Intercarpal • Intertarsal • Intermetatarsal • Intermetacarpal • Zygapophyseal	• Elbow • Knee • Ankle • Interphalangeal	• Superior radio-ulnar • Median atlanto-axial	• Temporo-mandibular • Metacarpo-phalangeal	• Radio-carpal (wrist) • Atlanto-occipital • Metacarpo-phalangeal • Metatarso-phalangeal	• First carpo-metacarpal • Sterno-clavicular • Calcaneo-cuboid • Incudo-malleolar (smallest)	• Hip joint (larges • Shoulc joint • Incudc stapedi (smalle

According to the plane/planes of movements

1. **Uniaxial joints:** In these joints, the movements occur in only one plane or axis. The examples are:
   (a) *Hinge joints* (e.g. elbow, ankle and interphalangeal joints). Here movements take place around a transverse axis. Hence only flexion and extension are possible.
   (b) *Pivot joints* (e.g. superior radio-ulnar (Fig. 7.16) and median atlanto-axial joints). Here movements take place around a vertical axis, hence only rotation is possible.
2. **Biaxial joints:** In these joints, the movements occur in two planes or axes. The examples are:
   (a) *Condylar joints* (e.g. knee and temporo-mandibular joints). These are modified hinge joints, where not only flexion and extension take place around a transverse axis but slight rotation also takes

place around a vertical axis.

(b) *Ellipsoid joints* (e.g. radio-carpal, metacarpo-phalangeal, metatarso-phalangeal and lateral atlanto-occipital joints). Here flexion and extension take place around the transverse axis, and abduction and adduction take place around an anteroposterior axes (Fig. 7.17). The circumduction is also possible.

(c) *Saddle (sellar) joints* (e.g. carpo-metacarpal joint of thumb, sterno-clavicular joint). Here flexion and extension take place around a transverse axis, and abduction and adduction take place around an anteroposterior axis. Some rotation is also associated with aforesaid movements. This is known as **conjunction rotation**.

3. **Multiaxial (polyaxial) joints:** In these joints, movements occur in three planes or axes (Fig. 7.18). Examples are the ball and socket joint (**spheroidal**) such as shoulder and hip joints. All kinds of movements, i.e. flexion, extension, abduction, adduction, rotation, circumduction, are possible.

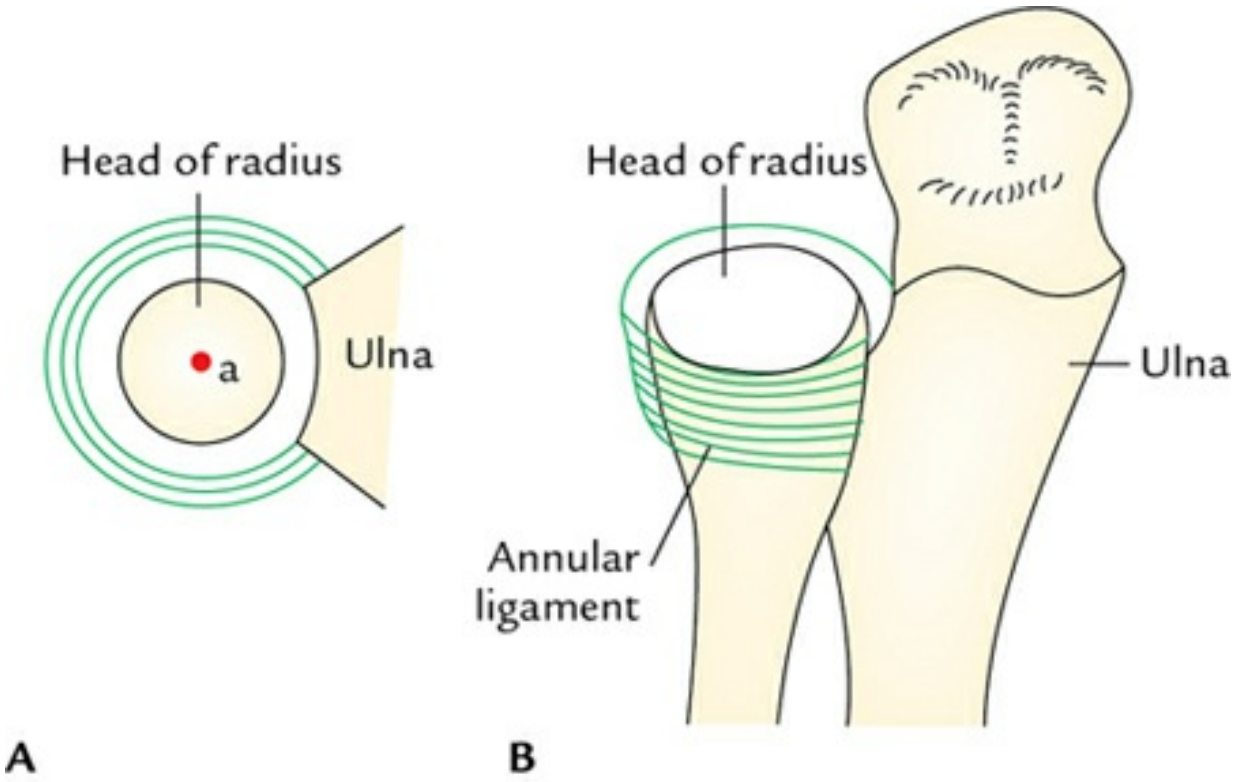


FIG. 7.16 ■ Superior radio-ulnar joint: **(A)** diagrammatic representation of the joint showing vertical axis and **(B)** actual superior radio-ulnar joint.

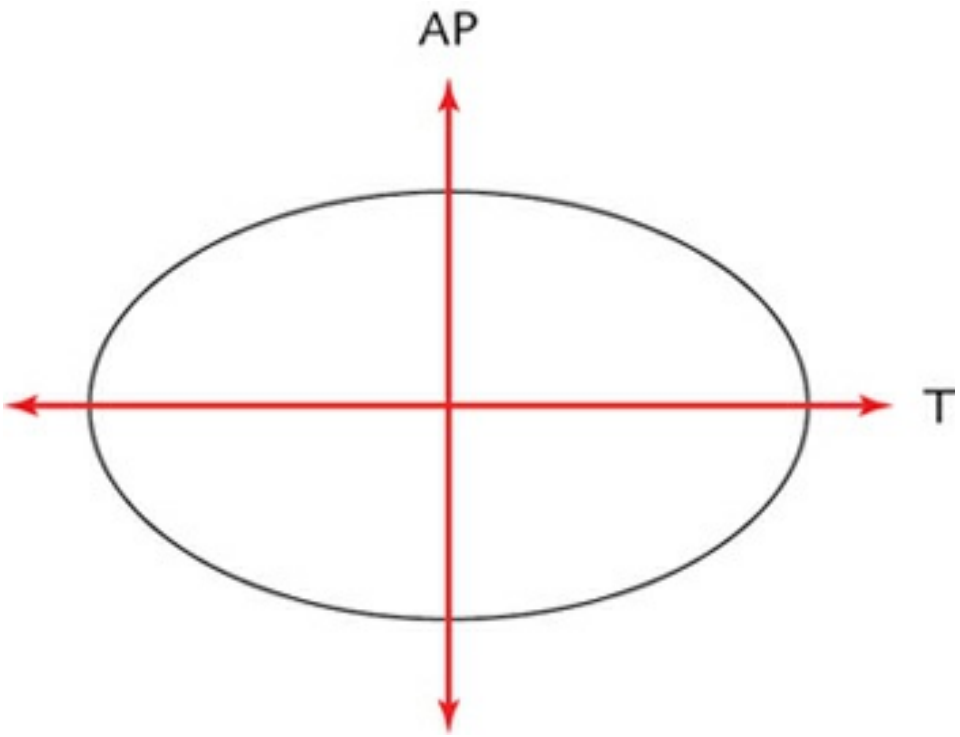


FIG. 7.17 ■ Two axes of a multiaxial joint. (AP, anteroposterior axis producing abduction and adduction; T, transverse axis producing flexion and extension.)

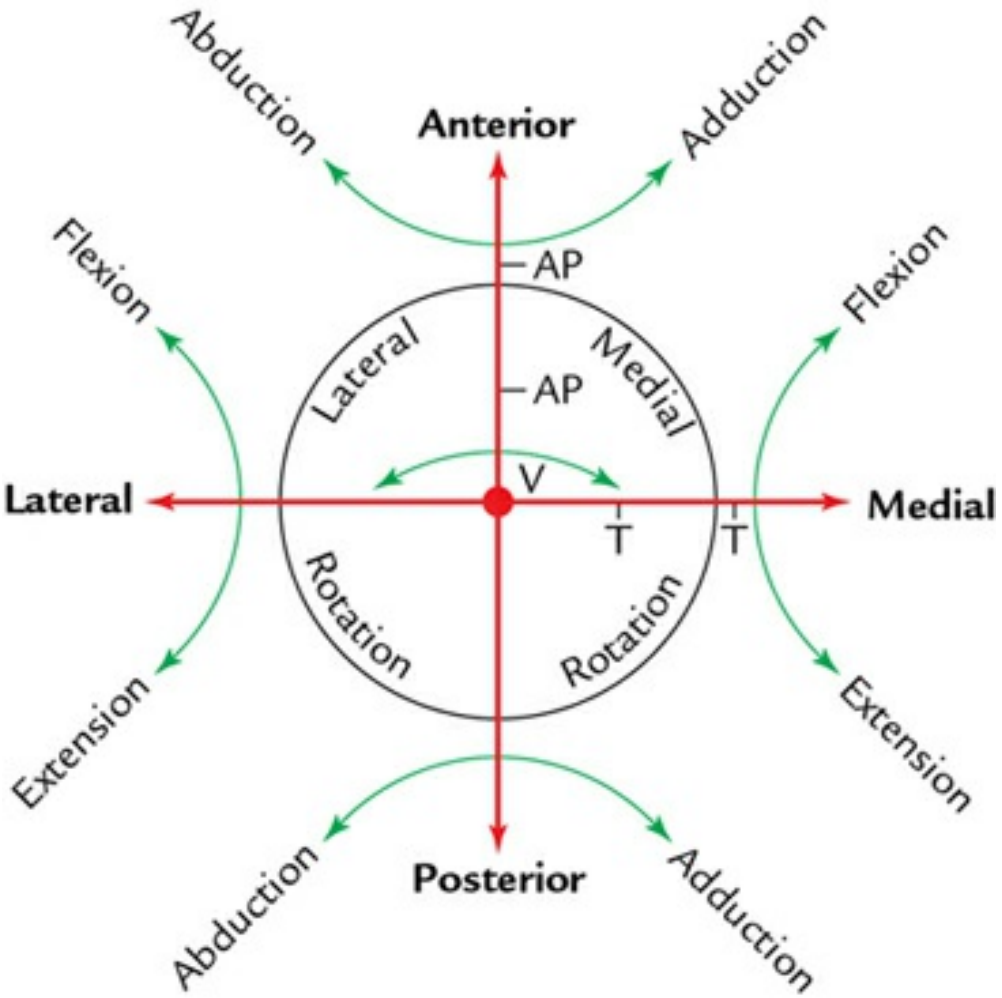


FIG. 7.18 ■ Axes and movements of a polyaxial joint. (AP, anteroposterior axis; T, transverse axis; V, vertical axis.)

According to the number of articulating bones

1. **Simple joints:** Here only two bones take part in the formation of a joint, e.g. interphalangeal joints of fingers and toes.
2. **Compound joints:** Here more than two bones take part in the formation of a joint. The examples are:
   (a) *Ankle joint*, where three bones (tibia, fibula and talus) take part to form this joint.
   (b) *Elbow joint*, where three bones (humerus, radius and ulna) take part to form this joint.

(c) *Radio-carpal (wrist) joint*, where four bones (radius, scaphoid, lunate and triquetral) take part in the formation of this joint.

N.B.

When the joint cavity is divided into two compartments by an articular disc or meniscus it is called a ***complex joint***, e.g. knee (Fig. 7.19), temporo-mandibular and sterno-clavicular joints.

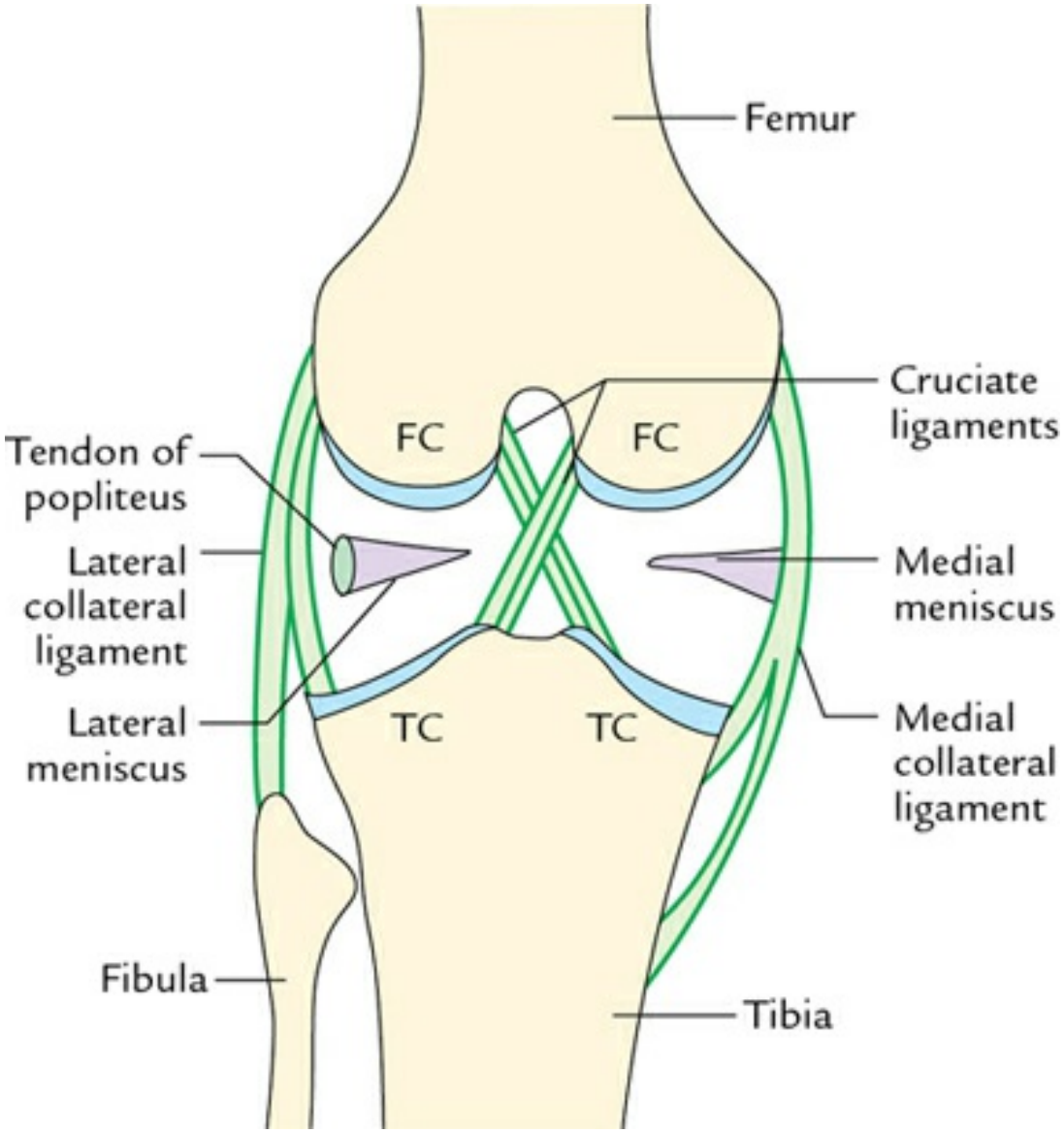


FIG. 7.19 ■ Knee joint—an example of a complex joint. (FC, femoral condyle; TC, tibial condyle.)

Movements of synovial joints

Active movements

Three types of **active movements** occur at the synovial joints:

1. Gliding or slipping movements
2. Angular movements
3. Rotary or circular movements.

Gliding or slipping movements

These movements occur in plane joints, where one bone slips over the other in a particular direction. Such movements are limited. The series of gliding movements in small joints of the hand, foot and vertebral column provides an efficient buffer against a force.

Angular movements

These movements increase or decrease the joint angle produced by the articulated bones. The four types of angular movements are as follows:

1. **Flexion**: It is the movement that decreases the joint angle in an anteroposterior plane, e.g. bending of elbow and knee. The flexion of the elbow joint is a forward movement, whereas the flexion of the knee is a backward movement.

N.B.

In the ankle joint, flexion occurs when the dorsum of the foot is elevated. This movement is termed *dorsiflexion*. The rising of toes is *plantar flexion*. In flexion of the shoulder joint, the arm is brought forward.

2. **Extension:** This movement is the reverse of flexion and in it, the joint angle is increased. In an extended joint, the angle between the articulating bones is 180°. The extension returns the body part to the anatomical position. The *exception* to this is the ankle joint where there is a 90° angle between the dorsum of the foot and the lower leg in an anatomical position so that the joint angle is greater than 180°, e.g. turning the head backward.
3. **Abduction:** The movement of a body part away from the midsagittal

plane of the body in the lateral direction, e.g. moving sideways and away from the body.

4. **Adduction:** The movement of the body part towards the midsagittal plane of the body. This is the opposite of abduction.

Rotary or circular movements

These movements are only possible if the round articular surface of one bone articulates with the corresponding cup-shaped articular surface of the other bone.

The two basic types of circular movements are as under:

1. **Rotation:** It is the movement of the body part around its own axis, e.g. (1) turning the head from side to side, i.e. 'no' movements, and (2) moving the forearm from palm up position to palm down position and vice-versa.
   (a) *Supination*: Rotation of forearm from a mid-prone position in such a way that the palm of the hand is turned forward (anteriorly).
   (b) *Pronation*: Rotation of the forearm from a mid-prone position in such a way that the palm of the hand is directed backward.

N.B.

The rotation around a longitudinal axis is called *rotation proper* which may be adjunct or conjunct. The *adjunct rotation* takes place actively by some muscles whereas *conjunct rotation* occurs passively due to the configuration of articular surfaces or tension of some ligaments. For example, the rotation of the hip is an adjunct rotation whereas the rotation of the knee during locking and unlocking is conjunct.

2. **Circumduction:** It is a movement of a limb so that distal end describes a circle while proximal end remains more or less fixed. It is a combination of four angular movements, viz. *flexion, extension, abduction and adduction* in successive order, forming a circular cone. In other words, it is a circular, cone-like movement of the body part. Such movements are possible at the shoulder and hip joints (Fig 7.20).

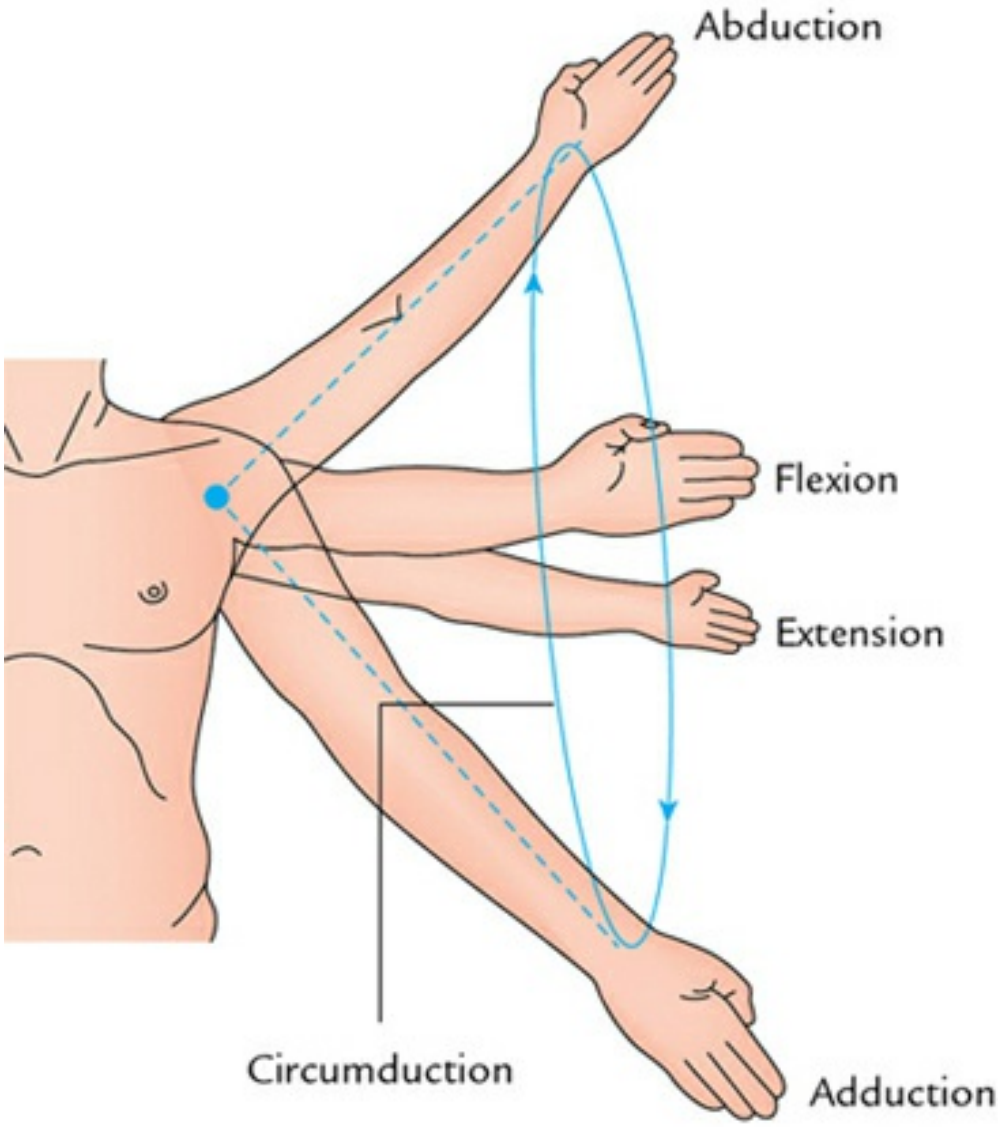


FIG. 7.20 ■ Circumduction at shoulder Joint.

Special active movements

These are as follows:

1. **Inversion:** Movement in which the sole faces inward and medially. It occurs when the medial border of the foot is raised.
2. **Eversion:** Movement in which the sole faces outward and laterally. It occurs when the lateral border of the foot is raised.

N.B.

The movements of *inversion and eversion* occur at subtalar, talocalcaneo-navicular and midtarsal joints. The range of motion of inversion is more than that of eversion. These movements correspond to movements of *supination* and *pronation* in the upper limb.

3. **Protraction:** Forward movement of the body part on a plane parallel to the ground, e.g. protraction of the lower jaw.
4. **Retraction:** Pulling back the protracted part of the body on the plane parallel to the ground, e.g. retraction of the lower jaw.
5. **Elevation:** The part of the body is lifted upward, e.g.
   (a) Elevation of the mandible to close the mouth.
   (b) Lifting of the scapula to shrug the shoulder.
6. **Depression:** The part of the body is moved downward e.g. depression of the mandible to open the mouth.

The active movements possible at synovial joints are summarized in Table 7.3.

TABLE 7.3

Movements possible at synovial joints

Movement	Definition
Angular movements	
Flexion	Bending (decreasing joint angle) the joint occasionally backward, e.g. knee joint
Extension	Straightening the joint (increasing the joint angle)
Abduction	Movement away from the midline of the body
Adduction	Movement toward the midline of the body
Circumduction	Combination of flexion, extension, abduction and adduction
Special movements	
Rotation	Movement around the long axis of the bone
Supination	Turning the palm of the hand forward or upward
Pronation	Turning the palm of the hand backward or downward
Inversion	Turning the sole of the foot inward
Eversion	Turning the sole of the foot outward

Protraction	Forward movement parallel to ground
Retraction	Pulling back the protracted part
Elevation	Lifting upward
Depression	Moving downward

Passive and accessory movements

The **passive movements** are produced by an external force such as gravity or examining doctor. For example, the doctor holds the patient's wrist so as to immobilize it. He can then flex, extend, adduct and abduct the hand at the wrist. These movements, the patient can normally carry out actively by himself.

By careful manipulation, the examining doctor can also produce a slight degree of gliding and rotation at the wrist. These movements the patient cannot carry out actively by himself, hence they are called **accessory movements**.

Clinical correlation

The assessment of passive and accessory movements is of great value in testing and diagnosing muscle and joint disorders in clinical practice.

Blood supply to synovial joints

It is derived from the periarticular network of arteries (**circulus articularis vasculosus**) that surround the joint. This network is formed from the branches of the arteries lying in the vicinity of the joint. It supplies the capsule, synovial membrane and epiphysis.

N.B.

- Articular cartilages are avascular.
- Fibrous capsules and ligaments have poor blood supply.
- The synovial membrane is richly supplied by the blood. The rich vascular plexus of the synovial membrane also helps to supply nutrition to the periphery of the articular cartilages.

Nerve supply to synovial joints AN2.6

The synovial joints have a rich nerve supply. The nerve fibres supplying the joint are of three types:

1. Sensory nerve fibres conveying pain.
2. Sensory nerve fibres conveying proprioceptive sensations.
3. Autonomic fibres which have vasomotor effects.

The innervation of various structures of a joint is as under:

(a) Capsule is innervated by encapsulated nerve endings (**Ruffini's corpuscles**) and free nerve endings:
  (i) **Encapsulated nerve endings** are sensitive to proprioceptive sensations, *viz*. postural reflexes and position of the joint sense.
  (ii) **Free nerve endings** are sensitive to pain.
(b) Ligaments are supplied by pain sensitive-free nerve endings.
(c) Synovial membrane is innervated by vasomotor sympathetic fibres and pain-sensitive-free nerve endings.
(d) Articular cartilage has no nerves.
(e) Articular discs are insensitive *except* at the attached margins.

Clinical correlation

Hilton's Law: The Hilton's law states that the nerves supplying the joint also supply the muscles regulating the movements of the joint and skin over the joint (Fig. 7.21). **AN 2.6**
If the joint is excessively stretched or suffers from a disease or injury, the irritation of nerves supplying the joint causes muscles acting on the joint to contract in such a way that the joint is brought in a position of maximum comfort to protect the joint. The pain of the joint is referred to as skin overlying the joint.

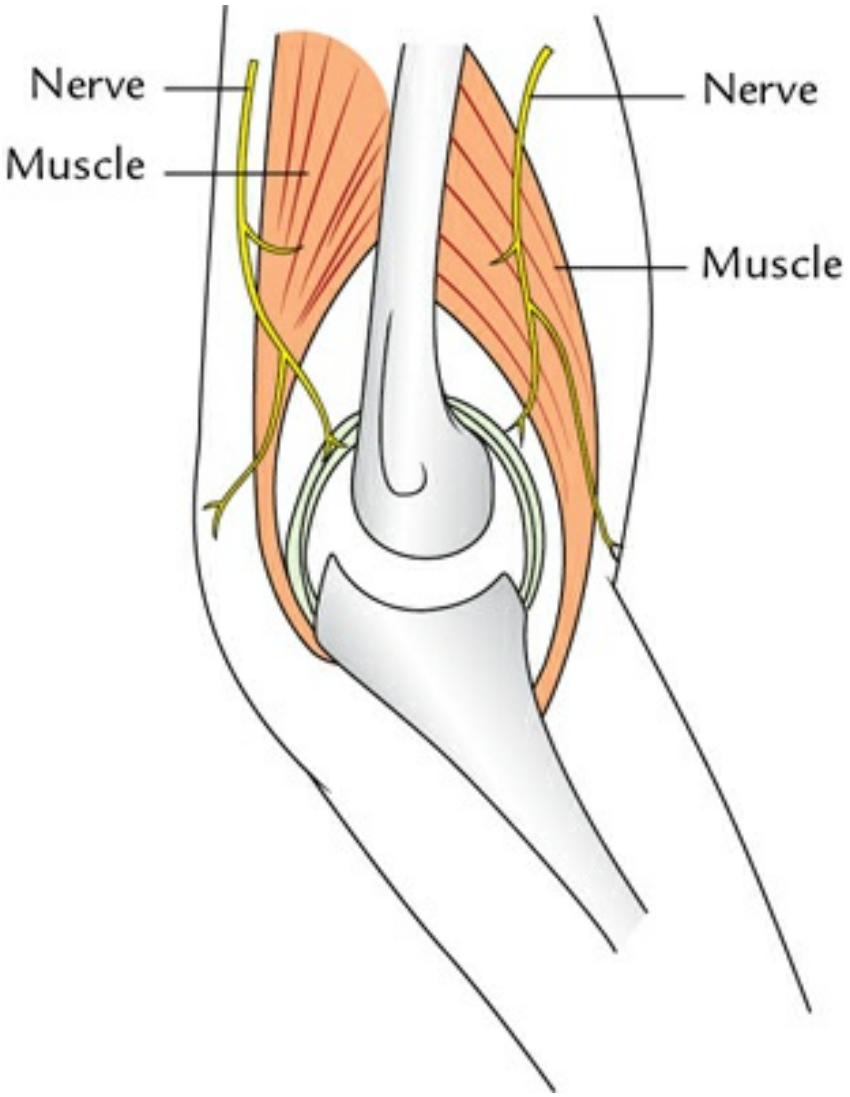


FIG. 7.21 ■ Innervation of synovial joint to depict Hilton's law.

Gardner's observation

The part of the joint capsule which is rendered taut by the contraction of a group of muscles is supplied by a nerve that innervates their antagonist muscles. This is essential to ensure the stability of the joint.

Last's formulation of segmental innervation of muscles regulating

joint movements of the limb (Fig. 7.22)

According to Last's formulation:

(a) Four consecutive spinal segments regulate the movements of each joint in the limb. The upper two segments regulate one movement and the lower two segments regulate the opposite movement.
(b) The joint, one segment distal in the limb is supplied by the centres one segment (en bloc) lower in the spinal cord.

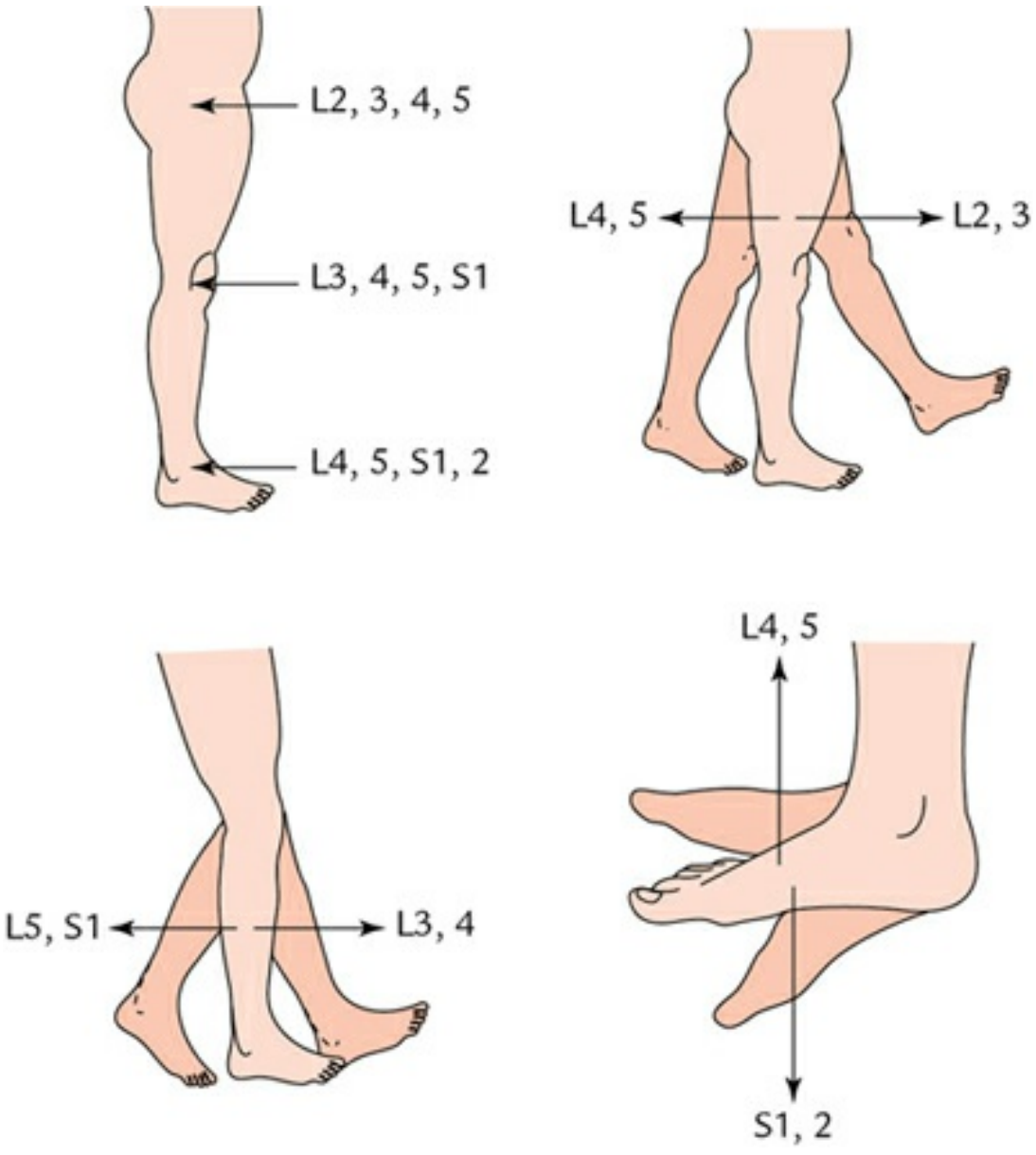


FIG. 7.22 ■ Segmental innervation of muscles regulating the movements of the lower limb.

To cite an example, the innervation and movements of the major joints of lower limbs are given in the boxes below as follows:

(a) Segmental innervation of the joints

Joint	Segmental innervation
Hip	L2, 3, 4 and 5
Knee	L3, 4, 5 and S1

(b) Segments regulating the joint movements

Joint	Segmental regulation	
Hip	Flexion L2, 3	Extension L4, 5
Knee	Extension L3, 4	Flexion L5, S1
Ankle	Dorsiflexion L4, 5	Plantar flexion S1, 2

Factors maintaining the stability of synovial joints

The stability of synovial joints is maintained by the following structures:

1. **Bones:** The bones play an important role in providing the stability to certain joints, e.g.
   (a) In the hip joint the head of the femur is perfectly fitted into the socket of the hip bone, hence acquired dislocation of the hip joint is rare.
   (b) In the ankle joint the talus is caught in tibiofibular mortice formed by medial malleolus, inferior surface of the lower end of the tibia and lateral malleolus.
2. **Ligaments:** The intracapsular and extracapsular ligaments not only provide stability to the joint to prevent its dislocation but also guide and prevent the unwanted movement, e.g.
   (a) Cruciate ligaments within the knee joint provide anteroposterior stability.

(b) The collateral ligaments of the knee joint provide side-to-side stability.

N.B.

Most of the ligaments are made up of bundles of collagen fibres, hence they do not help against a continuous strain because once stretched they tend to remain elongated.

3. **Muscles:** The tone and strength of a different group of muscles acting on the joint provide the *most important and indispensable factor to maintain the stability of the joint.* Once these muscles become weak, flabby or paralyzed, the joint becomes unstable and likely to dislocate.

Clinical correlation

Dislocation of a joint: The lack of support by ligaments, poor shape of articular surfaces, or lack of adequate support by muscles leads to dislocation of a joint. Once the joint is dislocated, the bones forming the joint no longer remain in their normal anatomical relationship with each other. The commonly dislocated joints of the body are the shoulder joint, acromio-clavicular joint and temporo-mandibular joint.

Biomechanics of body movements

Leverage

A lever is a rigid bar that can rotate about a fixed point (**fulcrum**) where force is applied to overcome the resistance. The levers are generally associated with machines but can equally apply to other mechanical structures such as the human body.

In human body, the synovial joint represents the fulcrum (F); the bones form the rigid lever arms that move the resisting object like the weight of the part being moved, gravity, or an external weight (R); the muscles provides the force or effort (E) that causes the lever to move.

Classes of levers

According to the arrangement of the fulcrum (F) in relation to the effort/force (E), and resistance (R), three kinds of levers are classified:

1. First class
2. Second class
3. Third class.

First class lever (Fig. 7.23)

The fulcrum (F) is located between the effort (E) and the resistance (R). A playground see-saw is a good example of the first lever, where the fulcrum (crossbar) is located between a child sitting on one end of the board and pushing it down against the ground (effort) and the weight of the other child sitting at the other end of the board (resistance).

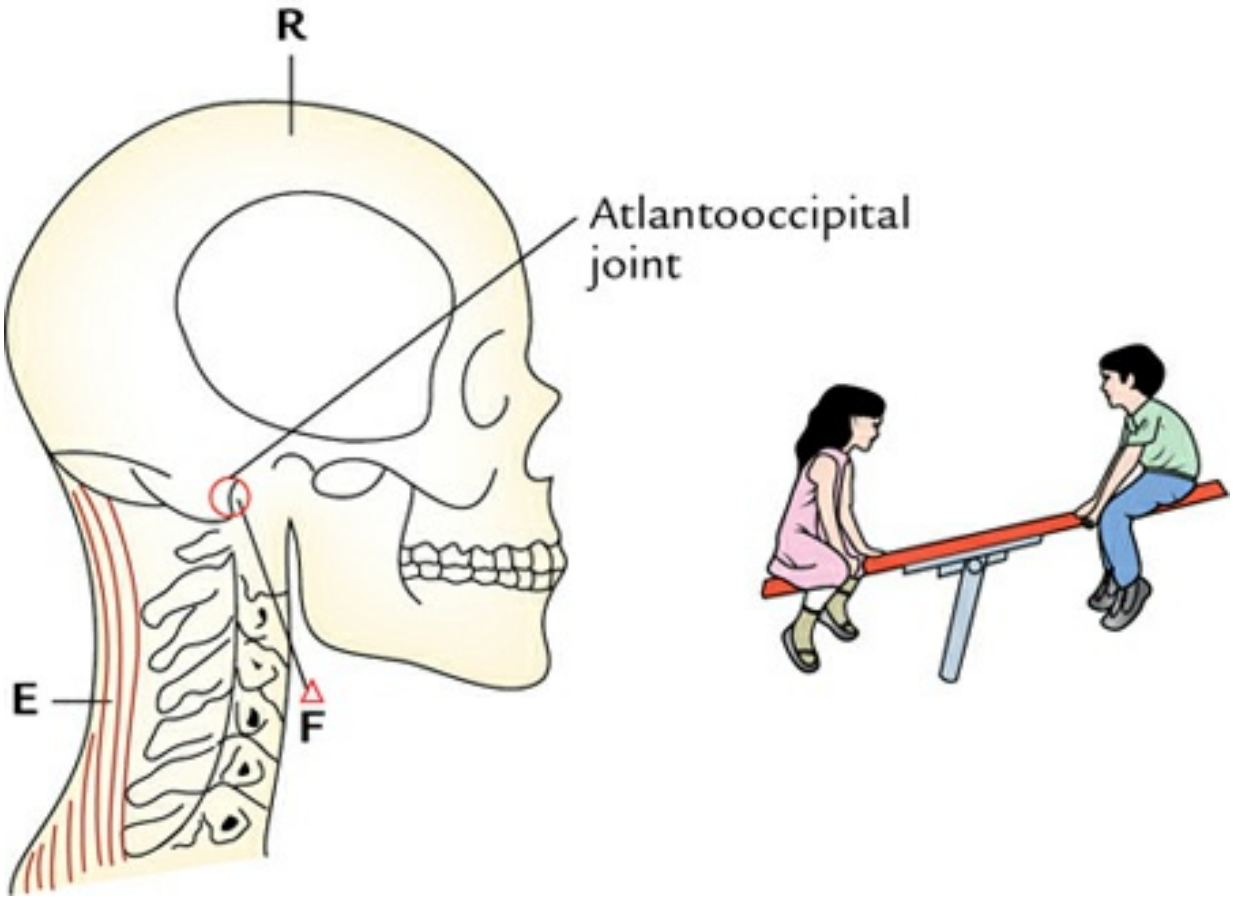


FIG. 7.23 ■ First class lever. (E, effort; F, fulcrum; R, resistance.)

The first lever is best designed for balance. An example of the first class lever in the human body will be the head sitting on the first (atlas) vertebra

and moving forward and backward. Here, atlanto-occipital joint acts as the fulcrum (F), the weight of the cranium and the facial portion of the head acts as resistance (R), and posterior neck muscles that contract to maintain the balance of the head on the joint are the effort (E).

Second class lever (Fig. 7.24)

In second class lever, resistance is positioned between the fulcrum and the effort, an example of a second class lever is a wheel barrow. The wheel at the front end acts as the fulcrum (F), the contents of the wheel barrow act as the resistance (R) and person pushing the wheel barrow acts as the effort (E). The best example of a second class lever in the human body is a contraction of the calf muscle (E) to elevate the body (R) on toes with balls of the foot (metatarso-phalangeal—MP joints) acting as the fulcrum (F).

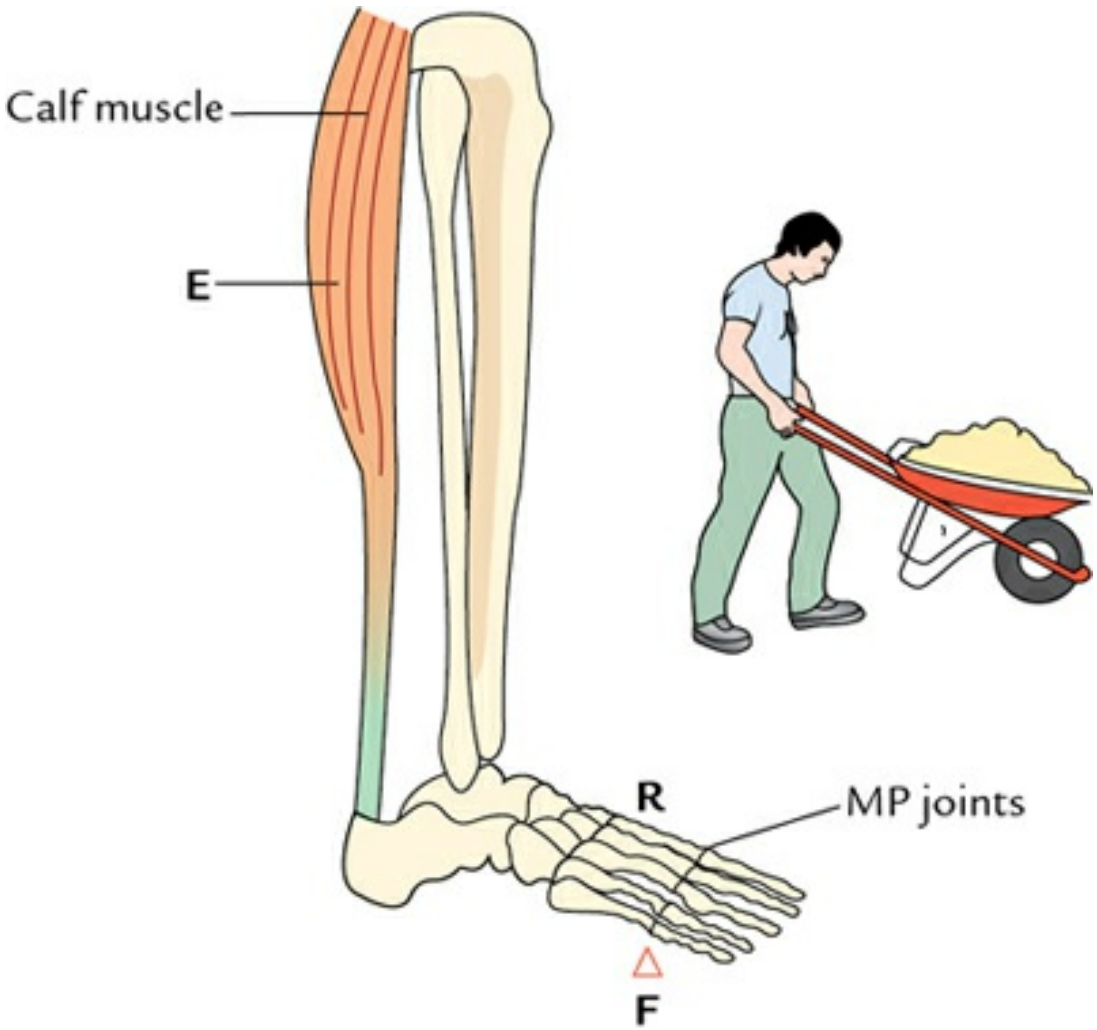


FIG. 7.24 ■ Second class lever. (E, effort; F, fulcrum; R, resistance.)

Third class lever (Fig. 7.25)

In third-class lever, the effort (E) lies between the fulcrum (F) and the resistance (R). An example of a third class lever is a person using a shovel. The hand placed on the part of the handle closest to the blade acts as the force/effort (E) to lift the weight, *viz*. shovel full of dirt acts as resistance (R) and the hand placed near the end of the handle acts as the fulcrum (F). An example of third-class lever in the human body is the flexion of the elbow joint: during the flexion of the elbow, the contraction of the biceps brachii muscle (E) pulling the radius (R) to flex the elbow (F).

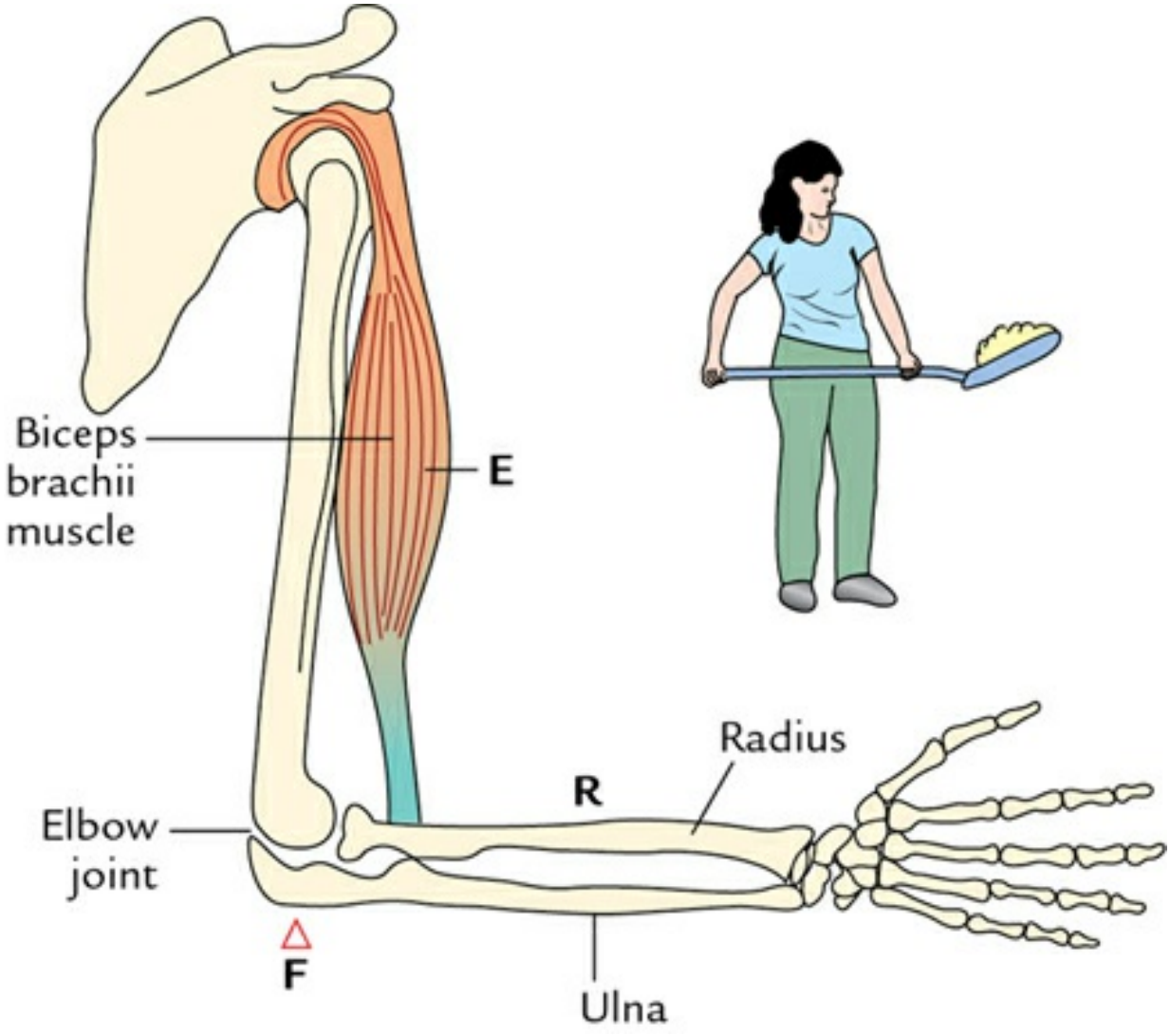


FIG. 7.25 ■ Third class lever. (E, effort; F, fulcrum; R, resistance.)

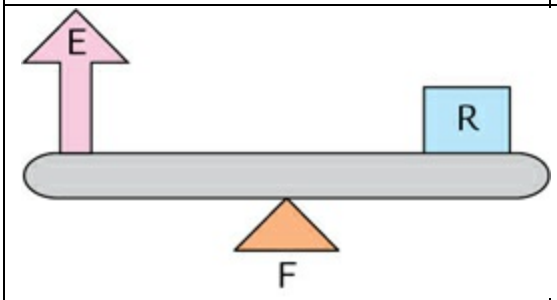
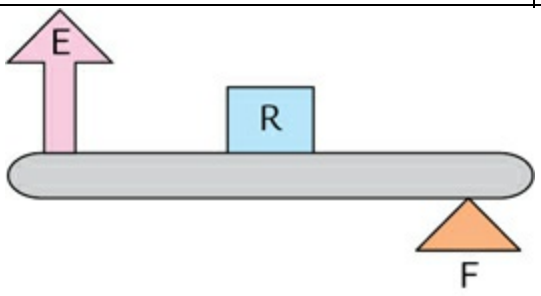
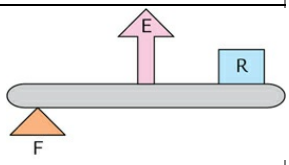
N.B.

- **First class lever** is best designed for balance, e.g. head sitting on the first cervical vertebrae.
- **Second class lever** is best used for power, e.g. action of the calf muscles to elevate the toes.
- **Third class lever** is designed for a range of motion.

The differences between three types of levers are listed in Table 7.4.

TABLE 7.4

Differences between first, second and third class levers

First class lever	Second class lever	Third class lever
	Features	
Fulcrum (F) located between effort (E) and resistance (R)	Resistance located between effort and fulcrum	Effort located between fulcrum and resistance
		
	Uses	
Best suited for balance	Best suited for power	Best suited for range of motion
Requires small amount of effort to lift the weight	Can lift reasonable amount of weight but to a lesser extent	Can lift great weight to a greater extent
	Example in the human body	
Forward and backward movements of head on atlanto-occipital joint	Elevation of foot and entire weight of the body when a person stands on his toes (MP) joints	Flexion of forearm on elbow joint

Position of the joints

Close packed position

It is the position of the joint, in which the articular surfaces are fully congruent and have a maximum area of contact.

All the ligaments are taut and so arranged that they force the articular surfaces to come together in the close-packed position in such a way that they cannot be pulled apart. Thus, two bones forming the joint functionally become one.

In a close-packed position, the joint is most firm and rigid. Hence, usually, there is no dislocation in this position but if it does take place, the damage to intra-articular structure is most likely to occur. The close-packed position of some of the joints is shown in Table 7.5.

 **TABLE 7.5**

Close-packed position of major joints of the body

Joint	Close-packed position
Hip	Extended and medially rotated
Knee	Fully extended
Ankle	Fully extended (dorsiflexed)
Shoulder	Abducted and laterally rotated
Elbow	Fully extended

Loose packed position

The position in which articular surfaces are incongruent is called the loose-packed position. The joint space is freely mobile in this position and hence prone to dislocation.

The loose-packed position of some of the joints is enumerated in Table 7.6.

 **TABLE 7.6**

Loose-packed position of major joints of the body

Joint	Loose-packed position
Hip	Semiflexed
Knee	Semiflexed
Ankle	Plantar flexed
Shoulder	Semiabducted

Golden Facts to Remember

• Largest joint in the body/most complex joint in the body	Knee joint
• Largest ball and socket joint in the body	Hip joint
• Smallest ball and socket joint in the body	Incudo-stapedial joint
• Most common variety of joints in the body	Hinge joints
• Largest symphyses joint in the body	The joint between the bodies of L5 and S1 vertebrae
• All the symphyses in the body belong to axial skeleton *except*	Pubic symphysis which belongs to appendicular skeleton
• Smallest saddle joint in the body	Incudo-malleolar
• Articular cartilages of all synovial joints are made up of hyaline cartilage *except*	Those of temporo-mandibular, sterno-clavicular and acromio-clavicular joints which are made up of fibrocartilage
• Thickest articular cartilage in the body	Articular cartilage of patella
• Most mobile joints in the body	Shoulder joint
• Joint exhibiting maximum types of movements	First carpometacarpal joint
• Most commonly dislocated joint in the body	Shoulder joint (in adults), pulled elbow (in children)

• Most commonly sprained joint in the body	Ankle joint
• Most commonly sprained ligament	Anterior talofibular ligament
• Most common joint to undergo recurrent dislocation	Shoulder joint
• Joint most commonly involved in osteoarthritis	Knee joint
• Joint which disappear after growth of an individual ceases	Primary cartilaginous joint
• Joint most commonly involved in congenital dislocation	Hip joint
• Most common joint disease	Osteoarthritis
• Most stable position of a joint	Close-packed position
• Most unstable position of a joint	Loose-packed position
• Most unstable joint in the body	Shoulder joint
• Most important factor to maintain the stability of a joint	Muscles around the joint
• Strongest ligament in the body	Iliofemoral ligament (also called Bigelow's ligament)
• Most common type of lever in the body	Third class lever

Multiple choice questions

1. **All of the following are the examples of the fibrous joint *except*:**
   (a) Suture

(b) Syndesmosis
(c) Symphysis
(d) Gomphosis

2. **All of the following secondary cartilaginous joints belong to the axial skeleton *except*:**
   (a) Manubriosternal joint
   (b) Intervertebral discs
   (c) Symphysis pubis
   (d) Symphysis menti
3. **All of the following are characteristic features of a synovial (diarthrodial) joint *except*:**
   (a) Articular surfaces are covered by an articular cartilage
   (b) Have a joint cavity filled with synovial fluid for lubrication
   (c) Mostly are freely movable joints
   (d) Articular cartilage is covered by a synovial membrane
4. **Most important factor for the stability of the joint is:**
   (a) Fibrous capsule
   (b) Ligaments
   (c) Atmospheric pressure
   (d) Surrounding muscles
5. **All of the following are the examples of synovial joint *except*:**
   (a) Pivot
   (b) Saddle
   (c) Syndesmosis
   (d) Ellipsoid
6. **All of the following are seen in diarthrosis *except*:**
   (a) Fibrous capsule
   (b) Synovial fluid
   (c) Little or no movement
   (d) Articular cartilage capping the articular surfaces of the bones
7. **All of the following are the examples of saddle joint *except*:**
   (a) Sterno-clavicular joint
   (b) Wrist joint
   (c) Calcaneo-cuboid joint
   (d) Incudo-malleolar joint
8. **All of the following are the examples of the close-packed position of different joints *except*:**
   (a) Extended and medially rotated hip joint

(b) Abducted and laterally rotated shoulder joint
(c) Dorsiflexed ankle joint
(d) Plantar flexed ankle joint

9. **Articular cartilages of all of the following joints are made up of thin plates of fibrocartilage *except*:**
   (a) Temporo-mandibular joint
   (b) First carpo-metacarpal joint
   (c) Sterno-clavicular joint
   (d) Acromio-clavicular joint
10. **Manubriosternal joint is an example of:**
   (a) Symphysis
   (b) Synchondrosis
   (c) Syndesmosis
   (d) Synovial joint
11. **Xiphisternal joint is an example of:**
   (a) Syndesmosis
   (b) Synchondrosis
   (c) Symphysis
   (d) Synovial joint
12. **Which of the following joint is not a fibrous joint?**
   (a) Syndesmosis
   (b) Gomphosis
   (c) Symphysis
   (d) Schindylesis

Answers

1. *c*, **2.** *c*, **3.** *d*, **4.** *d*, **5.** *c*, **6.** *c*, **7.** *b*, **8.** *d*, **9.** *b*, **10.** *a*, **11.** *b*, **12.** *c*

Chapter 8: Vertebral column

Specific learning objectives

After studying this chapter, the student should be able to:

- Describe the structure of the vertebral column.
- Write down the characteristics of a typical vertebra.
- Outline the cardinal features of typical cervical, thoracic and lumbar vertebrae.
- Describe the structure of intervertebral discs and discuss about their prolapse.
- Identify the differences in the facet/zygapophyseal joints in cervical, thoracic and lumbar regions.
- Explain the movements of the vertebral column and discuss their functional significance.
- Describe the curvatures of the vertebral column and discuss their abnormalities. **AN50.1**
- Present an overview of the actions of postvertebral muscles on the vertebral column.
- Describe the intervertebral joints. **AN50.2**
- Describe anatomical basis of scoliosis, lordosis and prolapsed disc. **AN50.4**
- Correctly solve the Multiple Choice questions given at the end of the chapter.

The vertebral column consists of vertebrae and intervening intervertebral discs (Fig. 8.1). The vertebrae contribute three-fourth of the total length of the column, whereas intervertebral discs contribute one-fourth of the total length. The length of the vertebral column amounts to about two-fifth of the total height of the body.

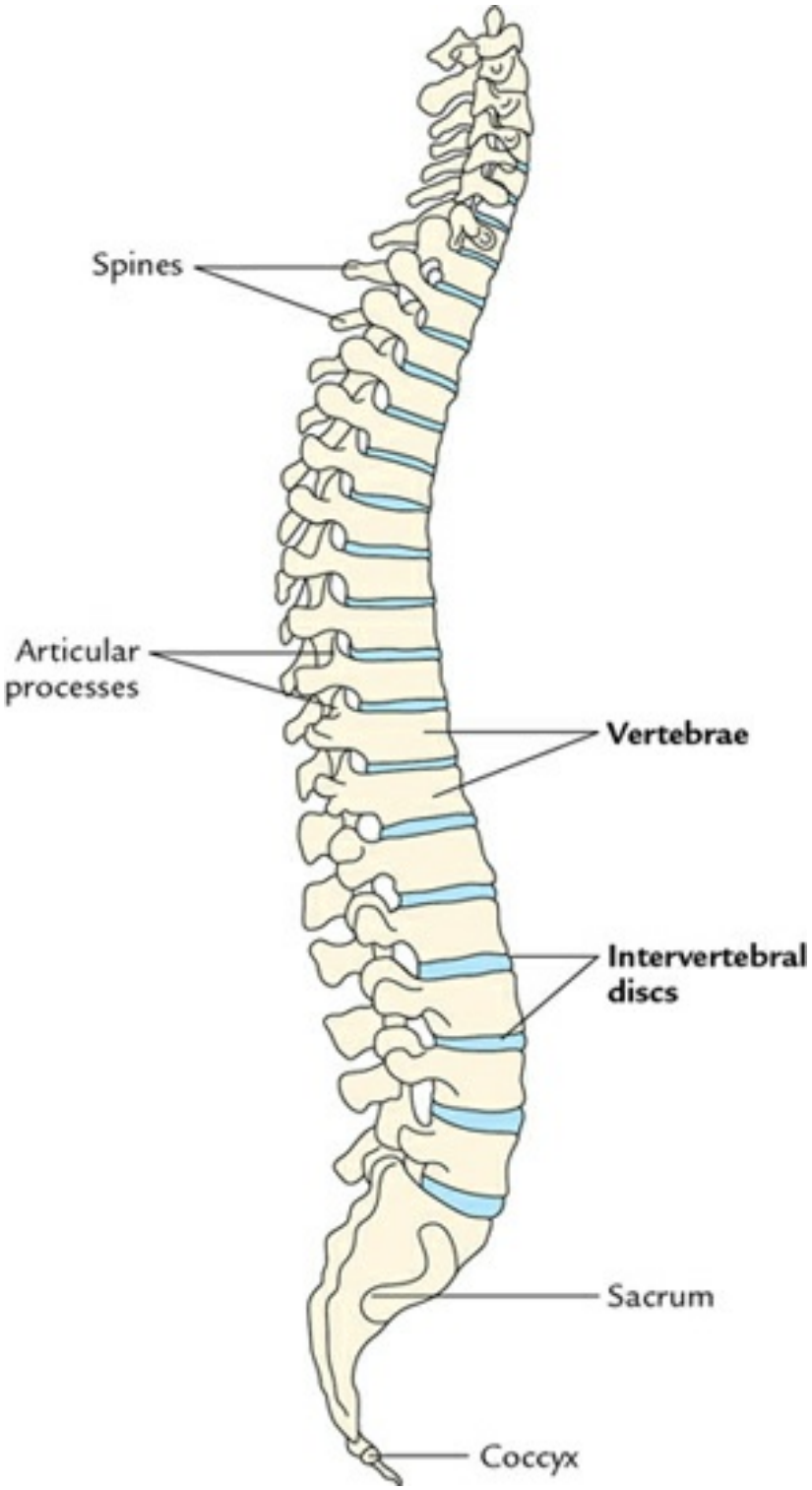


FIG. 8.1 ■ Architecture of the vertebral column (right lateral view).

The vertebral column serves the purpose of affording protection to the spinal cord, supporting the trunk, and transmitting the body weight to the pelvis and lower limbs.

The flexibility and mobility are served by its unique architecture because it is composed of a series of individual and movable segments, placed one over

the other and separated by soft tissue pads—the **intervertebral discs**.

In recent times, there is an alarming increase in the injuries to the vertebral column due to road traffic accidents and its degenerative changes due to sedentary habits. Therefore, detailed knowledge of the vertebral column is of utmost importance to all medical professionals.

Functions of vertebral column

The functions of the vertebral column are:

1. It forms the axis of the trunk.
2. It supports the trunk and transmits the body weight to the pelvis and lower limbs.
3. Its intervertebral discs act as a shock-absorber during running and jumping.
4. It supports the skull.
5. It provides protection to the delicate spinal cord and passage to the spinal nerves.
6. It serves as a surface for the attachment of the muscles.
7. It provides attachment to the ribs, shoulder and pelvic girdles.

Vertebrae

The vertebral column (spine/backbone) extends from base of the skull to the tip of the coccyx. It consists of 33 vertebrae. The 33 vertebrae are classified as 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal (Fig. 8.2).

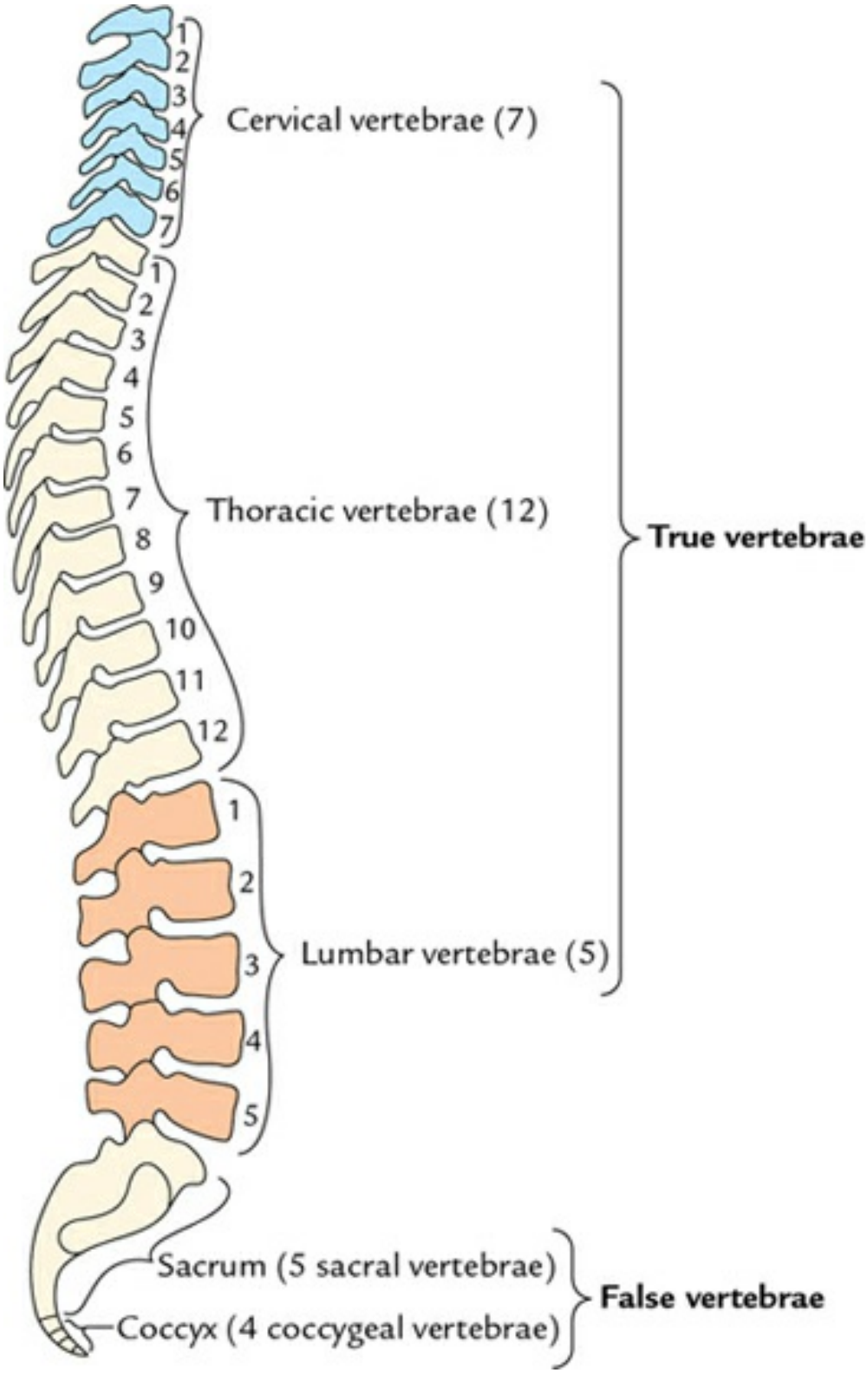


FIG. 8.2 ■ Bony components of the vertebral column (lateral view).

The presacral vertebrae are free and movable. They are 24 in numbers. They comprise 7 cervical, 12 thoracic and 5 lumbar.

The five sacral vertebrae immediately below the lumbar region are fused in

an adult to form the **sacrum**. The lowermost four coccygeal vertebrae are fused in later life to form the **coccyx** also thus the number of separate movable vertebrae in the vertebral column is only 24 and they all lie above sacrum as mentioned earlier.

There are 23 intervertebral discs in vertebral column: 6 in cervical region (neck), 12 in thoracic region (middle back) and 5 in lumbar region (lower back). There is no intervertebral disc between C1 and C2 vertebrae. Further 5th lumbar intervertebral disc lies between L4 vertebra and sacrum (S1vertebra).

The vertebral column is a semirigid structure and forms the axis of the axial skeleton. The movements of the neck trunk and back occur around it.

It is about 70 cm long in males and 60 cm in females.

True and false vertebrae

In the *cervical, thoracic* and *lumbar* regions, the vertebrae are separate and movable and are known as **true vertebrae**. In the sacral and coccygeal regions, they are fused and are known as **false vertebrae**.

The vertebrae in each region not only have features characteristic to that region but also some vertebrae in each region has one or more distinguishing features of its own. They are called **atypical vertebrae**.

However, each vertebra is built on the same general plan and therefore has many characteristics in common. The **'typical characters' of a vertebra** are seen best in the mid-thoracic region.

Characteristics of a typical vertebra

The following description deals with the typical thoracic vertebra of the mid-thoracic region.

Each vertebra is composed of the following parts (Fig. 8.3):

- **Body,** the weight-bearing part.
- **Vertebral arch** that protects the spinal cord.
- **Spinous process** that acts as a lever.
- **Right and left transverse processes** that act as levers.

- **Articular processes** (two superior and two inferior) that help to restrict the movements.
- **Spinous process** provides attachment to muscles and ligaments.

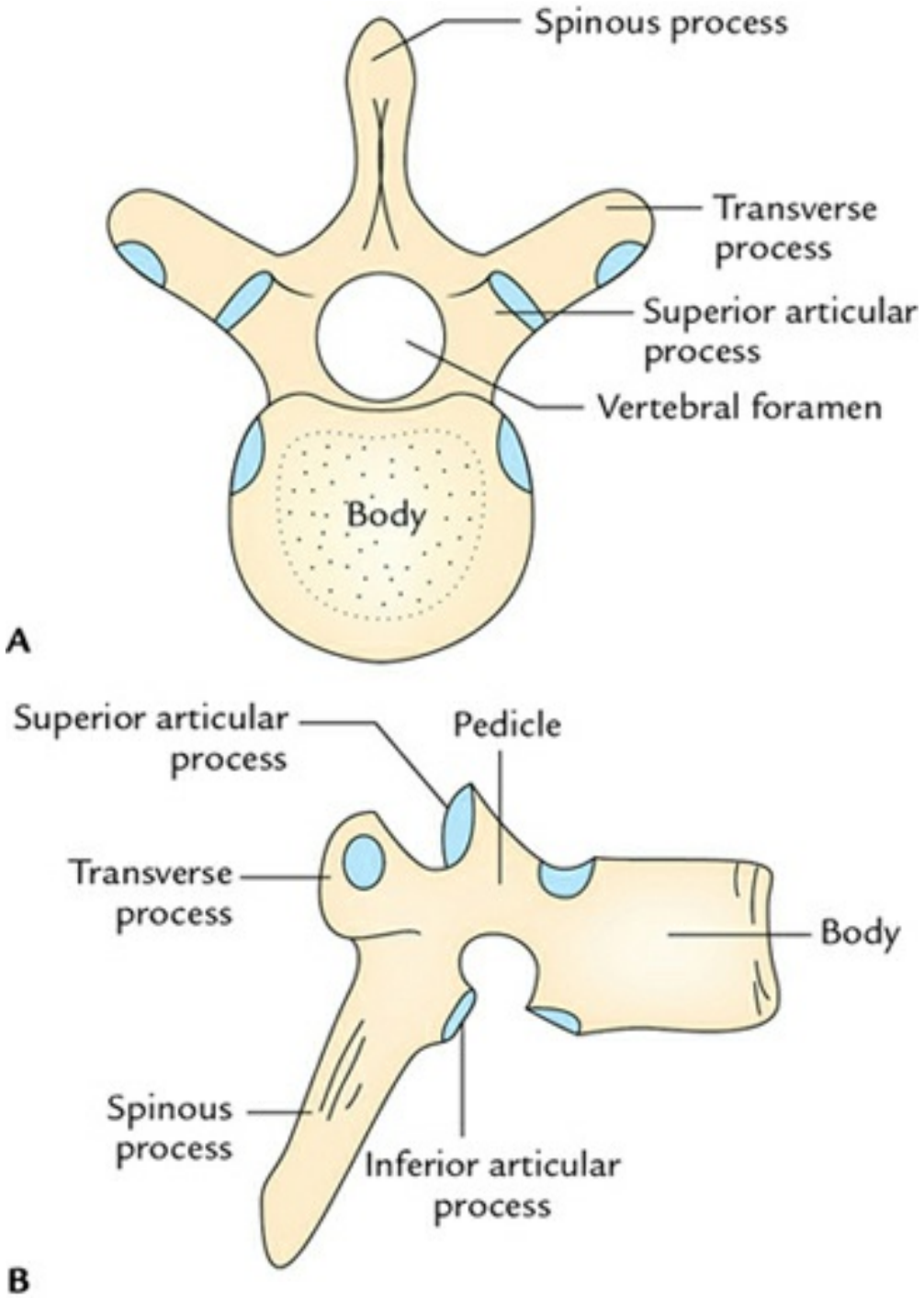


FIG. 8.3 ■ A typical thoracic vertebra showing parts of a vertebra: **(A)** superior view and **(B)** lateral view.

N.B.

The typical vertebra consists of nine parts:

- ***Two major parts:*** vertebral body and vertebral arch
- ***Seven processes:***
  - *Three paired processes,* viz. transverse, superior and inferior articular processes
  - *One unpaired process*—the spinous process

Body

The body of the vertebra is situated anteriorly. It gives strength and supports the weight. It consists mostly of spongy bone covered by an outer shell of compact bone. The spongy bone contains red bone marrow. The body is separated from the bodies of the vertebrae above and below by an intervertebral disc. The size of vertebral bodies varies with the site. It is smallest in the cervical region and becomes larger and longer towards the lumbar region.

In the cervical region, the superior surfaces of the vertebral bodies are saddle-shaped with flange-like lips arising from most of their lateral circumference. These flange-like lips are called **uncinate or neurocentral processes**. Between C3 and C7 vertebrae, the neurocentral processes of the inferior vertebral body articulate with the bevelled lateral border of the superior vertebral body forming **neurocentral joints of Luschka**.

These joints are synovial in nature and commonly involved in **cervical spondylosis** (osteoarthritis of the cervical spine).

Clinical correlation

Cervical spondylosis: It is the most common clinical condition affecting the cervical spine (neck). The degenerative changes appear during the third decade of life. The earliest changes are confined to the intervertebral discs but soon the *facet and uncovertebral joints* are also involved. The disc space between C5 and C6 is most frequently involved. The spondylosis causes

restriction of movements and nerve root pain.

Vertebral (neural) arch

It is posterior to the body. Each vertebral arch with the posterior surface of the body encloses a large vertebral foramen. The series of arches along with vertebral bodies forms the **vertebral canal**. In adult, the upper two-thirds of the vertebral canal is occupied by the spinal cord. Each half of the vertebral arch is divided into two parts, a **pedicle** and a **lamina**.

The two laminae meet in the midline posteriorly to form the **spinous process**. Each lamina is attached to the posterolateral aspect of the body by a rounded bar of bone called a **pedicle**. The **ligamenta flava** connect the laminae of adjacent vertebrae.

The pedicle is notched superiorly and inferiorly forming **superior and inferior vertebral notches**, respectively. The inferior vertebral notch is deeper than the superior vertebral notch.

Spinous process

It projects posteriorly from the site of the union of the right and left laminae of vertebrae. The spinous processes are interconnected by **ligamentum nuchae**, **supraspinous** and **interspinous ligaments**.

Transverse processes

The transverse processes project laterally on each side from the junction of a pedicle and a lamina.

N.B.

The movement of one vertebral body over the other is affected, in part, by the actions of muscles on the lever-like transverse and spinous processes.

In the cervical region, the transverse processes possess a foramen called

foramen transversarium. The upper six foramina transversaria transmit all-important vertebral artery.

In the thoracic region, the transverse processes act as struts for the ribs. Consequently, they are strong and stout. Their tips bear articular facets for the ribs except for the transverse processes of the 11th and 12th vertebrae because they do not articulate with the 11th and 12th ribs (called floating ribs).

In the lumbar region, the transverse processes are thin and flat, and in conformity to the rounded shape of the abdominal cavity, they are directed slightly posteriorly.

Morphology of the transverse processes

As mentioned earlier, the transverse processes project laterally from the vertebral arch at the pediculo-laminar junctions.

The costal elements (*pleurapophyses*) develop as basic parts of the vertebral arches in mammalian embryos but become independent only in thoracic vertebrae as ribs. Elsewhere they remain less developed and fuse with the corresponding transverse processes.

Thus, except in the thoracic region, a transverse process consists of two elements, a **costal element** and a **true element** (morphological transverse process; Fig. 8.4).

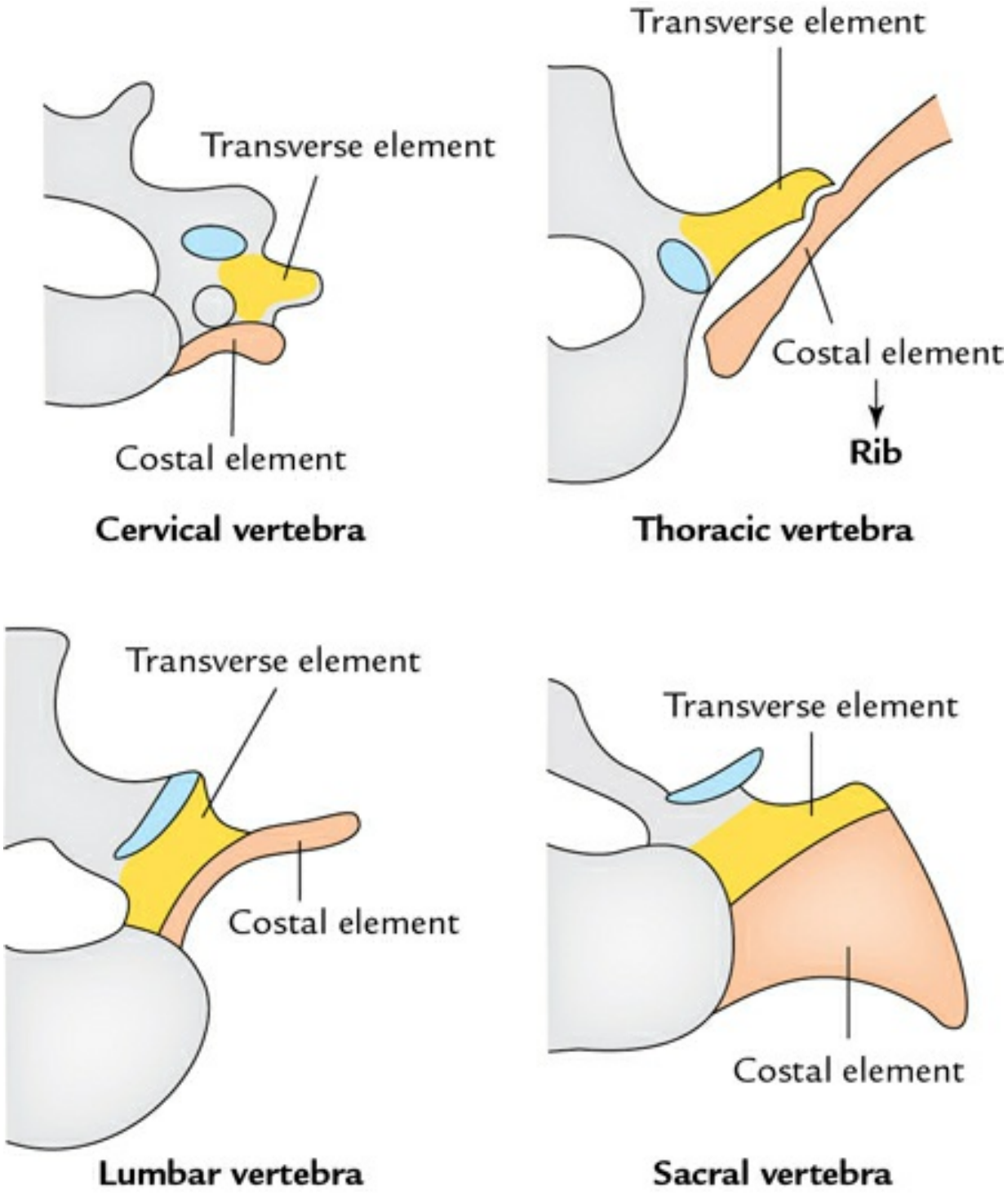


FIG. 8.4 ■ Transverse and costal elements of transverse processes of cervical, thoracic, lumbar and sacral vertebrae.

Articular processes

The neural arch has four articular processes: two superior and two inferior.

The superior processes project rather more from pedicles and articulate with the inferior articular processes of the vertebra above. The inferior articular processes spring from the laminae and articulate with superior articular processes of the vertebra below.

The superior and inferior articular processes are above and below the junction of pedicle and lamina, and the part of the arch which separates these processes is called **pars interarticularis**.

Direction of articular surfaces of the articular processes

The direction of articular surfaces differs in the cervical, thoracic and lumbar regions.

The articular surfaces of superior articular processes face:

(a) backwards and upwards in the **cervical region**,
(b) backwards and laterally in the **thoracic region** and
(c) backwards and medially in the **lumbar region**.

The articular surfaces of inferior articular processes are directed opposite to those of superior articular processes.

Zygapophyseal joints/facet joints

The joints between the superior and inferior articular processes of adjacent vertebrae are called **zygapophyseal joints**. They are synovial joints. A thin articular capsule attached to the margins of the articular facets encloses the joint cavity.

In the cervical region, the zygapophyseal joints slope inferiorly from anterior to posterior. This allows one to look sideways and upwards. The direction of these joints differs in cervical, thoracic and lumbar regions (Fig. 8.5).

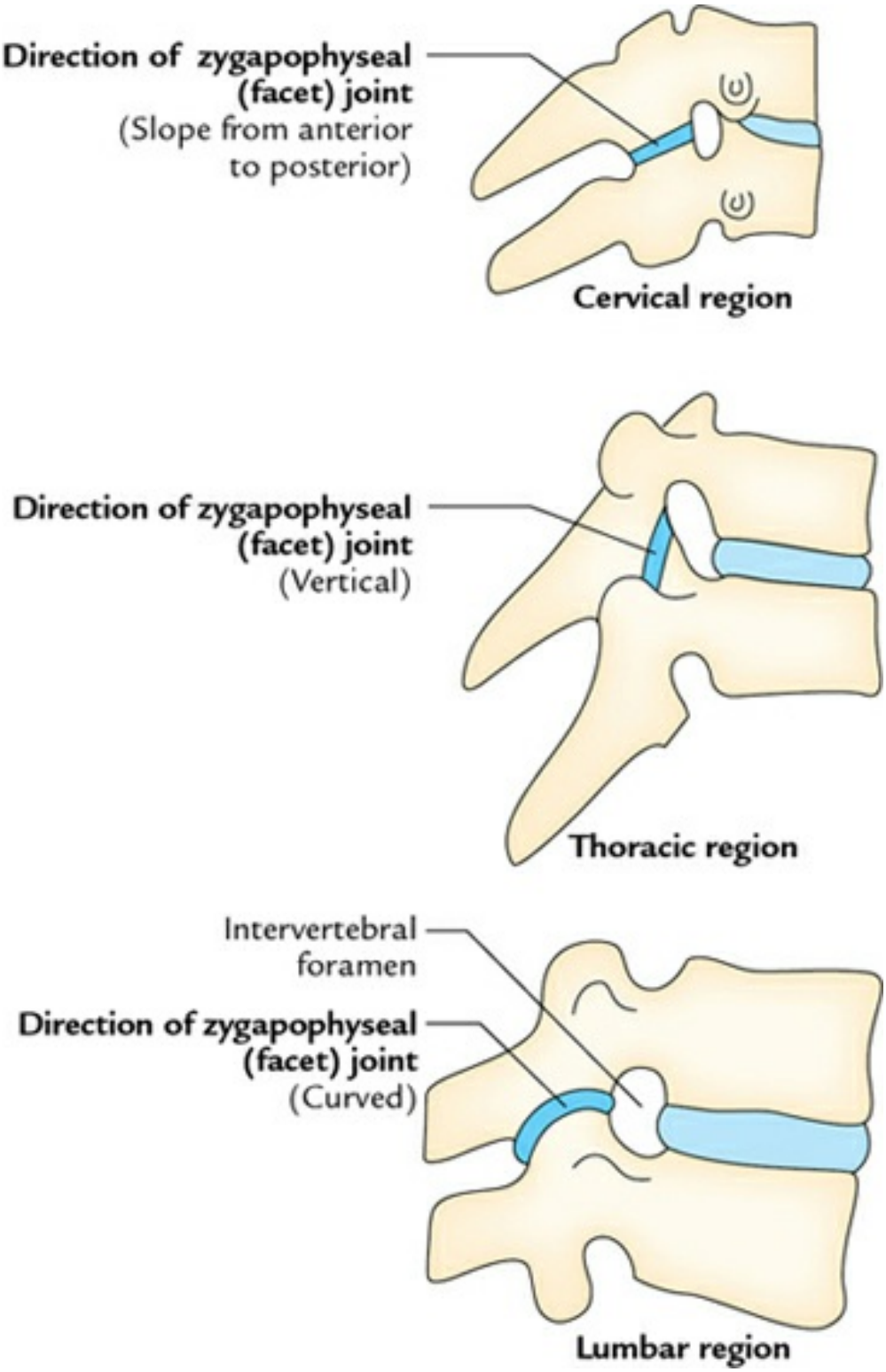


FIG. 8.5 ■ The direction of zygapophyseal (facet) joints in cervical, thoracic and lumbar regions of the vertebral column shown in the lateral view. Note the orientation of facet joints in 3 different regions.

In the thoracic region, the zygapophyseal joints are oriented vertically. This limits flexion and extension but facilitates rotation.

In the lumbar region, the joint surfaces of zygapophyseal joints are curved,

and adjacent articular processes interlock. This limits the range of movements in this region, though flexion and extension still remain the major movements in the lumbar region.

N.B.

In all three regions (cervical, thoracic and lumbar), the zygapophyseal joints prevent the vertebrae from slipping forward but allow the flexion and extension of the vertebral column.

Intervertebral foramina

The two adjacent vertebral notches together form an intervertebral foramen which can be seen when two adjacent vertebrae are viewed from the side (Fig. 8.6). Encircling the vertebral foramen are two pedicles, an intervertebral disc, two articular processes forming facet joint, and a capsule uniting them.

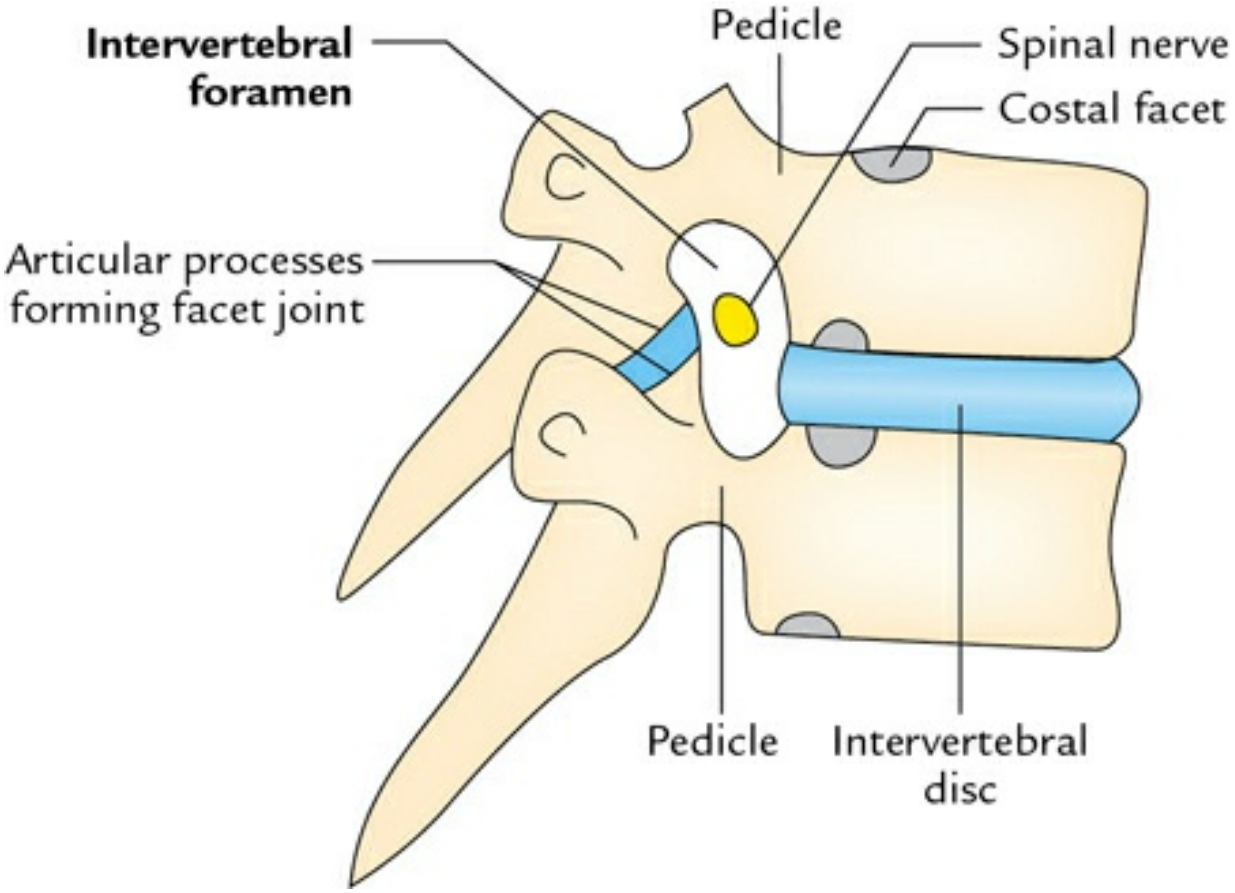


FIG. 8.6 ■ Location and boundaries of the intervertebral foramen.

Throughout the length of the vertebral column, intervertebral foramina provide passage to the spinal nerves. Each spinal nerve is attached to the spinal cord by a posterior and an anterior root (Fig. 8.7). The close relationship of the spinal nerve to the intervertebral disc is very important for it is compressed in disc prolapse producing neurological signs and symptoms.

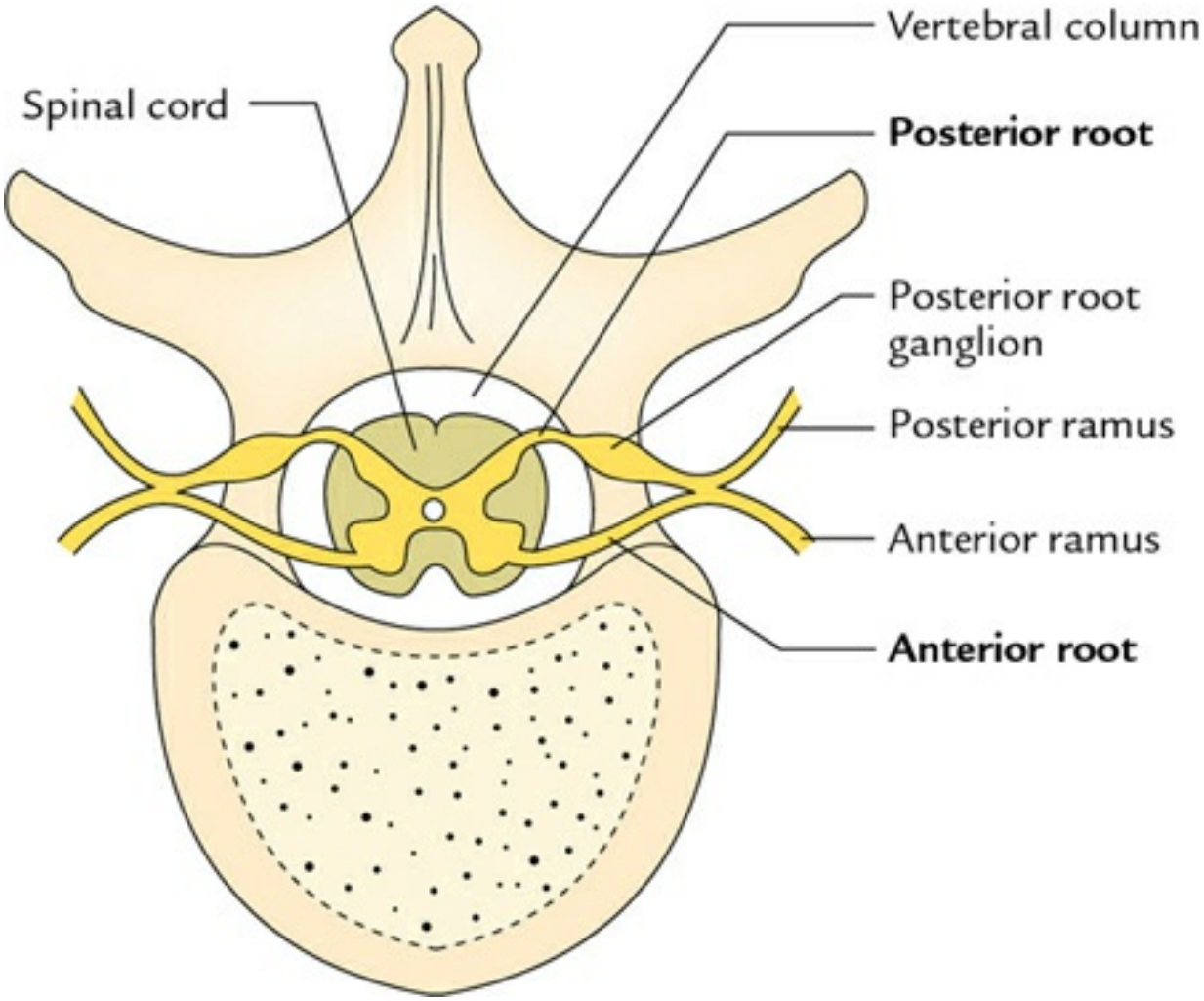


FIG. 8.7 ■ Location of spinal cord and roots of spinal nerves in the vertebral canal and intervertebral foramen, respectively.

Spaces between vertebral arches

The laminae and spinous process of adjacent vertebrae overlap in most parts of the spine, however, in the lumbar region where they leave a big gap between them. These spaces are widened further by flexion of the spine to

allow easy access to the vertebral canal to perform clinical procedures, viz. lumbar puncture.

N.B.

Nucleus pulposus of the intervertebral disc usually herniates posterolaterally, compressing a nerve root.

Clinical correlation

Radiographs of vertebral column: They are usually taken in anteroposterior and lateral views.

(a) In the *anteroposterior view,* the spinous processes appear as elongated shadows while pedicles appear as ovoid shadows.
(b) In *lateral view,* the bodies and intervertebral discs are clearly seen.

Special features of vertebrae in different regions

Cervical vertebrae

The transverse processes of cervical vertebrae possess a foramen called *foramen transversarium* for the passage of a vertebral artery (except for C7) to supply the brain (Fig. 8.8). The foramen transversarium is the cardinal feature of the cervical vertebrae. Their spine is bifid.

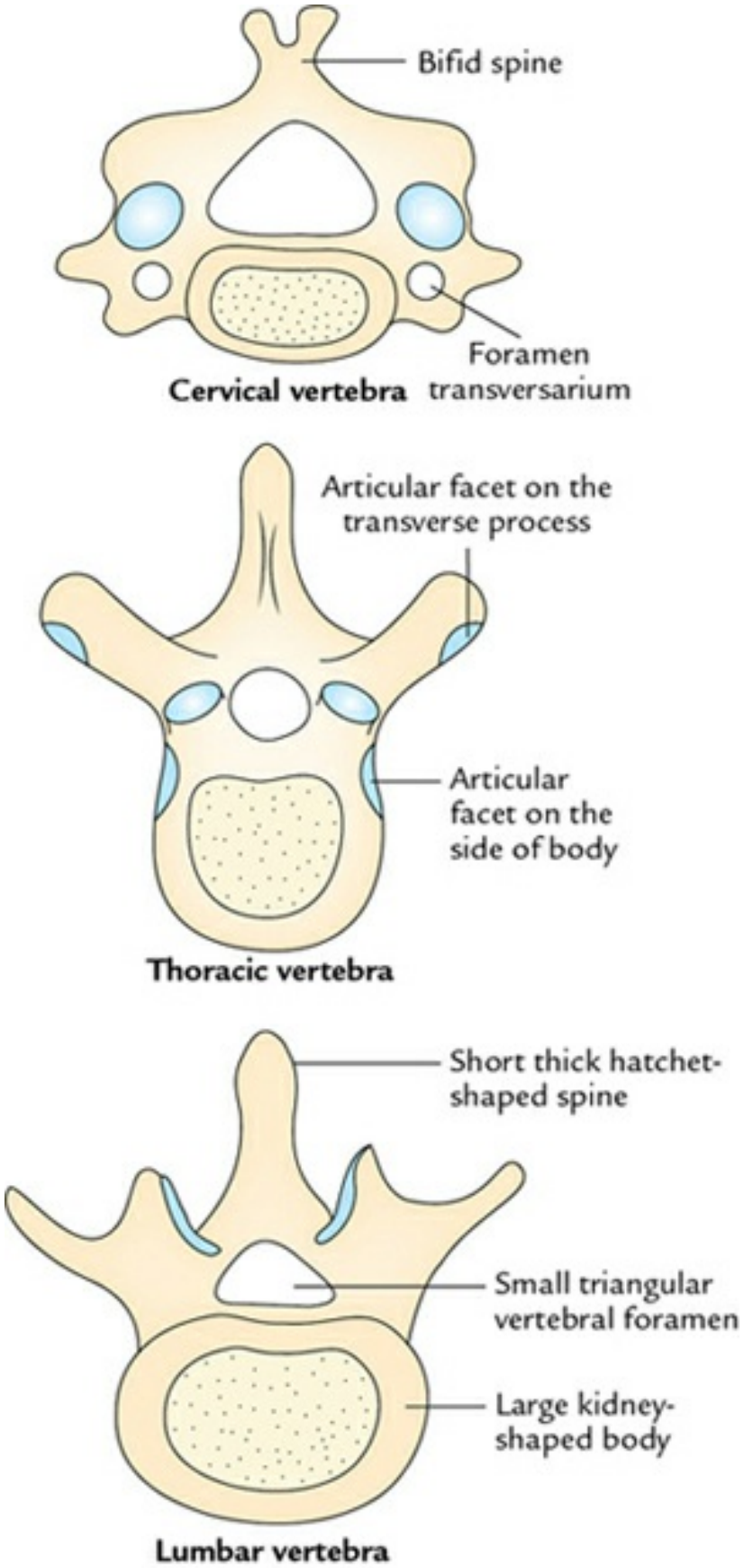


FIG. 8.8 ■ Special features of vertebrae in cervical, thoracic and lumbar regions.

The first cervical vertebra consists simply of a ring of bone with two short transverse processes. Remember, the first cervical vertebra has neither body nor spine. The anterior part of the large vertebral foramen is occupied by the dens (also called the odontoid process), a tooth-like projection from the body of the axis. The odontoid process of the axis is held in position by the transverse ligament of the atlas. The posterior part of the vertebral foramen is occupied by the spinal cord.

The two superior articular facets on the superior aspect of the atlas bone form the joints with the condyles of the occipital bones called atlanto-occipital joints. The nodding movements ('yes' movements) of the head take place at these joints.

N.B.

The first cervical vertebra is called the *atlas* and supports the head. It is named after *Atlas*, a famous Greek Titan, who according to a Greek myth was reputed to support the heavens on his shoulders.

The second cervical vertebra has a small body with an upward projecting tooth-like process—the dens or odontoid process that articulates with the first cervical vertebra—the atlas to form the median atlanto-occipital joint. The presence of the *odontoid process* is the *cardinal feature* of the second cervical vertebra. This joint allows the side-to-side movements ('no' movements) of the head.

The second cervical vertebra is called the *axis* because it forms the pivot around which the atlas (carrying head) rotates like a wheel. The term 'axis' is derived from the Sanskrit word *aksha* meaning pivot.

Thoracic vertebrae

The bodies and transverse processes of thoracic vertebrae possess the articular facets for articulation with the ribs. The **articular facets** on the sides of the body for articulation with ribs form the cardinal feature of thoracic vertebrae (Fig. 8.8).

Lumbar vertebrae

The lumbar vertebrae have large kidney-shaped bodies. The spinous processes are broad and hatchet-shaped (in profile view). The special feature of lumbar vertebrae is the presence of mammillary and accessory processes; they are, however, visualized only on careful examination (Fig. 8.8).

The **cardinal features** of cervical, thoracic and lumbar vertebrae are given in Table 8.1.

TABLE 8.1

Cardinal features of cervical, thoracic and lumbar vertebrae

Vertebrae	Cardinal feature
Cervical	Presence of foramen transversaria
Thoracic	Presence of costal facets on the body
Lumbar	Presence of mammillary and accessory processes

Sacrum

It is a triangular wedge-shaped bone formed by the fusion of five rudimentary sacral vertebrae.

The upper aspect of the body of the first sacral vertebra articulates with the body of the fifth lumbar vertebra. On each side, upper part of the sacrum articulates with ilium to form the strong sacroiliac joint. The inferior tip of the sacrum articulates with base of the coccyx. Cavity within the sacrum (**sacral canal**) contains roots of sacral and coccygeal nerves.

Coccyx

It is a small triangular bone formed by the fusion of four terminal rudimentary vertebrae. The broad base of the coccyx articulates with the tip of the sacrum. The coccyx represents the tail of human beings.

Intervertebral discs

The intervertebral discs lie between the vertebral bodies (Fig. 8.9). They constitute about 25% length of the vertebral column. They increase in size from above downwards. The disc between the 5th lumbar vertebra and sacrum is the largest. In cervical and lumbar regions, cervical vertebrae are thicker in front than behind.

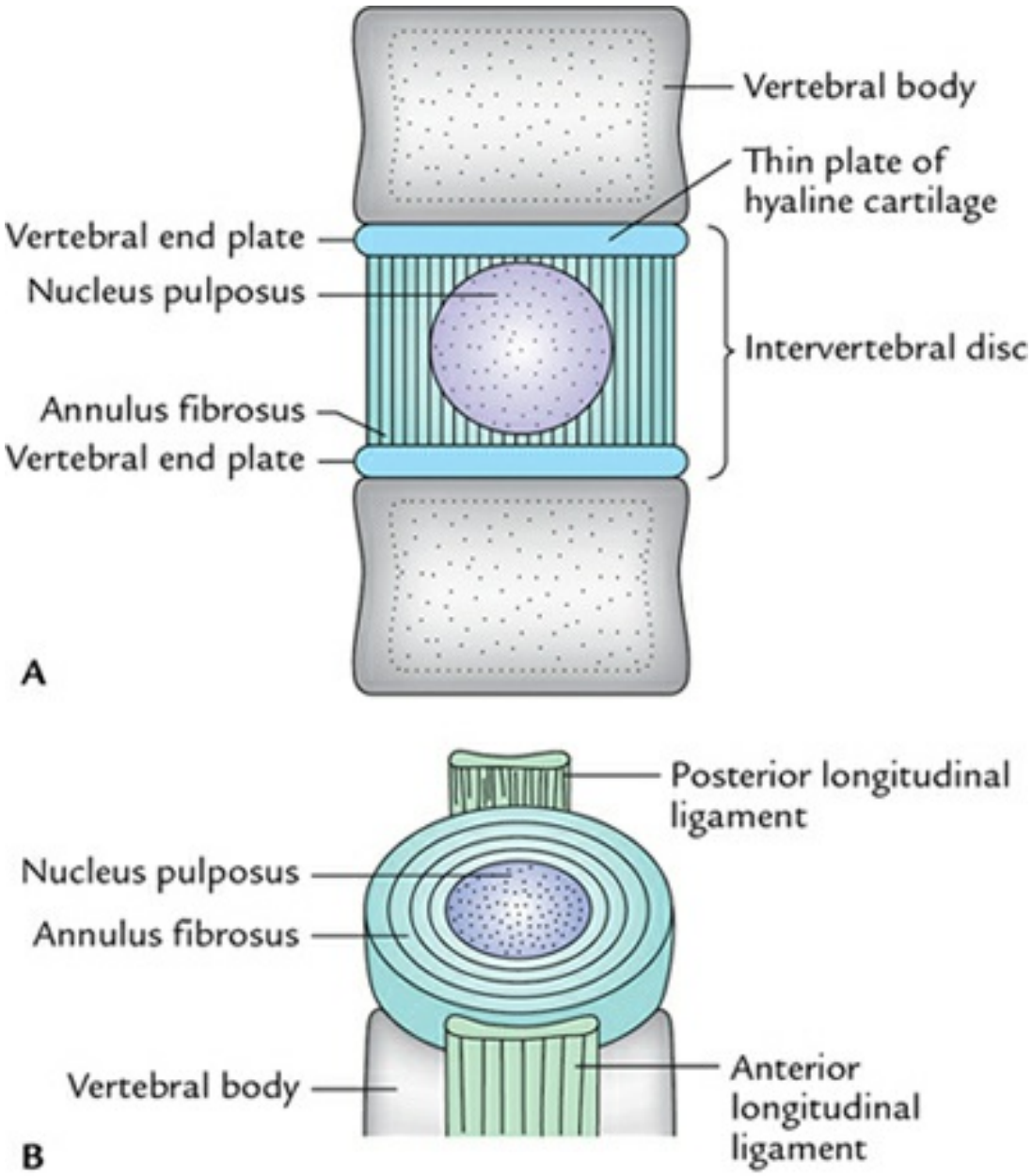


FIG. 8.9 ■ Structure of an intervertebral disc: **(A)** anterior view and **(B)** superior view of the transverse section.

The first Intervertebral disc is located between C2 and C3 vertebrae and

last i.e. 23rd intervertebral disc is located between L5 and S1 vertebrae.

Structure

The disc consists of three distinct parts: (a) **two vertebral end plates,** (b) an outer rim of fibrocartilage called **annulus fibrosus** and (c) a central core of soft gelatinous (jelly-like) material called **nucleus pulposus** (remnant of embryonic notochord) which acts as cushion or shock-absorber.

Although the nucleus pulposus is central in cervical and thoracic regions, in the lumbar region it lies slightly more posteriorly.

The water content of the nucleus pulposus decreases with age. In newborn infants, the water content is almost 90%, but with advancing age, it decreases so that in elderly individuals, it is under 70%. When the vertebral column is exposed to an increased load, it acts as a hydraulic shock absorber. The semifluid character of the nucleus pulposus permits it to adapt itself readily to the changes in its form as one vertebra rocks over another during the movements of the vertebral column.

The **annulus fibrosus** consists of many concentric layers of collagenous fibres. This arrangement of fibres limits the rotation between the vertebrae. The annulus is slightly thinner posteriorly than what it is anteriorly and can rupture, particularly in the lumbar region.

In the lumbar region, the discs become somewhat thicker anteriorly, especially between L4 and L5, and between L5 and S1.

The degenerative changes in the annulus fibrosus can lead to herniation of the nucleus pulposus, inappropriately called a **slipped disc**.

Along with cartilaginous end plate—the plates of hyaline cartilage covering the vertebral bodies, the intervertebral disc forms a *secondary cartilaginous joint (symphysis)*. The intervertebral discs are kept in position by the anterior and posterior longitudinal ligaments of the vertebral column.

The **anterior longitudinal ligament** extends the whole length of the column and lies in front of the vertebral bodies.

The **posterior longitudinal ligament** also extends the whole length of the vertebral column and lies inside the vertebral canal in close contact with the vertebral bodies.

The anterior longitudinal ligament is a broad strong band whereas the

posterior longitudinal ligament is weak and narrow.

Functions

The functions of intervertebral discs are:

1. Act as a shock absorber when the shock is given to the spine by weight transmission, muscle pull or movements.
2. Allow movements.
3. Constitute 25% length of spine (i.e. vertebral column).

Clinical correlation

Slipped disc: The protrusion of the nucleus pulposus through a tear in the annulus fibrosus is termed as the slipped disc (Fig. 8.10). The prolapse generally occurs posterolaterally, but sometimes it may occur posteriorly.

Posterior prolapse directly presses the spinal cord, whereas posterolateral protrusion presses on the roots of the spinal nerves and their sensitive covering leading to pain in the area of distribution of nerve root (root pain).

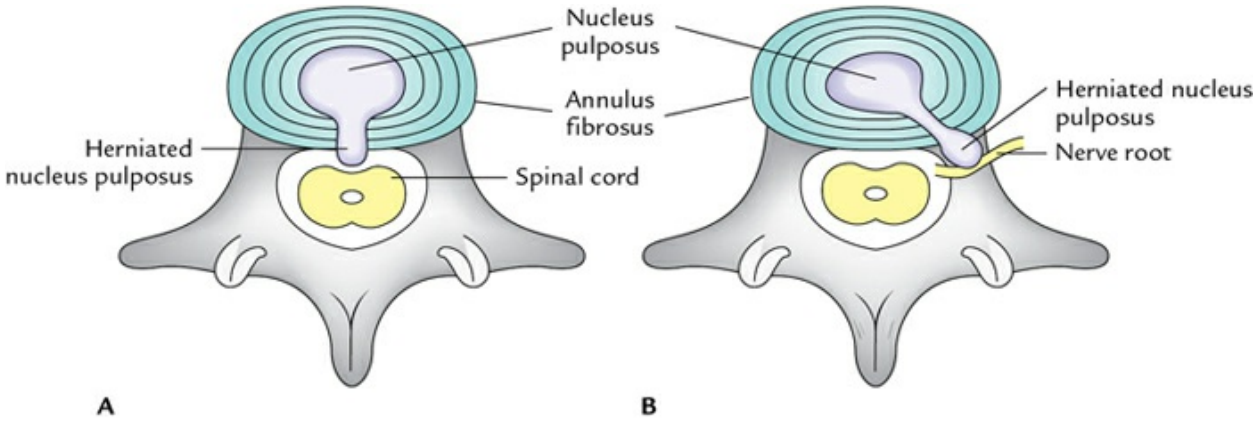


FIG. 8.10 ■ Slipped disc (prolapse (herniation) of nucleus pulposus): **(A)** posterior herniation and **(B)** posterolateral herniation.

The disc prolapse is generally seen in cervical and lumbar regions:

1. **Cervical disc prolapse**: The prolapse of the disc in the cervical region is less common than in the lumbar region. The disc between C5/C6 or C6/C7 is most susceptible.
2. **Lumbar disc prolapse**: The prolapse of the disc is common in the

lumbar region. The discs between L4/L5 and L5/S1 are more susceptible. The commonest presenting symptom is **low backache** (*lumbago*).

The important clinical features of a prolapsed disc at various vertebral levels are presented in Table 8.2.

TABLE 8.2

Important clinical features of a prolapsed disc at various vertebral levels

Herniated disc	Compressed nerve root	Area of sensory loss/pain	Muscles affected	Movement affected	Reflex involved
Between C4/C5	C5	Shoulder and lateral aspect of the arm	Deltoid, biceps	Abduction of the arm, flexion of the forearm	Biceps jerk
Between C5/C6	C6	Lateral aspect of forearm and hand	Extensor carpi radialis longus, brachioradialis	Extension of wrist	Supinator jerk
Between L4/L5	L5	Lateral aspect of the thigh, leg and dorsum of the foot	Tibialis anterior, extensor hallucis longus, extensor digitorum longus	Dorsiflexion of the ankle (cannot stand on heels)	None
Between L5/S1	S1	The posterolateral aspect of the calf, lateral border of the foot	Gastrocnemius, soleus	Plantar flexion of the ankle (cannot stand on toes)	Ankle jerk

The disc between L5 and S1 is most commonly herniated. It compresses the S1 nerve root.

The herniated disc can be well located by an MRI (Fig. 8.11). Sometimes the plate of hyaline cartilage covering the body of the vertebra cracks following

the fracture of the vertebral body. This leads to herniation of the nucleus pulposus into a spongy part of the body forming a nodule (Schmorl's node) that may be detected in a radiograph.

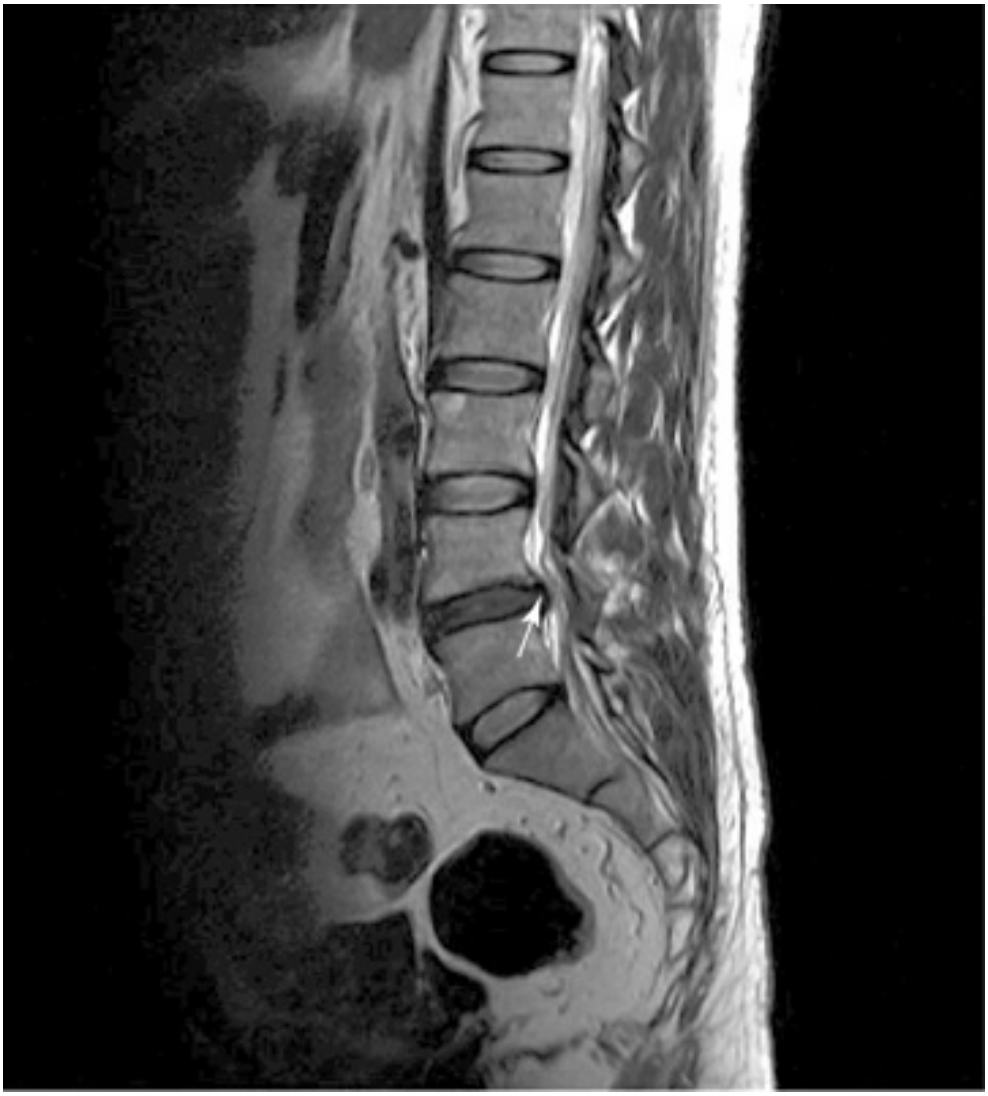


FIG. 8.11 ■ MRI of the lumbar region showing herniation of intervertebral disc between L4/L5 (arrow).

Curvatures of the vertebral column

When viewed from the side, adult vertebral column presents four curvatures (Fig. 8.12):

1. Cervical
2. Thoracic

3. Lumbar
4. Sacral.

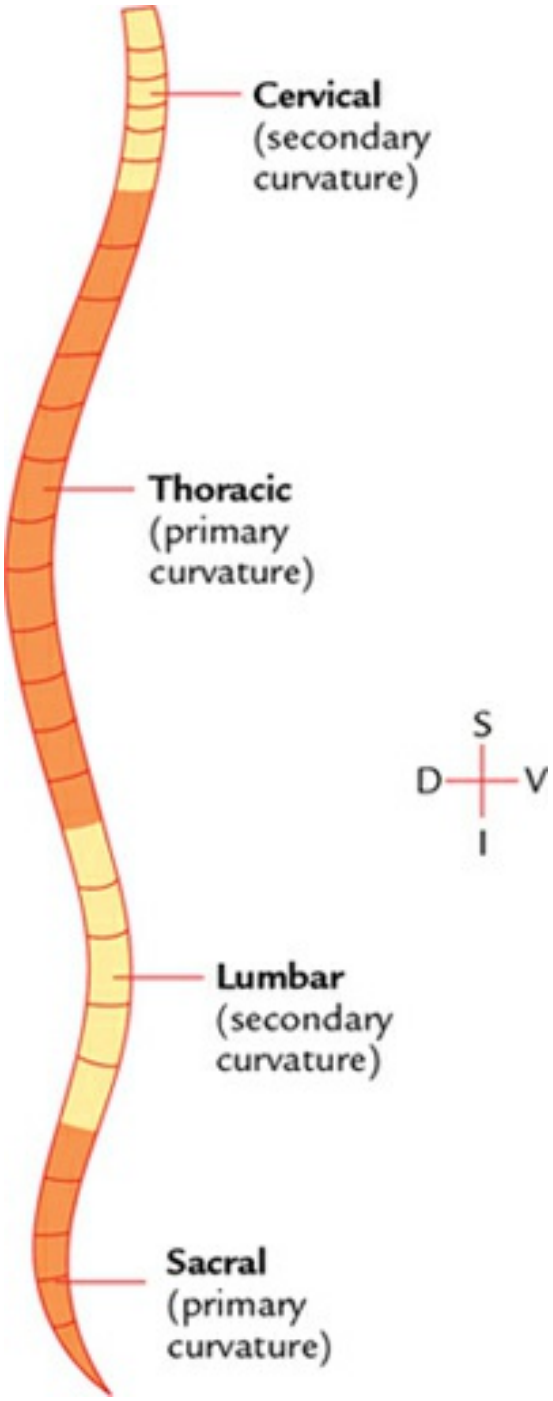


FIG. 8.12 ■ Curvatures of the vertebral column.

The thoracic and sacral curvatures are termed **primary curvatures** because they are in the same direction as the curvature of the foetal vertebral column. The cervical and lumbar curvatures are termed **secondary curvatures** as they

develop after birth. The secondary curvatures are concave posteriorly; therefore, they compensate for and counteract the primary curvatures.

Development of curvatures

In prenatal (before birth) life, the vertebral column is uniformly curved with the concavity facing ventrally with the result that the head and neck are more or less touching each other (Fig. 8.13). This position shows primary curvature/foetal curvature. The secondary curvatures appear after birth as follows:

1. **Cervical curvature** with convexity facing forwards develops when an infant learns to hold his/her head erect and directs his/her visual axes forward at about the age of 3 months.
2. **Lumbar curvature** with convexity facing forwards develops when the child acquires the art of standing and walking erect at about the age of 18 months.

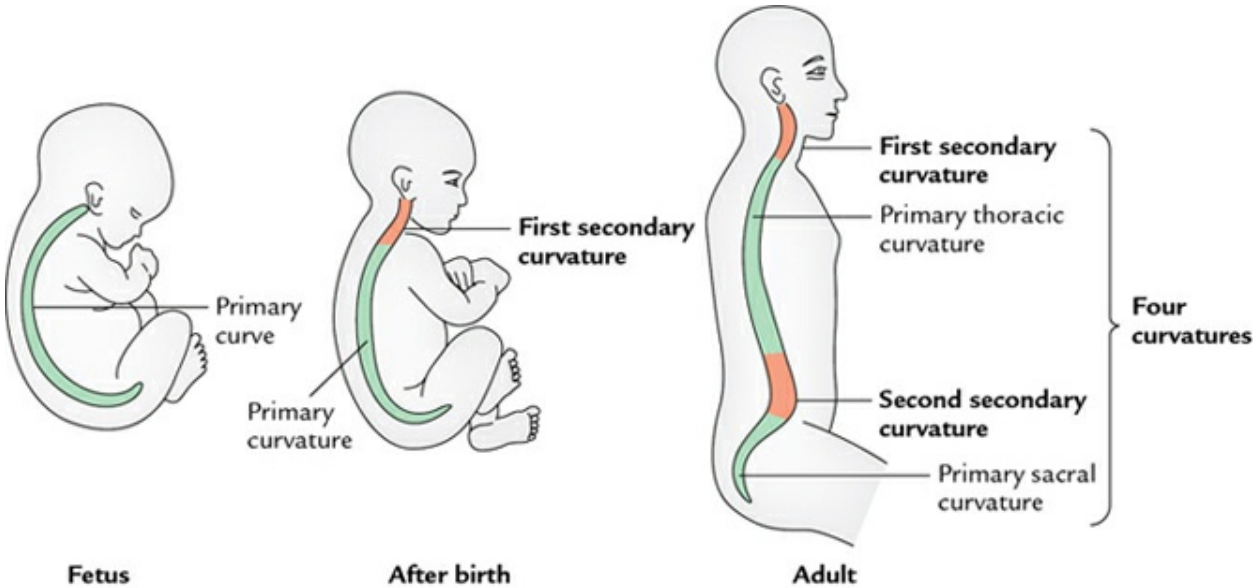


FIG. 8.13 ■ Development of curvatures of the vertebral column. The secondary curvatures are marked bold.

In the thoracic and sacral regions, ventral concavities persist as in prenatal life; hence, called **primary curvatures.**

N.B.

Primary curvatures of vertebral column are concave forwards while *secondary curvatures* of vertebral column are convex forwards.

Abnormalities of vertebral curvatures (Fig 8.14)

These are as follows:

1. **Kyphosis (hunchback)**: This is an exaggeration of posterior convexity of thoracic curvature. It can occur in old age due to osteoporosis or disc degeneration.
2. **Lordosis (swayback)**: This is an exaggeration of the anterior convexity of the lumbar curvature. It can occur as a result of pregnancy or a pot-belly.
3. **Scoliosis (crookedness)**: This is an abnormal lateral curvature of the vertebral column either to the right or to the left. It is commonest in the thoracic region. It can be caused by poliomyelitis, a short leg, or a hip disease.

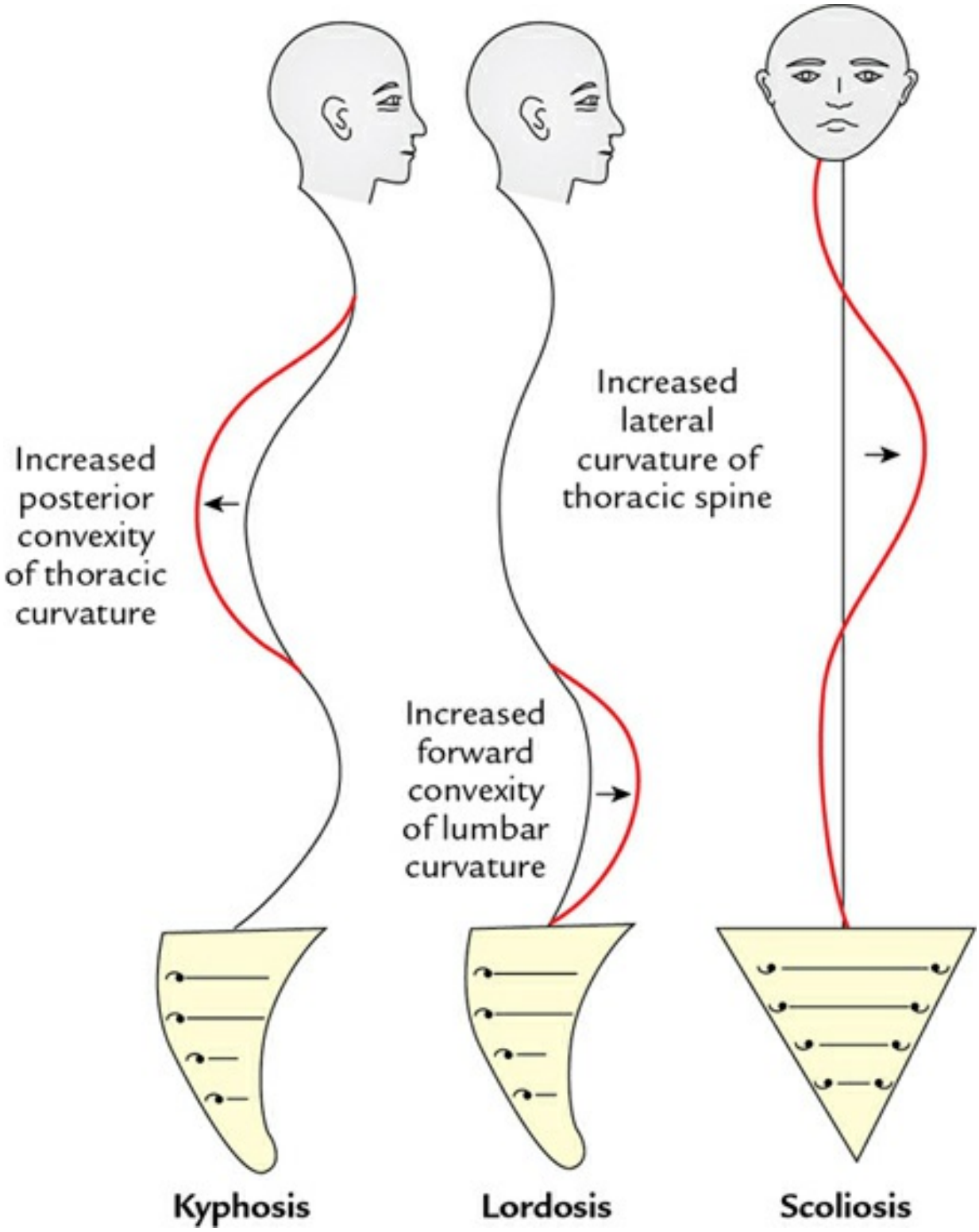


FIG. 8.14 ■ Abnormal curvatures of spine.

Clinical correlation

Decrease in height of an individual

(a) The height of an individual, particularly the one who carries a heavy load on his head, may be shorter in the evening than in the morning because of fatigue:
  – Curvatures of the spine are increased.
  – Turgor of the nucleus pulposus of the intervertebral discs is decreased.
  – Height of the arches of the feet is decreased.
  After recuperative rest at night, the person regains normal height in the morning.

(b) The height of an individual in old age becomes less due to flattening of the intervertebral discs following desiccation and dehydration of the nucleus pulposus.

Line of gravity

The line of gravity passes through the body of the axis vertebra, anterior to the sacrum, posterior to the centre of the hip joints, anterior to the centre of knee joints and anterior to the centre of ankle joints. Since the greater part of the body weight lies anterior to the vertebral column, deep muscles of the back are important in maintaining the normal curvatures of the vertebral column in the standing position (Fig. 8.15).

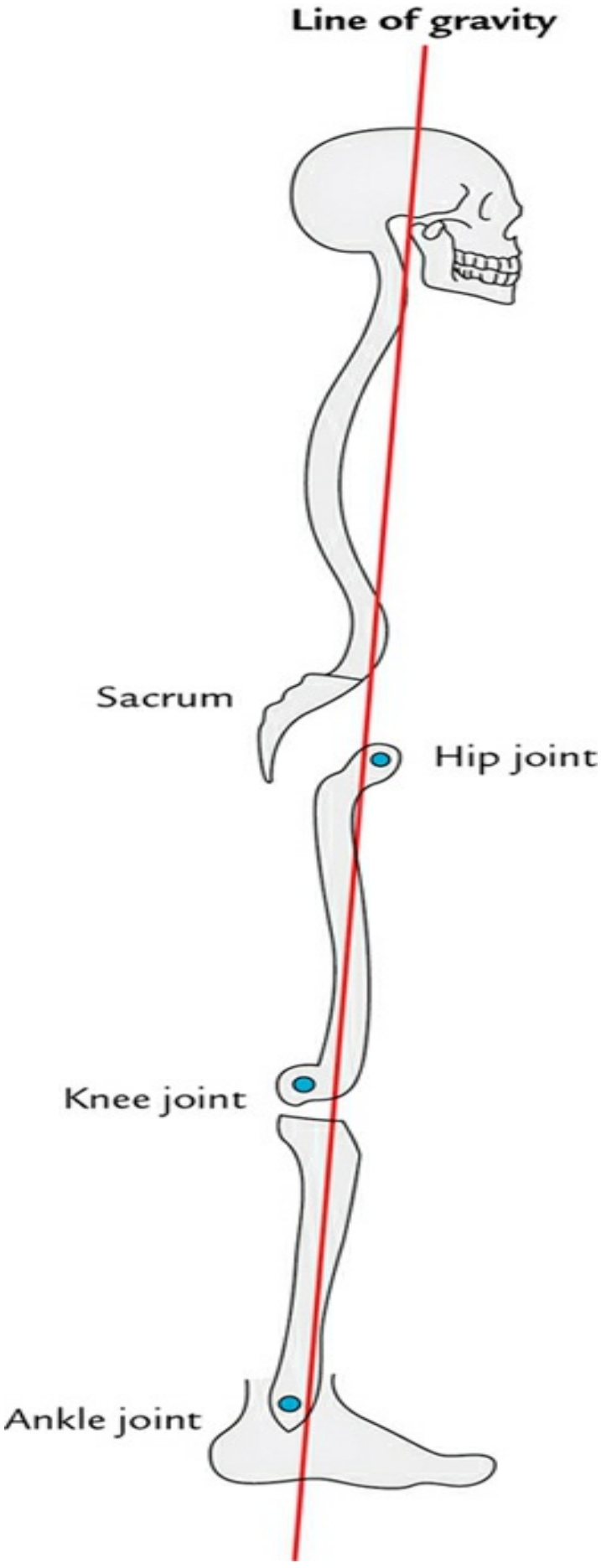

Line of gravity
Sacrum
Hip joint
Knee joint
Ankle joint

FIG. 8.15 ■ Line of gravity.

Clinical correlation

Backache and leg ache in females: In females who wear high-heeled shoes, the posture becomes unnatural. There is a forward tilt of their bodies, their knees are excessively bent, and their spine is thrust forward at the lumbar curvature to maintain balance. Consequently, there is a shift in the line of centre of gravity of their body putting an undue strain on muscles and ligaments of the back and leg to maintain an erect posture. This leads to backache and leg ache. Thus females who wear high-heeled shoes have perpetual backache and leg ache.

Vertebral column and its muscles

The posture and flexibility of the vertebral column are controlled by groups of muscles that are disposed: (a) vertically parallel to the column and (b) obliquely surrounding the trunk on the back. These groups of muscles form a discontinuous layer or sheet that extends from the base of the skull to the sacrum, i.e. this muscle sheet is broken up into short segments. Although broken up into short segments, the functional unity of the whole is secured by having the insertions of one short group overlapped by the origins of another in a relay-race fashion.

The muscle groups have specific actions when they act against the resistance such as gravity. Due to the influence of gravity upon the muscle action, when the trunk is bent forward, the extensor muscles of the back get tense and control bending. Similarly, when the column bends slightly to one side, the contralateral muscles become tense to control this movement. Thus there is an ever-shifting balance of power between different muscle groups to steady the column and oppose the influence of gravity.

Due to increasing incidence of backache, students should have some working knowledge of the muscles of the back. The muscles of the back are divided into two columns called **erector spinae** (true muscles of the back). Each column consists of superficial long muscles and deeper short muscles.

The long muscles passing across many vertebrae and deeper shorter muscles join adjacent vertebrae. The longer muscles maintain normal

posture, i.e., they maintain normal spinal curvature while the smaller deeper muscles constantly adjust the position of one vertebra to another.

The erector spinae has an aponeurotic attachment to the back of the sacrum, adjacent iliac crest and lumbar spinous processes. As it ascends, it splits into three columns—lateral, intermediate and medial, known as iliocostalis, longissimus and spinalis, respectively.

Each of these columns is divided into three relays (Fig. 8.16), according to their level, as given in Box 8.1.

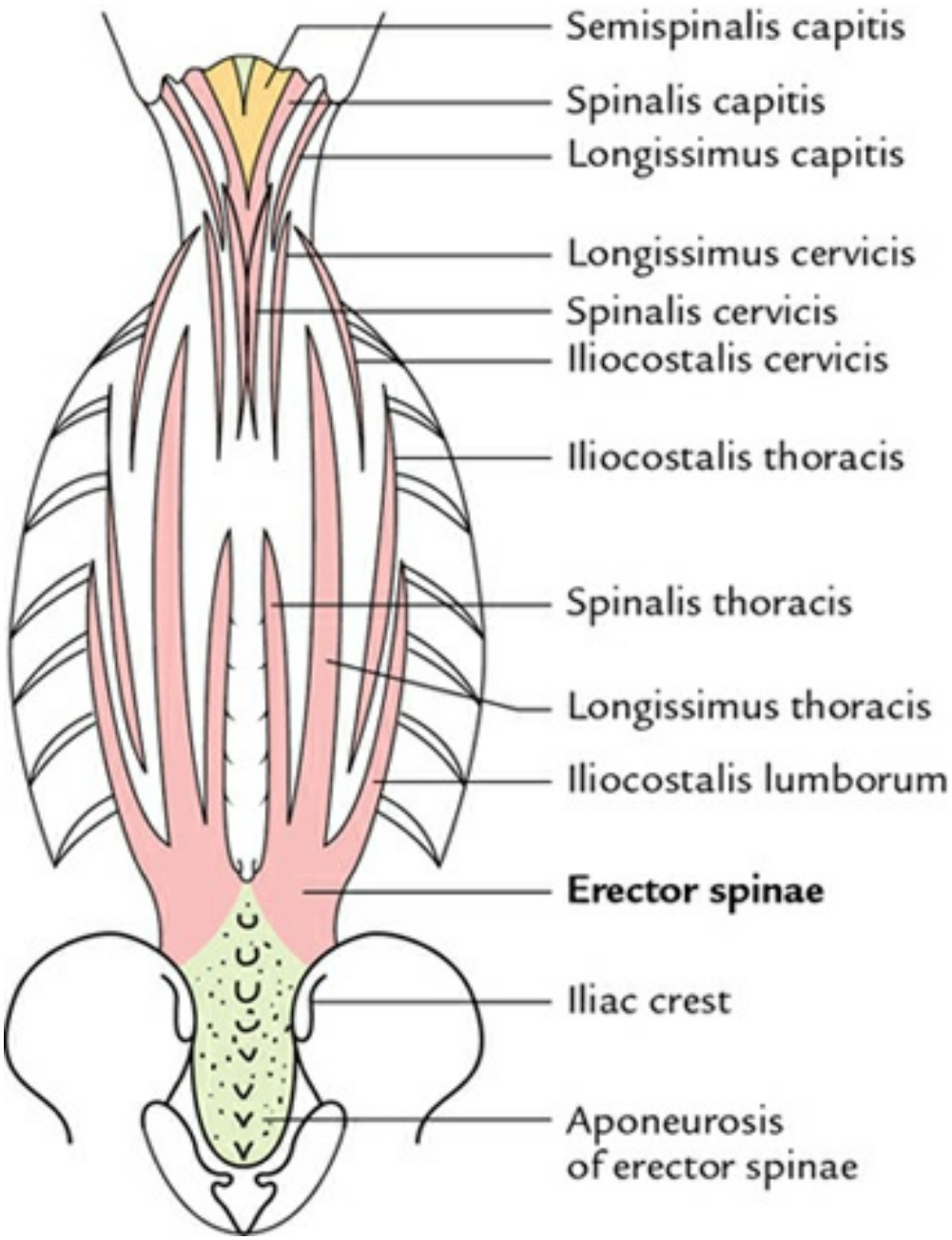


FIG. 8.16 ■ Erector spinae muscles (true muscles of the back).

Box 8.1.

Columns of erector spinae and its relays.

Column of erector spinae	Relays
1. *Iliocostalis*	(a) Iliocostalis lumborum (b) Iliocostalis thoracis (c) Iliocostalis cervicis
2. *Longissimus*	(a) Longissimus thoracis (b) Longissimus cervicis (c) Longissimus capitis
3. *Spinalis*	(a) Spinalis thoracis (b) Spinalis cervicis (c) Spinalis capitis

Clinical correlation

Significance of posture at work: Normal posture is very important while working particularly for a longer period. Some people instinctively adopt postures that relieve the tired muscles but remember it throws undue strain on the ligaments of intervertebral joints, leading to continuous backache. While working one should try to keep his/her vertebral column erect (i.e. in extension).

The flexion of the vertebral column increases the pressure on the anterior portion of the intervertebral disc, thus pushing the nucleus pulposus posteriorly where the annulus fibrosus is thinner. This is especially so in the lumbar portion of the vertebral column. Any weakness posteriorly allows the nucleus pulposus to herniate posterolaterally causing disc prolapse.

Movements of the vertebral column

The amount of movement between any two adjacent vertebrae is very small, but when these movements are put together, movements of the column as a whole become quite extensive.

The movements of vertebral column include the following:

1. Flexion (bending forward)
2. Extension (bending backward)
3. Lateral flexion (bending to the side)
4. Rotation (twisting on either side).

The movement between the two vertebrae is most free where the disc is thickest (vertical height), namely in the cervical and lumbar regions. Conversely, the movement is least where the disc is thinnest such as in the mid-thoracic region.

The movements of the vertebral column, flexion, extension, lateral flexion and rotation are self-explanatory but degree of movement in cervical, thoracic and lumbar regions requires further consideration (Fig. 8.17). While considering the degree of movement, the three principal features that should be taken into account are:

1. Zygapophyseal joints,
2. Ribcage and
3. Elasticity of the intervertebral discs.

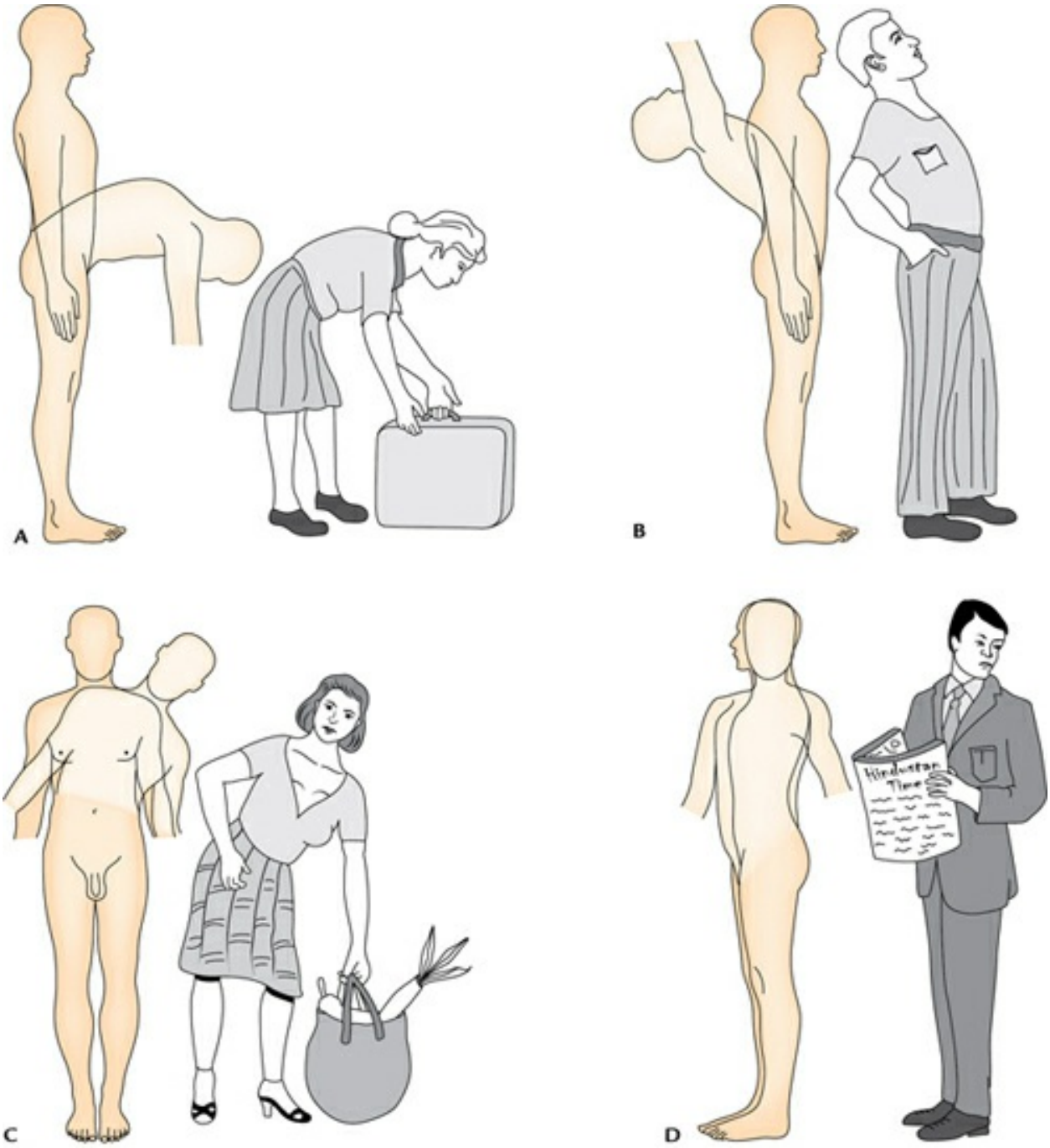


FIG. 8.17 ■ Movements of vertebral column: **(A)** flexion; **(B)** extension; **(C)** lateral flexion and **(D)** rotation.

In the ***cervical region,*** all the movements are possible and they are enhanced by the movements occurring between the atlas and the axis and between the atlas and the base of the skull.

The head and neck have a considerable range of movements which are controlled to a fine degree. This is in keeping with the need to accurately position the organs of sight, hearing and smell.

Clinical correlation

Whiplash injury: The movements of flexion and extension of the cervical spine diminishes from the superior half to the inferior half of the cervical region. Accordingly, the inferior half is likened to the *handle of the whip* and superior half to the *lash*. Therefore, sudden changes of momentum produce the so-called *whiplash injury*, roughly at the mid-cervical region. The whiplash injury occurs classically as a result of a rear impact when a slightly moving vehicle strikes another vehicle in front. Whiplash injuries are now a common cause of persistent cervical pain.

In the ***thoracic region***, movements of the vertebral column are handicapped by the ribcage. However, the zygapophyseal joints are designed to allow maximum rotation, as if to compensate for the limitation imposed by the ribcage. The maximum rotation occurs in the mid-thoracic region.

In the ***lumbar region***, little rotation occurs due to the nature of the configuration of the zygapophyseal joints in this region.

The flexion, extension and lateral flexion are the principal movements of the lumbar spine.

Clinical correlation

- **Back pain:** The back pain particularly, the *low back pain* is a common health problem second only to headaches. It often occurs due to:
  - Muscle spasm of back muscles
  - Facet joint arthrosis
  - Disc herniation
  - Spinal stenosis.
- **Forward bending of the lumbar spine** also includes the movement at the hip joints. An orthopaedic surgeon/physiotherapist while analyzing the flexion of the lumbar spine must take into account the flexion at hip joints.

Golden Facts to Remember

• Total number of vertebrae in the vertebral column	33
• Total number of true vertebrae in the vertebral column	24
• Largest vertebra	Fifth lumbar (L5)
• All true vertebrae have a body except	First cervical vertebra
• Thickest intervertebral disc	Disc between L5 and S1 vertebrae
• Commonest site of disc prolapse	Intervertebral disc between L5 and S1
• Most susceptible disc for a herniation in the cervical region	Disc between C5 and C6
• Most important investigation to confirm disc prolapse	Magnetic resonance imaging (MRI)
• Commonest site of spondylosis	Cervical region
• Commonest site of 'whiplash injury'	Mid-cervical region
• Most commonly fractured thoracic vertebra	Twelfth (T12) thoracic vertebra
• Commonest site of scoliosis	Thoracic region
• Commonest site of spondylolisthesis	Between L5 and S1 vertebrae (slipping of one vertebra over the other)
• Commonest congenital anomaly of vertebral column	Spina bifida
• Commonest site of fracture-dislocation in vertebral column	Dorsolumbar region between T12 and L1 vertebrae
• Most common site of compression fracture of vertebra	Lumbar region
• Most common tumours	Secondaries (metastatic tumours)

of vertebral column	
• Commonest site of tuberculosis of vertebral column	Cervical region
• Schmorl's node	Extrusion (i.e. herniation) of nucleus pulposus into the body of the vertebra

Multiple choice questions

1. **Select incorrect statement about the vertebral column:**
   (a) It consists of 33 vertebrae
   (b) It has 24 separate movable vertebrae
   (c) It possesses 2 curvatures
   (d) It forms the axis of the trunk
2. **All of the following statements are true about the vertebral column except:**
   (a) Vertebrae contribute three-fourth of its total length
   (b) Intervertebral discs contribute one-quarter of its total length
   (c) Provides firm support to the body
   (d) Vertebral bodies act as shock-absorber during running and jumping
3. **Select incorrect statement about the zygapophyseal joints:**
   (a) They are joints between the laminae of two adjacent vertebrae
   (b) They slope inferiorly from anterior to posterior in the cervical region
   (c) They are oriented vertically in the thoracic region
   (d) Their articular surface curve and interlock with each other in the lumbar region
4. **Select incorrect statement about the direction of articular surfaces of superior articular processes:**
   (a) Directed backwards and upwards in the cervical region
   (b) Directed backwards and downwards in the thoracic region
   (c) Directed backwards and laterally in the thoracic region
   (d) Directed backwards and medially in the lumbar region
5. **All of the following statements are true about the intervertebral discs except that:**

(a) Their outer rim is formed by the fibrocartilage
(b) Their centre is filled with the nucleus pulposus
(c) They take part in the formation of symphyses between the adjacent vertebral bodies
(d) They are thickest in the thoracic region

6. **The functions of intervertebral discs include all except that they:**
(a) Act as shock-absorber
(b) Contribute to the height of the vertebral column
(c) Contribute to the flexibility of the vertebral column
(d) Enhance the rotation between the vertebrae
7. **Select the incorrect statement regarding the movements of the vertebral column:**
(a) Rotation occurs in the lumbar region
(b) Movements are facilitated by ribcage in the thoracic region
(c) Movements are enhanced in the cervical region by movements occurring at atlanto-axial and atlanto-occipital joints
(d) Movements are maximus at atlanto-axial joint
8. **Select the incorrect statement about the disc prolapse:**
(a) It occurs due to rupture of annulus fibrosus
(b) It mostly occurs anterolaterally
(c) The disc between L5 and S1 is most commonly herniated
(d) It mostly occurs posterolaterally

Answers

1. *c*, **2.** *d*, **3.** *a*, **4.** *b*, **5.** *d*, **6.** *d*, **7.** *b*, **8.** *b*

Chapter 9: Muscular system

Specific learning objectives

After studying this chapter, the student should be able to

- Define muscle and describe its four basic properties. Differentiate skeletal, cardiac and smooth muscles.
- Classify muscle tissue according to structure and action. **AN 3.1**
- Enumerate parts of skeletal muscle and differentiate between tendon and aponeurosis with examples. **AN 3.2**
- Describe gross features of a typical skeletal muscle and discuss its lubricating devices which facilitates movements of muscle tendons.
- Compare and contrast the red and white fibres in the skeletal muscle.
- Describe morphological types of muscles according to their fascicular architecture.
- Discuss microscopic and ultramicroscopic features of a skeletal muscle.
- Describe the principles of motor and sensory innervation of muscles. **AN 7.5**
- Define ‘motor unit’ and explain why motor units are considered basic functional units of muscle contraction.
- Describe various ways of naming the muscles.
- Discuss group action of muscles and explain what is meant by synergistic and antagonistic muscle groups.

- Explain shunt and spurt muscles. **AN 3.3**
- Correctly solve the Multiple Choice questions given at the end of the chapter.

The **muscular system** comprises all the muscles of the body. They form an important part of the locomotor system. The study of muscles is called **myology**.

The muscle is a contractile tissue of the body, derived from the mesodermal layer of embryonic germ cells. It forms the red flesh of the body and accounts for about 40% of the body weight.

The muscle tissue is composed of differentiated cells containing contractile proteins. The muscle cells are often termed *muscle fibres* because they are long and narrow in a relaxed state. The structural biology of these proteins generates the forces necessary for cellular contraction. Thus muscles are responsible for bringing about movements within certain organs and the body as a whole. Hence they are regarded as the '**motors of the body**' (Fig. 9.1).

FIG. 9.1 ■ Muscles, the **'motors of the body'** moving its various parts.

Thus muscle can be defined as follows: It is a contractile tissue that brings about the movements of organs and the body as a whole.

N.B.

All the muscles of the body develop from mesenchyme except arrectores pilorum, muscle of the iris, and myoepithelial cells of glands that develop from ectoderm.

Types of muscles AN 3.1

On the basis of morphological and functional characteristics, the muscles are classified into three types:

1. Skeletal muscles (voluntary)
2. Smooth muscles (involuntary)
3. Cardiac muscles (involuntary).

The **skeletal muscles** are attached to the skeleton, the **smooth muscles** form the walls of the viscera and the **cardiac muscles** form the wall of the heart (myocardium).

Microscopically, three types of muscles differ considerably from each other (Fig. 9.2). The differences between these three are enumerated in Table 9.1.

N.B.

Apart from skeletal, cardiac and smooth muscles, there are contractile cells that function as single-cell units, viz.

1. Myoepithelial cells
2. Myofibroblasts.

Myoepithelial cells are spindle-shaped epithelial cells containing contractile protein in the form of **actin filaments**. They are present at the bases of secretory acini of glands (e.g. salivary, lacrimal, mammary and sweat glands) between the basement membrane and peripheral surface of epithelial cells of acini.

The contraction of myoepithelial cells helps in the expulsion of secretion from the acini.

Myofibroblasts are involved in wound healing.

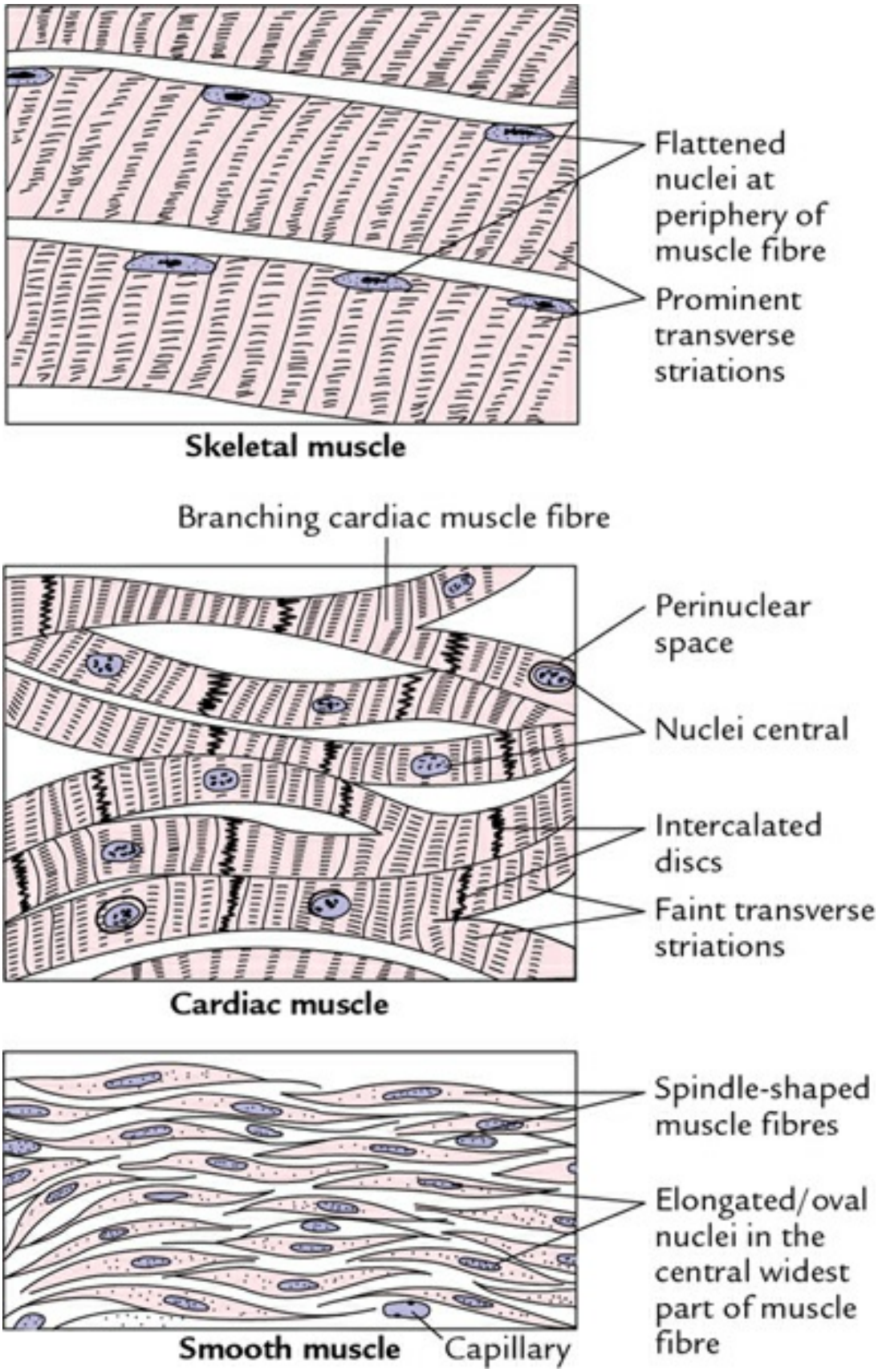


FIG. 9.2 ■ Microscopic structure of 3 types of muscles.

TABLE 9.1

Differences between three types of muscles: skeletal, cardiac and smooth

Characteristic features	Skeletal muscle	Cardiac muscle	Smooth muscle
Synonyms	Somatic or voluntary or striated	Myocardium	Involuntary or nonstriated or smooth
Location	Usually attached to the skeleton	Present in the wall of the heart	Present in the wall of hollow viscera, viz. gastrointestinal tract, respiratory tract, urogenital tract
Control	Voluntary	Involuntary	Involuntary
Muscle fibres	(a) Unbranched cylindrical	(a) Branched cylindrical with characteristic intercalated discs (junctions between the muscle fibres)	(a) Unbranched-spindle shaped
	(b) Multinucleated, nuclei located peripherally	(b) Single nucleus, nuclei located centrally	(b) Single nucleus, nuclei located centrally
	(c) Cross-striations present	(c) Cross-striations faint	(c) No cross-striations
Rhythmicity	Absent	Present	Present
Functions	Movement of body parts	Pumping of blood from the heart	Movement of viscera
Nerve supply	Somatic	Autonomic	Autonomic
Stretch receptors	Present	Absent	Absent
Neuromuscular junction	Present	Absent	Absent

Basic properties of muscles

Although the structure and functions of skeletal, cardiac and smooth muscles are different from each other, they share the following four basic properties:

1. **Irritability**, i.e. sensitivity to stimuli.
2. **Contractility**, i.e. when stimulated, the muscle contracts lengthwise leading to its shortening.
3. **Extensibility**, i.e. once the stimulus is removed, the muscle fibres return to their original length.
4. **Elasticity**, i.e. muscle assumes the desired shape regardless of how it might be stretched.

The structure and functions of smooth muscles are better understood when studying the involuntary organs of the body and the cardiac muscle when studying the heart.

The following description is restricted only to the skeletal muscles as they are commonly encountered by the students.

Skeletal muscles

The skeletal muscles are most abundant. The majority of muscles you see in your body or in cadaver during dissection are skeletal muscles. They constitute the bulk of muscle mass of your body (i.e. 30%–40% of total body mass). They are located superficially and mostly found attached to the skeleton. They are displayed by students during the dissection of cadavers. The skeletal muscles perform the function of levers to move the body and its appendages to perform day-to-day activities. An overview of the layout of major superficial skeletal muscles in the body is shown in Figure 9.3.

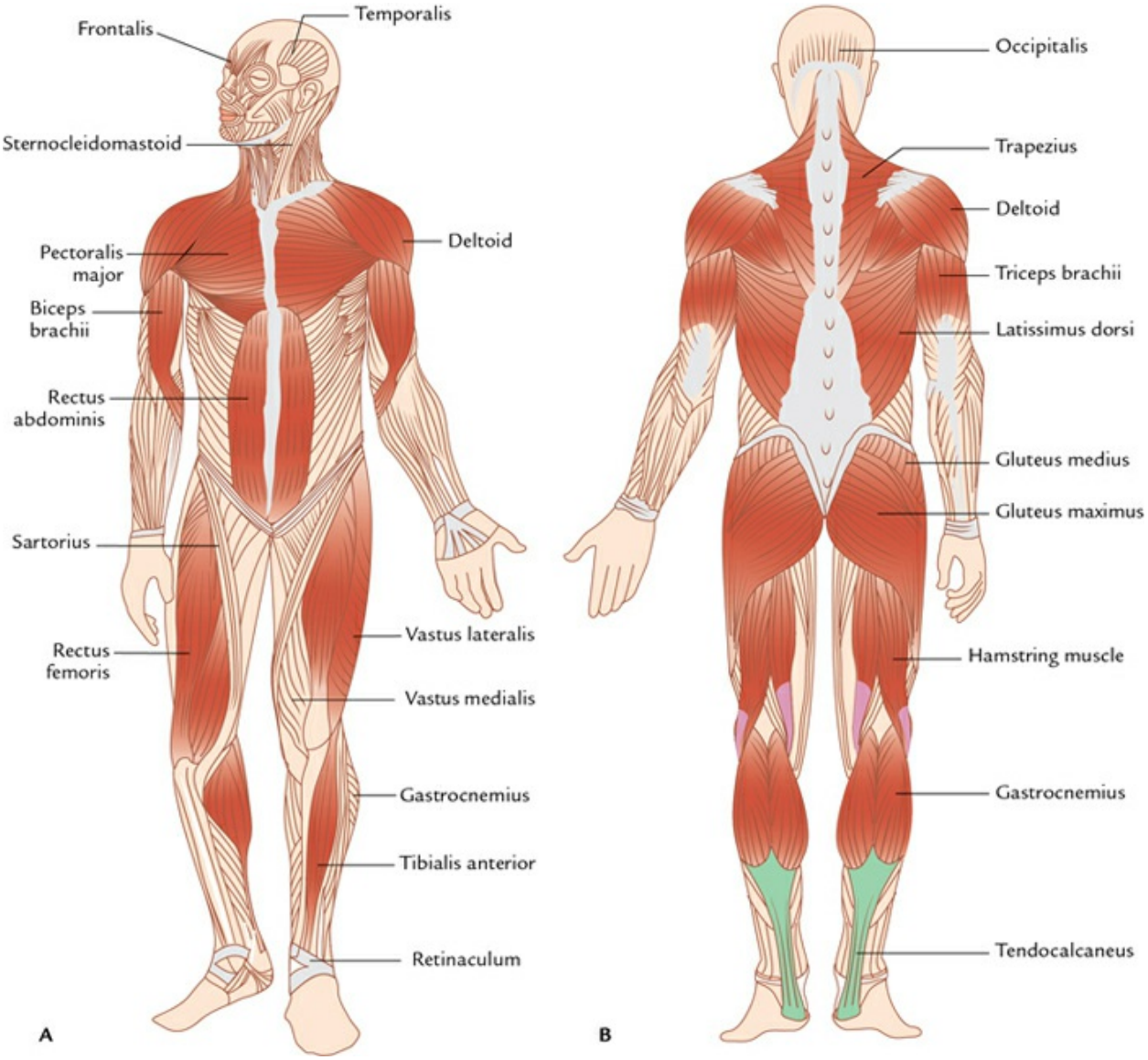


FIG. 9.3 ■ Major skeletal muscles of the body: **(A)** anterior view and **(B)** posterior view.

Clinical correlation

Common disorders of skeletal muscles

- **Paralysis:** The muscles are often ***paralyzed***, hence tested routinely by clinicians in clinical practice.
- **Muscle strain:** It is common particularly in athletes, viz. groin strain.
- **Rupture of muscle tendons:** For example, rupture of long head of biceps brachii etc.
- **Sites of intramuscular injections:** The skeletal muscles are commonly used for ***intramuscular injections***, viz. *deltoid muscle* in the shoulder

region, *gluteus medius* muscle in the gluteal region, and *vastus lateralis* muscle in the thigh region.

The sites of intramuscular infection are given in Table 9.2 and shown in Figure 9.4. For the above reasons, they are described in detail in the following text.

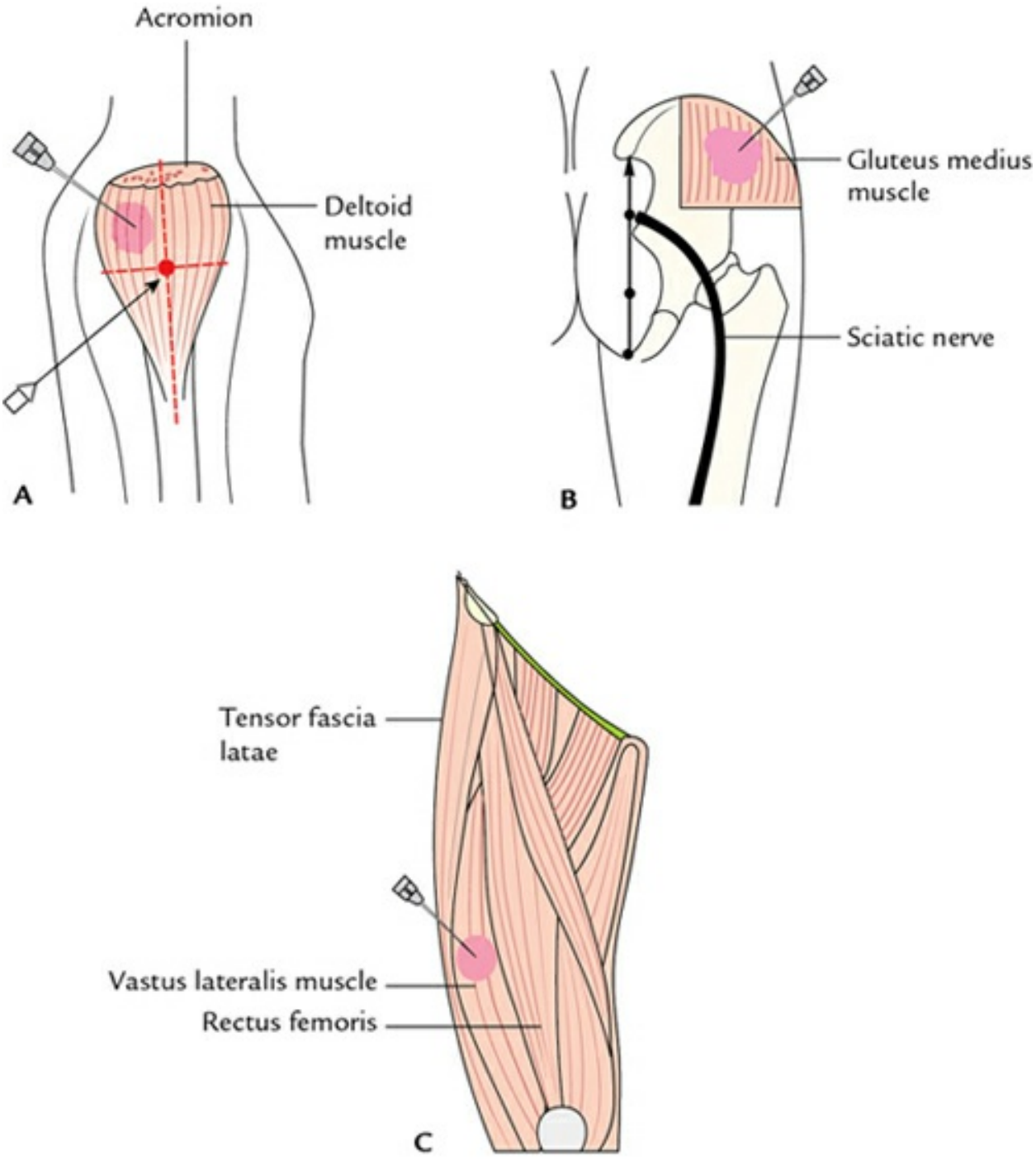


FIG. 9.4 ■ Common sites of intramuscular infections. **(A)** shoulder region; **(B)** gluteal

region and **(C)** thigh.

 **TABLE 9.2**

Common muscles and their respective sites for intramuscular infections

Muscle	Site
1. Deltoid	• Middle of lateral aspect of deltoid region
2. Gluteus medius	Upper and outer quadrant of gluteal region
3. Vastus lateralis	Anterolateral aspect of mid-thigh

Functions

The skeletal muscles perform the following general functions:

1. Motion
2. Heat production
3. Posture and body support.

Motion

It is the most obvious function when the skeletal muscles contract. The muscles move the body and/or its appendages, i.e. walking, running, etc.

Heat production

Metabolism within the muscle cells releases heat as an end product. The rate of heat production increases immensely when a person performs strenuous exercises.

Posture and body support

The skeletal muscles maintain posture by providing support around the

flexible joints. Postural muscles are at work even when you think that you are relaxed, e.g. when one is sitting, the head is balanced at the atlanto-occipital joint by muscles at the back of the neck. When one gets sleepy, the head suddenly nods forward as postural muscles relax and the weight (resistance) overcomes the effort.

Microscopic and ultramicroscopic structure

The skeletal muscle is made up of supporting connective tissues and muscle fibres (Fig. 9.5 and 9.6).

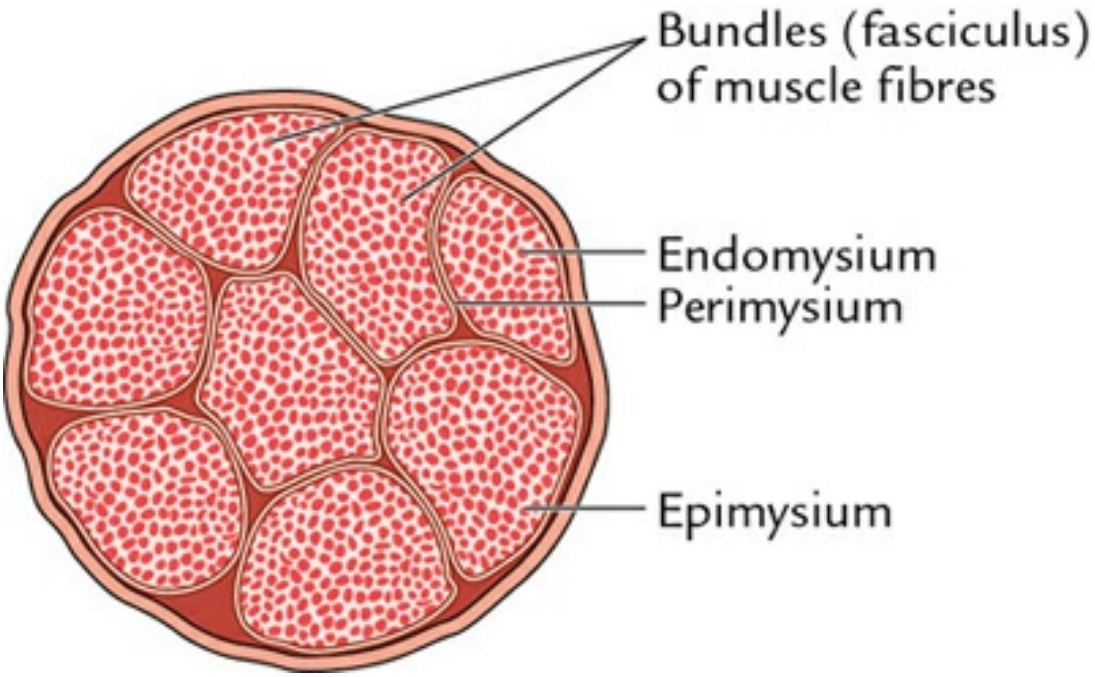


FIG. 9.5 ■ Cross-section of a muscle showing various connective tissue sheaths.

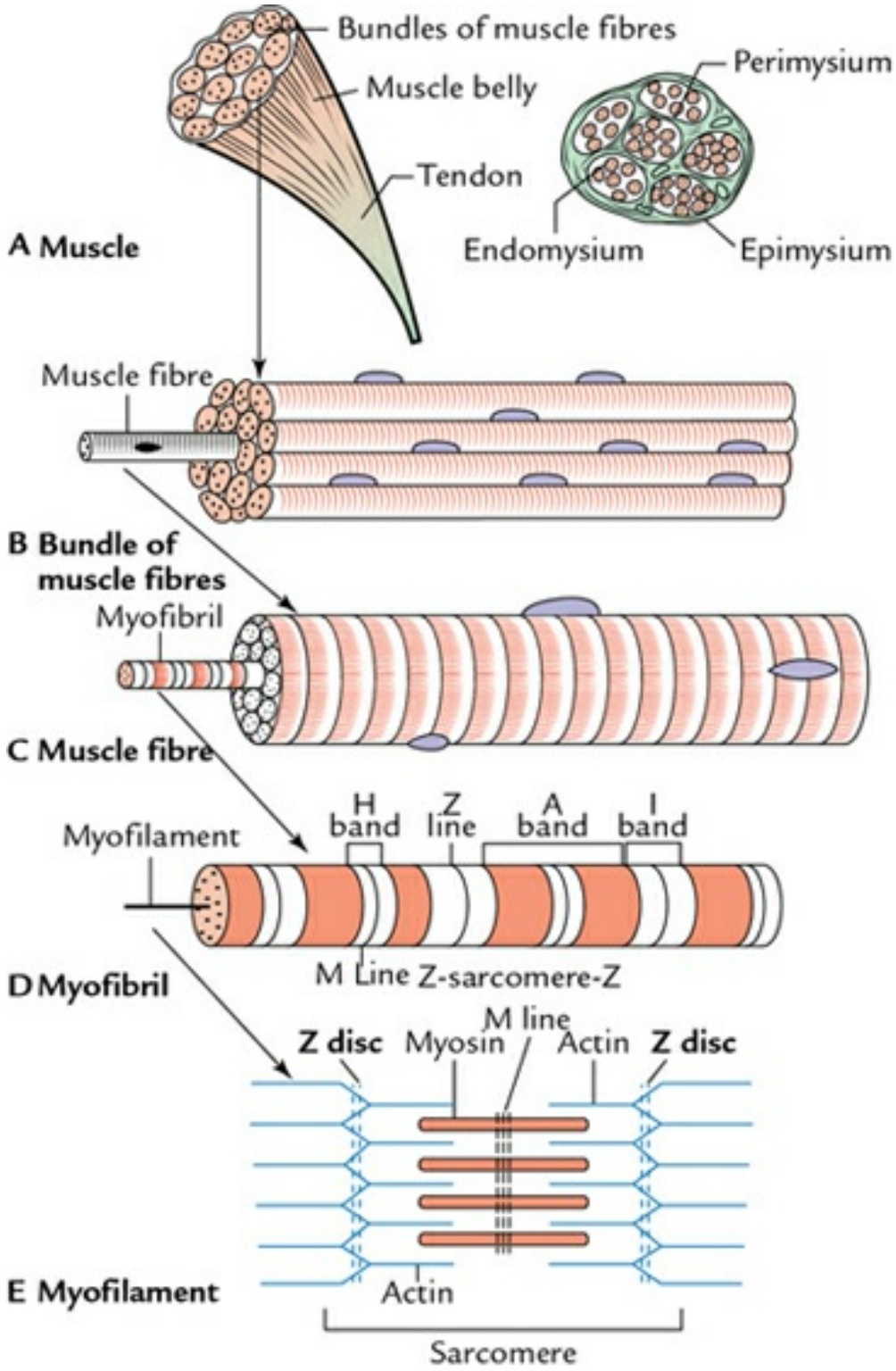


FIG. 9.6 ■ Structure of muscle at gross **(A)**, microscopic **(B-D)** and ultramicroscopic **(E)** levels.

Supporting tissue

Each fibre is surrounded by a delicate connective tissue called **endomysium**. Each bundle of muscle fibres (i.e. *fasciculus*) is surrounded by a coarser connective tissue called **perimysium**. The dense connective tissue surrounding the entire muscle is called **epimysium (**Fig. 9.5).

N.B.

At the junction of a muscle belly with a tendon, the fibres of **endomysium, perimysium** and **epimysium** become continuous with the fibres of the tendon.

Muscle fibres (Fig 9.6)

The following special terms are used while describing the muscle fibres:

- *Muscle cell* = Muscle fibres/myocytes
- The *cell membrane of myocyte* = Sarcolemma
- The *cytoplasm of myocyte* = Sarcoplasm
- The endoplasmic reticulum of myocyte = Sarcoplasmic reticulum.

The skeletal muscle fibres are longer than those of smooth muscle fibres. Their length ranges from 20 to 40 mm and the diameter from 10 to 100 μm.

Each muscle fibre (myocyte) is multinucleated, cross-striated and cylindrical. The nuclei are oval and located at the periphery of the fibre, under the plasma membrane or sarcolemma. The cytoplasm of muscle fibre is called **sarcoplasm**.

The sarcoplasm contains longitudinally oriented bundles of **myofibrils**, which are made up of contractile proteinaceous filaments called **myofilaments**. The myofilaments are of two types: thin and thick. The regular arrangement of myofilaments within the muscle fibre gives it a characteristic cross-striated appearance.

The cross-striated appearance is due to the cytoplasm of the fibres, which shows alternating dark and light bands. With polarized light, the bands that appear darker with the light microscope are anisotropic while those that appear light with the light microscope are isotropic. Accordingly, darker

bands are called **A bands** and lighter bands are **I bands**. Middle of the A band is dissected by a less dense line called the **H line** [Figs 9.5(D) and 9.7(1)]. The I bands are dissected by a thin dark line called **Z line**.

- In the region of dark A band, thin and thick myofilaments partially overlap each other.
- The I band contains only thin myofilaments.
- The H band present in the centre of the A band contains only thick myofilaments.
- The M line is a dark line seen in the centre of the H band, where the thick filaments are held together.
- The region of thick and thin myofilaments between the two Z lines is called a **sarcomere**. It is the contractile unit of the myofibril.

Myofibrillar proteins

They are of two types:

1. The thick myofilaments consist of a protein called **myosin**. Myosin constitutes 60% of the myofibrillar protein and is the most abundant contractile protein.
2. The thin myofilaments consist of proteins called **actin** and **tropomyosin**.

Mechanism of contraction (Fig. 9.7)

A sarcomere is the basic unit of the contraction. It consists of two types of myofilaments arranged parallel to the long axis of the myofibril:

1. **Thick filaments** are composed of protein **myosin** and occupy the A band.
2. **Thin filaments** are composed mainly of protein **actin** and also of **tropomyosin** and **troponin**. One end of each of this filament runs between and parallel to the thick filaments in the A band for some distance. Other end of thin filament is attached to the Z line in the I

band. During muscular contraction, thin actin filaments slide between thick myosin filaments towards the centre of sarcomere, thus bringing the attached Z lines closer, leading to shortening of the contractile unit, i.e. sarcomere.

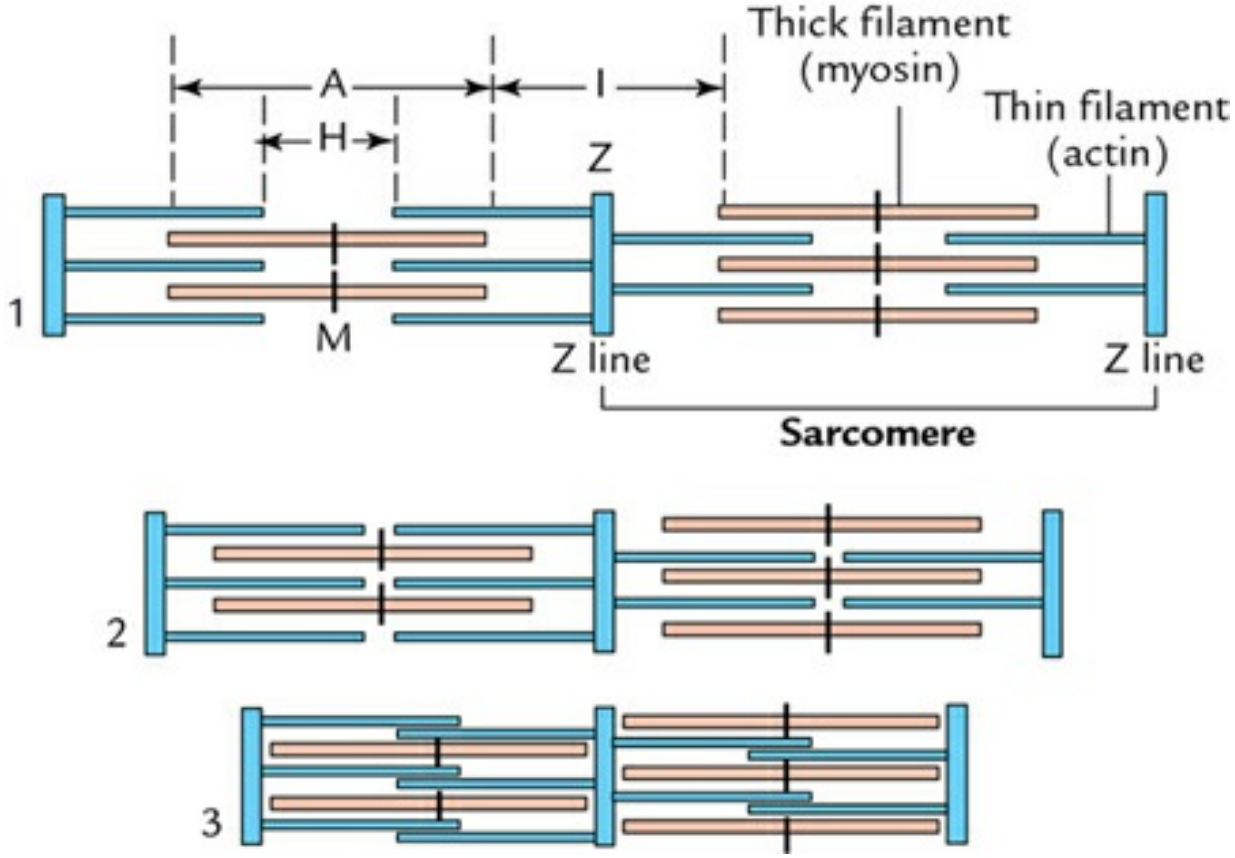


FIG. 9.7 ■ The sliding filament model of muscle contraction. When the myofilaments slide, the Z lines are brought closer together. The length of A band remains same during contraction. The I and H bands narrow progressively and are eventually obliterated.

N.B.

During contraction, there is no shortening of individual thick and thin filaments.

The sliding of filaments occurs under the influence of energy released from adenosine triphosphate (ATP) and calcium ions released from the sarcoplasmic reticulum.

Clinical correlation

Rigor mortis: It is the stiffening of voluntary and involuntary muscles of

the body after death. It starts 2–4 h after death and completes after 6–12 h. It gradually disappears within 2–4 days. It helps in medicolegal cases to determine the time of death.

The *rigor mortis* occurs due to depletion of ATP from the muscle. The mechanism is as under:

(a) ↓ ATP level → stops the transport of Ca^{2+} ions into sarcoplasmic reticulum.

(b) Leakage of Ca^{2+} ions from sarcoplasmic reticulum to sarcoplasm due to breakdown of reticulum after cell death.

(c) ↑ Ca level in sarcoplasm → formation of cross-bridges between actin and myosin.

(d) Myosin fails to separate from actin due to lack of ATP and consequently, muscle fails to relax and remain stiff unless tissue degeneration occurs.

Types of skeletal muscle fibres

The skeletal muscle fibres are classified mainly into two types:

1. Red (type I) fibres
2. White (type II) fibres.

Red fibres are slow-twitch fibres, i.e. their speed of contraction is slow but more sustained. They are fatigue resistant and hence largely present in postural muscles, long muscles of the back (antigravity muscles).

White fibres are fast-twitch fibres, i.e. their speed of contraction is fast but less sustained. They are easily fatigued and hence largely present in extraocular muscles of the eyeball.

The above-mentioned fibres have different characteristic features based on their functions (Table 9.3).

 TABLE 9.3

Characteristic features of red and white skeletal muscle fibres

Characteristic feature	Red fibre	White fibre
Speed of contraction	Slow	Fast
Fatigability	Fatigue-resistant	Fatigue-susceptible
Blood supply	Rich	Poor
Myoglobin content	High	Low
Generation of ATP	By aerobic glycolysis	By anaerobic glycolysis
Number of mitochondria	Many	Few
Glycogen content	High	Low
Diameter	Smaller	Larger
Examples	Postural muscles	Extraocular muscles

Clinical correlation

The slow-twitch muscle fibres function very well for *long-distance running*. In addition, exercises that cause muscle to perform aerobic metabolism improve their ability. Aerobic exercises combined with slow-twitch fibres are the best combination for long-distance running.

Morphological types of muscles according to their fascicular architecture

The arrangement of muscle fibres in individual muscles varies a great deal and is often dependent upon the function of the muscle concerned. Major types of arrangement of muscle fibres in fasciculi are described in the following text:

1. **Parallel fasciculi (Fig. 9.8):** The muscle fibres or fasciculi are parallel to the line of muscle pull. Such muscles contract over a great distance (i.e. they have a maximum range of movement) and have good endurance. They may be:
   (a) *Quadrilateral*, e.g. thyrohyoid, pronator quadratus.
   (b) *Strap-like*, e.g. infrahyoid muscles, sartorius.
   (c) *Strap-like* with tendinous intersections, e.g. rectus abdominis.
   (d) *Fusiform*, e.g. biceps, digastric.
2. **Convergent fasciculi (Fig 9.8):** The muscle fibres or fasciculi converge at the insertion point to maximize contraction. This arrangement makes the muscle very powerful, although range of movement is

reduced. Such muscles may be:
   (a) *Triangular*, e.g. adductor longus.
   (b) *Fan-shaped*, e.g. temporalis.
3. **Spiral or twisted fasciculi (Fig 9.8):** In some muscles, the fibres are twisted or spiralled, e.g. trapezius, latissimus dorsi, pectoralis major, supinator.
4. **Cruciate muscles (Fig 9.8):** In some muscles, the fibres or fasciculi are arranged in superficial and deep planes and crossed 'X', e.g. sternocleidomastoid, masseter, adductor magnus.
5. **Sphincteric fasciculi:** In some muscles, the fibres or fasciculi surround an opening or orifice, thus when they contract, the opening is closed or constricted, e.g. orbicularis oculi around the eye and orbicularis oris surrounding the oral orifice.
6. **Pennate fasciculi (Fig. 9.9):** The pennate muscles resemble the feather, hence the name pennate. The fleshy fibres correspond to the bars of the feather and the tendon to the shaft, as they are all inserted by a tendon. The pennate muscles have many fibres per unit area, and hence, they are strong muscles. They may be:
   (a) *Unipennate*: when fibres have a linear origin and have the appearance of one-half of a feather, e.g. extensor digitorum longus, flexor pollicis longus, peroneus tertius.
   (b) *Bipennate*: when the arrangement of the fibres is that of a whole feather, e.g. flexor hallucis longus, dorsal interossei.
   (c) *Multipennate*: when septa (partitions) extend into the origin and the insertion. The arrangement of fibres is such that it provides the appearance of many feathers, e.g. deltoid.
   (d) *Circumpennate*: when fibres converge from the walls of a cylindrical space to a buried central tendon, e.g. tibialis anterior.

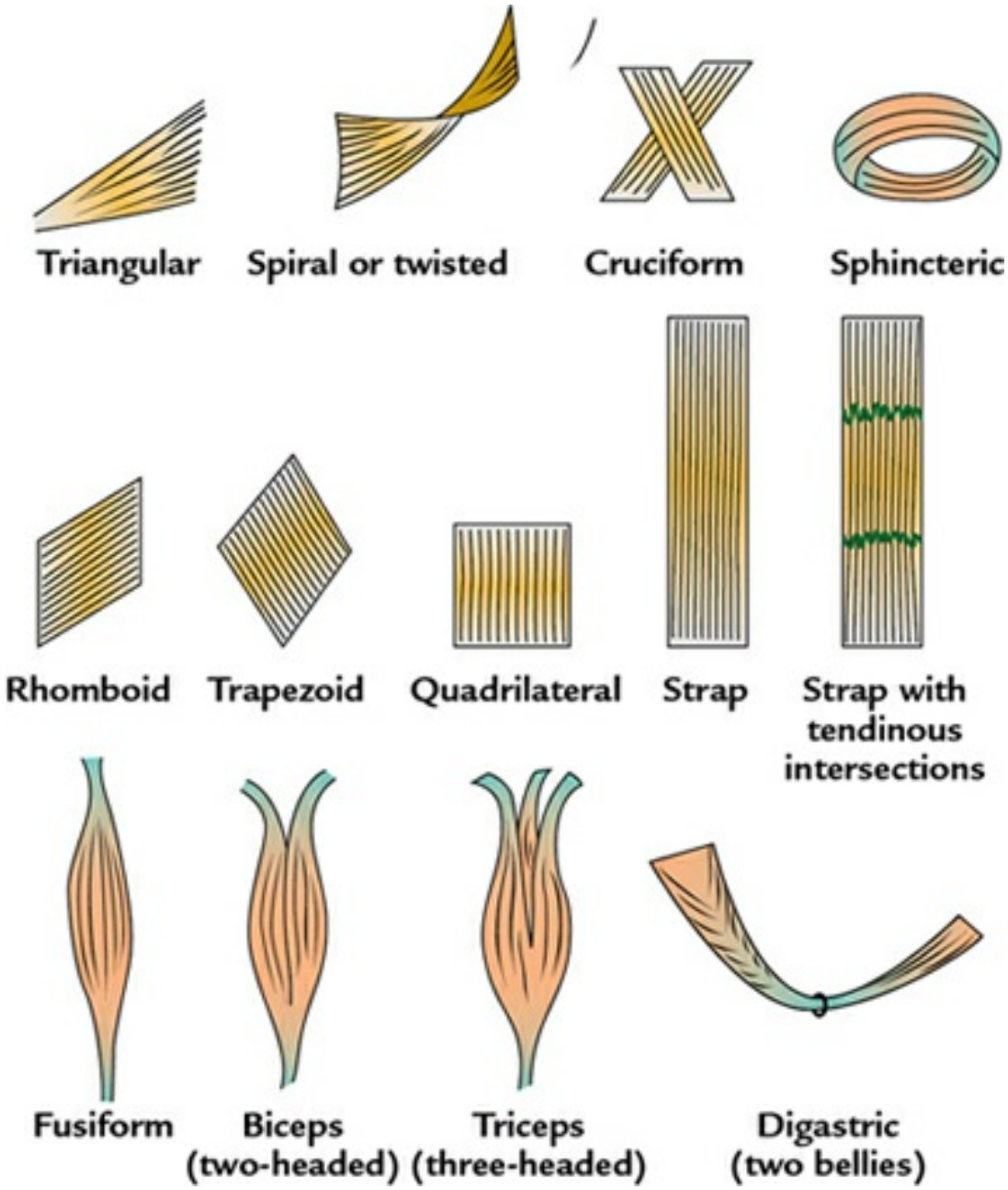


FIG. 9.8 ■ Muscles with parallel, convergent, spiral, cruciate and sphincteric fasciculi.

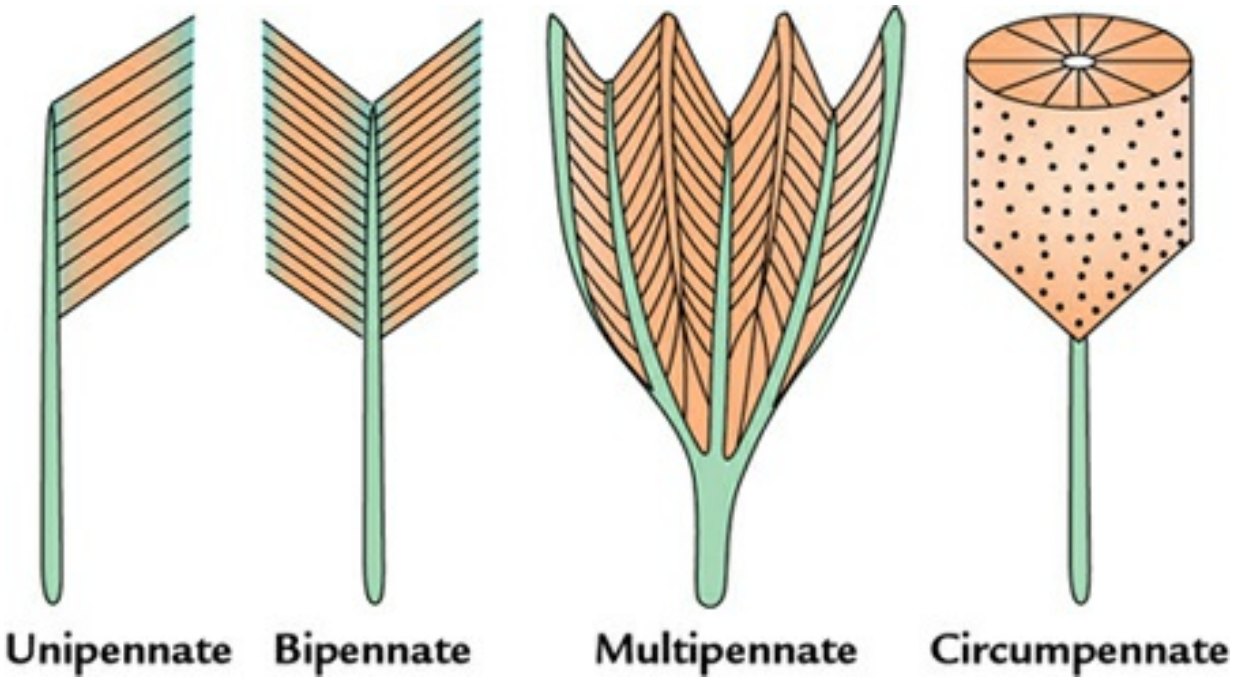


FIG. 9.9 ■ Muscles with pennate fasciculi (pennate muscles).

Nomenclature of muscles in general

The muscles are named according to their: (1) location, (2) shape, (3) action, (4) number of heads, (5) attachments (origin and insertion), (6) direction of fibres and (7) size of muscles.

Thus, the name of a muscle can often tell you a lot about that muscle.

Thus muscle's name tends to fall into one or more of the aforementioned categories:

(1) **According to location**

Muscle	Location
Tibialis anterior	Anterior aspect of tibia
Temporalis	Temporal fossa
Supraspinatus	Supraspinous fossa
Infraspinatus	Infraspinous fossa
Pectoralis	In front of chest (chest = pectus)
Intercostals	Between the ribs

(2) **According to shape**

Muscle	Shape
Trapezius	Trapezoid
Serratus anterior	Serrated/jagged-shaped anterior attachment
Quadratus	Quadrangular
Rhomboideus	Rhomboid

(3) **According to action**

Muscle	Action
Extensor carpi ulnaris	Extension of the wrist (corpus)
Flexor carpi radialis	Flexion of the wrist on the radial side

(4) **According to number of heads**

Muscle	Number of heads
Biceps brachii	Two-headed muscle on the front of the brachium
Triceps brachii	Three-headed muscle on the back of brachium
Quadriceps femoris	Four-headed muscle on the front of femur

(5) **According to attachments**

Muscle	Attachments
Sterno-cleidomastoid	On sternum, clavicle and mastoid process of skull
Stylohyoid	On styloid process and hyoid bone
Cricothyroid	On cricoid and thyroid cartilage

(6) **According to direction of fibres**

Muscle	Direction of fibres
Rectus abdominis	Straight (rectus = straight) muscle on the anterior abdominal wall
Transversus abdominis	Muscle running transversely on front of the anterior abdominal wall
Rectus femoris	Muscle lying straight on front of the femur
External oblique	Superficial (external) muscle having oblique fibres

(7) **According to size of muscles**

Muscle	Size
Gluteus maximus, gluteus medius and gluteus minimus	Largest, medium and smallest muscles attached on the gluteal surface of the hip bone (*L. maximus* = largest, *medius* = in between, i.e. medium size, *minimus* = smallest)
Adductor magnus, adductor longus, and adductor brevis	Largest (*L. magnus* = largest), long (*L. longus* = long), and short (*L. brevis* = short) muscles in the adductor compartment of the thigh

Gross features of a typical skeletal muscle

The typical skeletal muscle is usually long and narrow. It spans a joint and is attached to a bone at either end of joint by a tendon (Fig. 9.10). It consists of two ends and two parts.

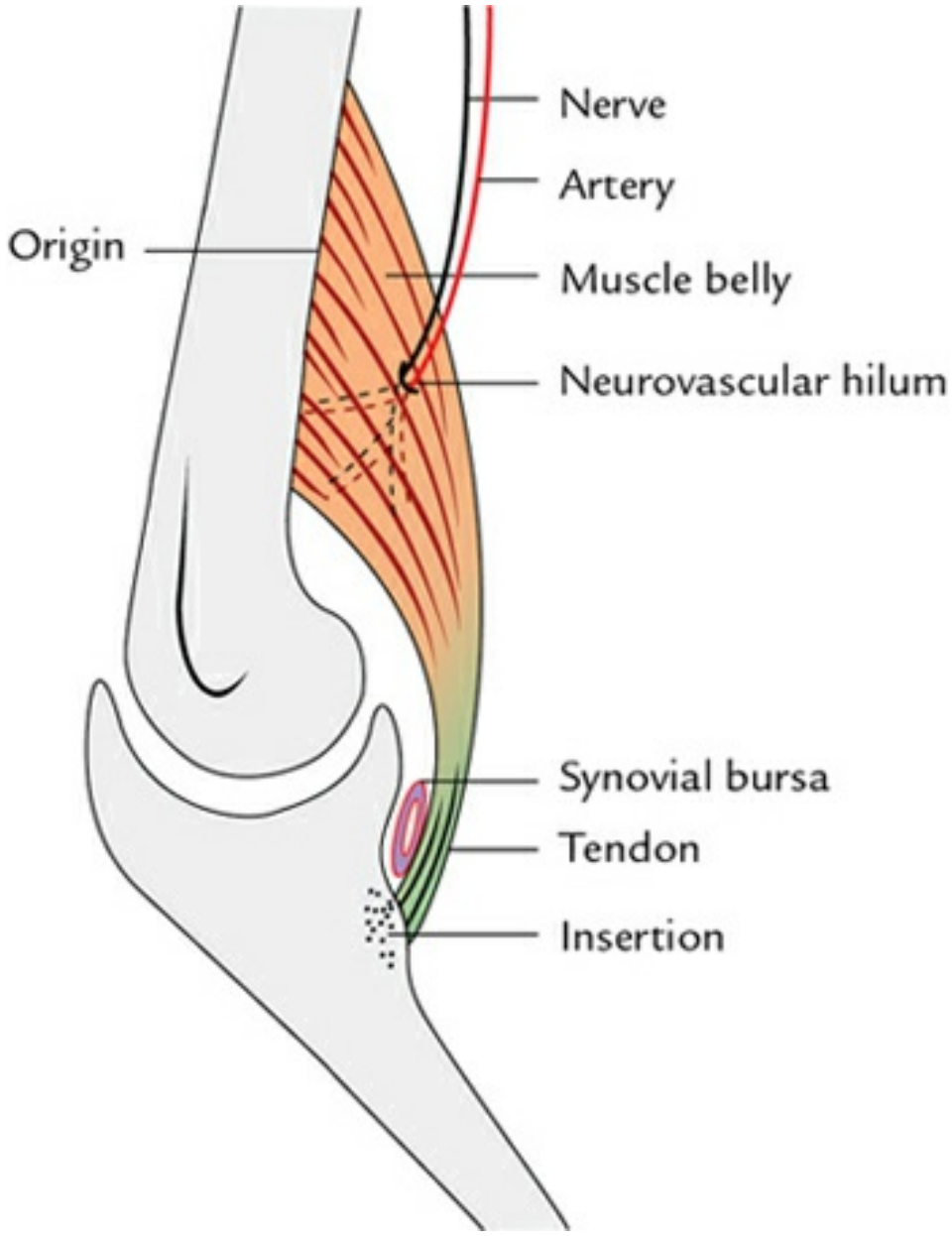


FIG. 9.10 ■ Schematic diagram of a typical skeletal muscle showing origin, insertion (by means of a tendon), nerve supply, blood supply and a lubricating device (synovial bursa).

Ends of a muscle

Each skeletal muscle has two ends: fixed and movable.

When the muscle contracts, one of the bone moves relative to the other at the joint. The more fixed or stationary attachment is designated as the **origin** of the muscle and the movable end as the **insertion**. In limb muscles, the origin is usually proximal to the insertion.

The inspection of Figure 9.10 suggests that the upper attachment is the

origin and the lower attachment is the **insertion**. Therefore, one may expect that the contraction of the muscle would move the distal (lower) bone.

However, this arrangement can be reversed if the more movable end becomes less movable. For example, what would happen if the hands were holding on to a chin-up bar when the biceps contracted? The biceps would still flex the elbow but now the humerus would move towards the insertion. This is because the proximal bone, which is usually more stable, has become more movable. This is termed as the **reversal of muscle action**.

Clinical correlation

Reversal of muscle action: Almost every muscle can work with its apparent origin and insertion reversed. For example, the latissimus dorsi is inserted into the floor of the intertubular groove at the upper end of the humerus and is usually described as an adductor and medial rotator of the arm. But if the arm is fixed, the insertion of the muscle will act as the origin and the muscle becomes most important to the patients shifting their position in bed by placing their hands on the bed and lifting the pelvis to the new position.

Parts of a muscle AN 3.2

A typical skeletal muscle consists of two parts: belly and tendon. It refers to: (a) a thickened fleshy part called **belly** and (b) a cord- or a rope-like fibrous part called a **tendon**.

The word 'muscle' is derived from the Latin word *musculus*, which means little mouse (mus). This is probably because some muscles bear fancied resemblance to mice with fleshy parts representing the body and tendons representing the tail.

The **belly** is the contractile part and attached to the bone proximal to the bone that is to be moved. It is highly vascular with a higher metabolic rate. It cannot withstand pressure or friction.

The **tendon** spans the joint and is attached to the bone that is to be moved. When a tendon is flattened, it is called *aponeurosis*.

Changes at the myotendinous junction (Fig. 9.11):

(a) the connective tissue framework of the muscle belly becomes

continuous with the connective tissue framework of the tendon and (b) the muscle fibres of the muscle belly are contiguous but not continuous with tendon fibres.

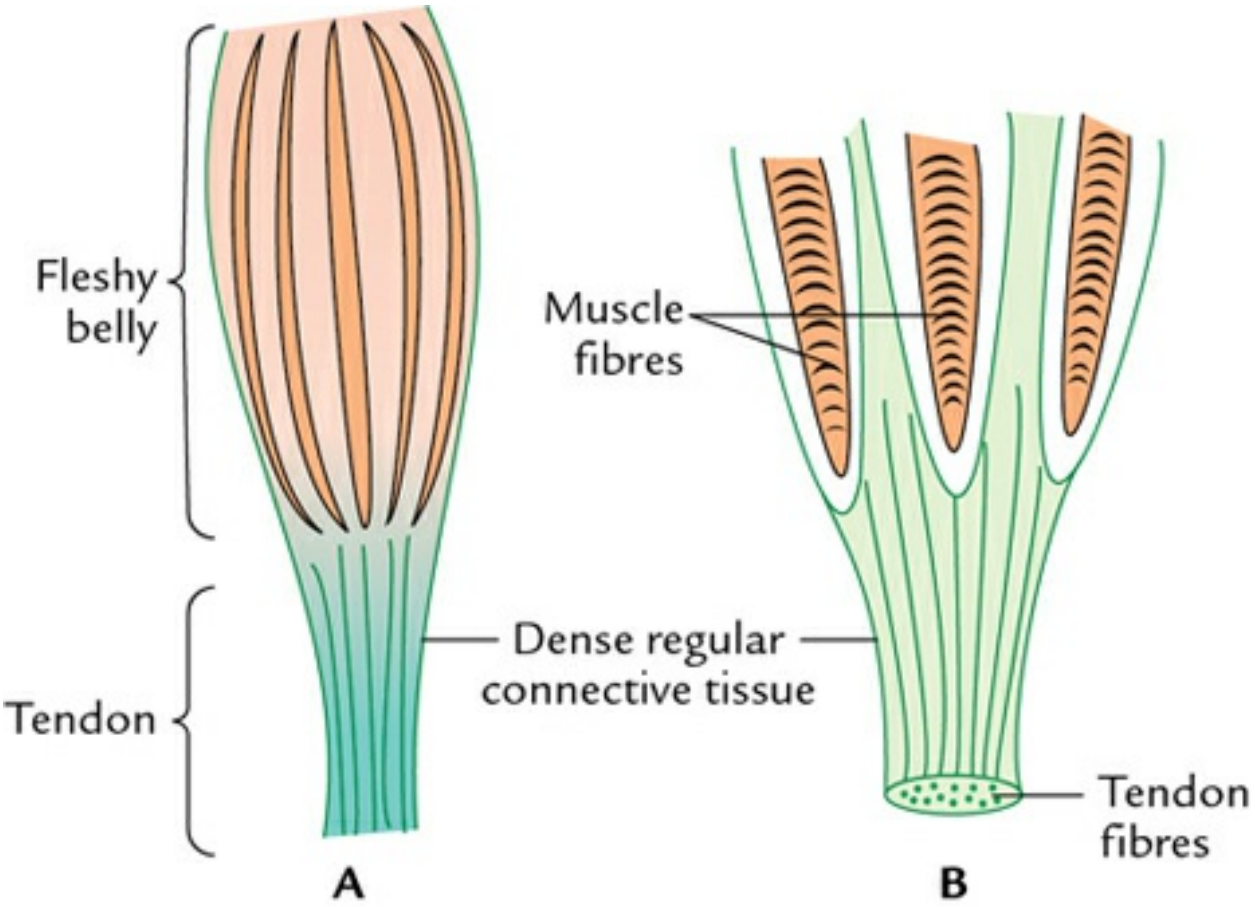


FIG. 9.11 ■ Myotendinous junction: **(A)** contiguity of muscle fibres with tendon fibres and **(B)** dove-tail type of junction between belly and tendon.

This arrangement at the myotendinous junction resembles the '**dove-tail arrangement**'.

Tendons AN 3.2

Salient features of tendons are as follows:

1. The tendon is a cord-like structure, formed by dense regular connective tissue (white fibrous tissue) that connects the muscle belly to the periosteum of the bone.
2. It functions to transfer the force of contraction from muscle across the

joint and onto the bone that is to be moved.

3. The blood supply of the tendon is derived from two sources: (1) from the vessels of its own muscle and (2) from the periosteal vessels of the bone to which it is attached.
4. In many situations where the tendons are subjected to friction, a lubricating device, a **synovial bursa** or a **synovial sheath** is interposed to enable them to move freely. The synovial sheath consists of two layers: a visceral layer that covers the tendon itself and a parietal layer. The two layers are separated by a thin film of synovial fluid.
5. The tendons serve to withstand pressure. The tendons are immensely strong, e.g. a tendon whose cross-sectional area is 6 cm can support a weight of 4000–8000 kg.
6. The tendons are supplied by sensory nerve endings; the golgi tendon organs play a role in tendon reflex.

Aponeuroses

The flattened sheets of tendons are called aponeuroses. Therefore both are made up of white fibrous tissue (dense regular connective tissue). Differences between the tendon and aponeurosis are given in Table 9.4.

TABLE 9.4

Differences between tendon and aponeurosis AN 3.2

Tendon	Aponeurosis
• Connect muscle with the bone • Round in shape and tough in consistency • Provides body movements • More prone to injury • Examples: *tendo-achilles* above heel, *tendons of biceps brachii* in front of elbow	Connect muscle with muscle or skin Flat in shape and delicate in consistency Provides strength and stability Less prone to injury Examples: *Palmar and plantar aponeurosis*

Clinical correlation

Rupture of tendons: If the tendon of a muscle is severed or ruptured, the muscle becomes ineffective. To assess the integrity of a tendon, one must know the site of its insertion and the movement that contraction of its muscle would normally produce.

The tendons are ruptured by direct trauma, especially when they are weakened by rubbing over a fractured callus or the osteophytes, a new bone produced by arthritis. The **tendons of the biceps brachii** on front of the arm and the **Achilles tendon of triceps surae** on back of the leg are the ones most often ruptured.

The tendons have a poor blood supply, so if ruptured does not heal themselves. Hence, surgical reconstruction is generally needed for the treatment of severed tendons.

Lubricating mechanisms

Synovial bursa and synovial sheath

If a muscle tendon is subjected to friction, a lubricating device, a synovial bursa or a synovial sheath is always interposed.

Synovial bursa

A synovial bursa (*L. bursa* meaning a purse) is a closed sac differentiated out of areolar tissue. It is similar to a synovial membrane in structure. Its walls are separated from each other merely by a thin film of slippery fluid. The bursa, a lubricating device, helps in diminishing friction and allowing free movement of muscle tendons. They are formed whenever tendons rub against bone, cartilage, ligament, or other tendons; hence, they are the commonest in the limbs. They are also found close to the joints where skin rubs against underlying bony structures, e.g. the *prepatellar bursa*. Occasionally bursa communicates with the joint cavity, viz. *suprapatellar bursa*.

Types of bursae

The bursae are of the following three types (Fig. 9.12):

1. *Subtendinous*
2. *Articular*
3. *Subcutaneous*.

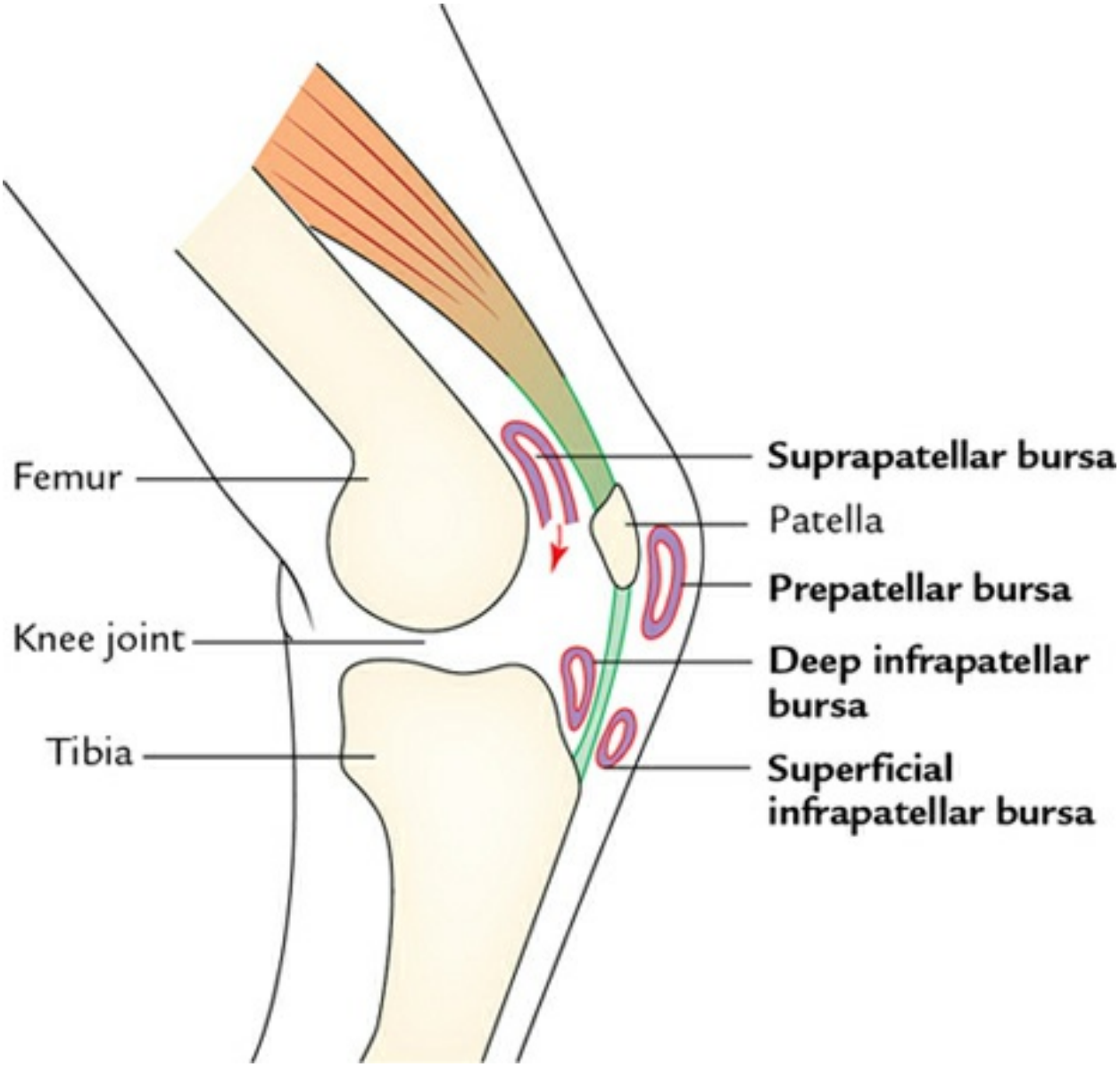


FIG. 9.12 ■ Bursae related to the knee joint. Note that the suprapatellar communicates with the cavity of the knee joint.

Subtendinous bursa intervenes between tendon and bone, tendon and ligament, or between two adjacent tendons. Most of the synovial bursae of the limbs belong to this type.

Articular bursa subserves the function of a joint, e.g. the bursa between

the dens of axis (second cervical vertebra) and transverse ligament of atlas (first cervical vertebra).

Subcutaneous bursa intervenes between the skin and bony prominence near the joints, e.g. prepatellar (housemaid's bursa) and superficial infrapatellar bursa (clergyman's bursa).

N.B.

Subdeltoid/subacromial bursa is the largest synovial bursa in the body.

Clinical correlation

- **Bursitis:** The synovial bursa is commonly inflamed leading to swelling and pain. This clinical condition is called *bursitis*.
- **Adventitious bursa:** Sometimes, *adventitious bursa* is formed from tissue spaces of loose areolar tissue subjected to continuous pressure and friction-producing clinical conditions. For example:
  (a) *Porter's shoulder*: The formation of the bursa between clavicle and skin in porters.
  (b) *Tailor's ankle*: The formation of the bursa between lateral malleolus and skin in tailors.

Synovial sheaths (Fig. 9.13A–C)

When tendons pass through the fibrous bands/osseofibrous tunnels, they are surrounded by **synovial sheaths**. The synovial sheath extends 1 cm on either side of the site of friction. The tendon invaginates the bursa from one side so that the tendon becomes suspended within the bursa by a **mesotendon**. The mesotendon enables blood vessels to enter the tendon. Thus, structurally, the synovial sheath is made up of two concentric layers (parietal and visceral) of the synovial membrane. The two layers are separated by a capillary film of synovial fluid, where the range of movement is excessive, the mesotendon either disappears completely or may be reduced to narrow cords, viz. **vincula** of digital synovial sheaths around the long flexor tendons of the fingers and toes.

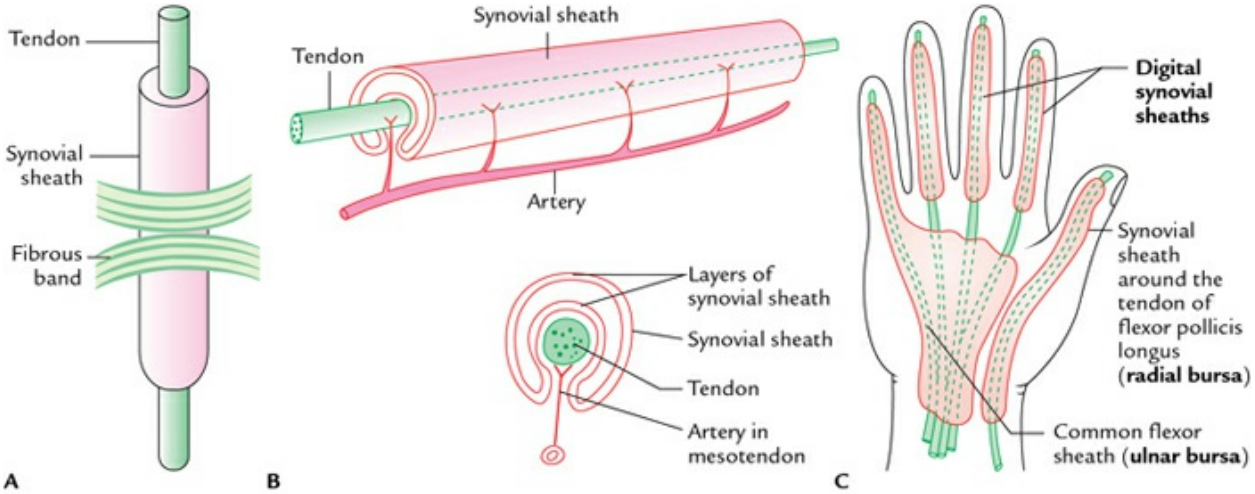


FIG. 9.13 ■ Synovial sheath: **(A)** synovial sheath around a tendon passing underneath a fibrous band; **(B)** invagination of the synovial sheath by a tendon and blood vessels reaching the tendon through mesotendons and **(C)** synovial sheath around the long flexor tendons of the fingers.

Blood supply

The muscle cells have a high rate of metabolic activity. Hence they require extensive vascularity to receive nutrients and oxygen and to eliminate waste products:

1. Small muscles are generally supplied by a single artery and perhaps two veins to return the blood.
2. Large muscles are usually supplied by several arteries and veins.

N.B.

Microscopic capillary exchange between arteries and veins occurs throughout the endomysium that surrounds the individual muscle fibres.

Clinical correlation

Stiffness of muscles: The feeling of stiffness, the day after the strenuous exercise is due to the strain on muscle fibres and the accumulation of lactic acid within the muscle. The *lactic acid* is the waste product of metabolism and is removed by the venous flow from the muscle. If the individual is in a good physical condition, the lactic acid is readily removed and he/she does not suffer from *stiffness.*

Classification of muscles according to vascular pedicles

Muscles are classified into five types according to the number of vascular pedicles which enter the muscle and their relative dominance:

- Type I
- Type II
- Type III
- Type IV
- Type V.

Type I

These muscles possess a single vascular pedicle, e.g. tensor fascia latae (supplied by an ascending branch of the lateral circumflex femoral artery, and gastrocnemius supplied by the sural artery).

Type II

These muscles possess a *single dominant vascular pedicle and several minor vascular pedicles*, e.g. gracilis (supplied by a medial circumflex artery in the dominant pedicle).

Type III

These muscles possess *two separate dominant pedicles* from different source arteries, e.g. rectus abdominis (supplied by superior and inferior epigastric arteries) and gluteus maximus (supplied by superior and inferior gluteal arteries).

Type IV

These muscles possess *multiple small vascular pedicles* which in isolation are not capable of supplying the entire muscle, e.g. sartorius and tibialis anterior.

Type V

These muscles possess *one dominant vascular pedicle* and *multiple secondary segmental pedicles*, e.g. latissimus dorsi (supplied by thoracodorsal artery as the dominant pedicle while thoracolumbar artery perforators from lower six

posterior intercostal arteries, and lumbar arteries supply as the secondary segmental pedicles), the pectoralis major (supplied by a pectoral branch of thoraco-acromial trunk as the dominant pedicle and by anterior perforators from internal thoracic artery as secondary segmental pedicles).

Clinical correlation

Muscle graft: The classification of muscles according to their blood supply has important surgical relevance in determining which muscles will survive when used as grafting in plastic and reconstructive surgery.

Nerve supply of muscle AN 7.5

Nerves enter the muscles at one or more **neurovascular hila** (Fig. 9.10) which are fairly constant in location. The knowledge of the location of these hila is important to physiotherapists since these hila are the points at which cardiac stimulation of the nerve is most effective.

Generally, the nerve supplying the muscle is called the **motor nerve** but strictly speaking, it is a mixed nerve, i.e. it contains both motor and sensory fibres.

The **motor fibres** conduct nerve impulses to muscle fibres to stimulate them to contract, whereas the **sensory fibres** conduct impulses away from neuromuscular spindles in the muscle and golgi nerve endings in the tendon to the central nervous system (CNS).

N.B.

Muscle fibres will atrophy if they are not periodically stimulated to contract.

Further details:

1. **Motor fibres** (60%) supplying the muscles are of two types:
   (a) *Large myelinated alpha (α) fibres* which supply extrafusal muscle fibres of muscle spindles.
   (b) *Small myelinated gamma (γ) fibres* which supply intrafusal fibres of muscle spindles.
2. **Sensory fibres** (40%) supplying the muscles are of two types:

(a) *Myelinated fibres* carrying proprioceptive sensations from muscle spindles and tendons.
(b) *Nonmyelinated fibres* carrying exteroceptive (pain, touch and temperature) sensations.

The relative size of the nerve supplying a muscle depends upon the size of the motor units in that muscle.

Motor point

It is the point of entry of the nerve trunk into the muscle. The nerves mostly enter the muscles from their deep surfaces with few exceptions such as the long thoracic nerve supplies serratus anterior muscle from its superficial surface. The motor points correspond to **neurovascular hila**.

Motor unit (Fig. 9.14)

A motor unit consists of a single motor neuron (as anterior horn cell), its axon, and all muscle fibres that it supplies.

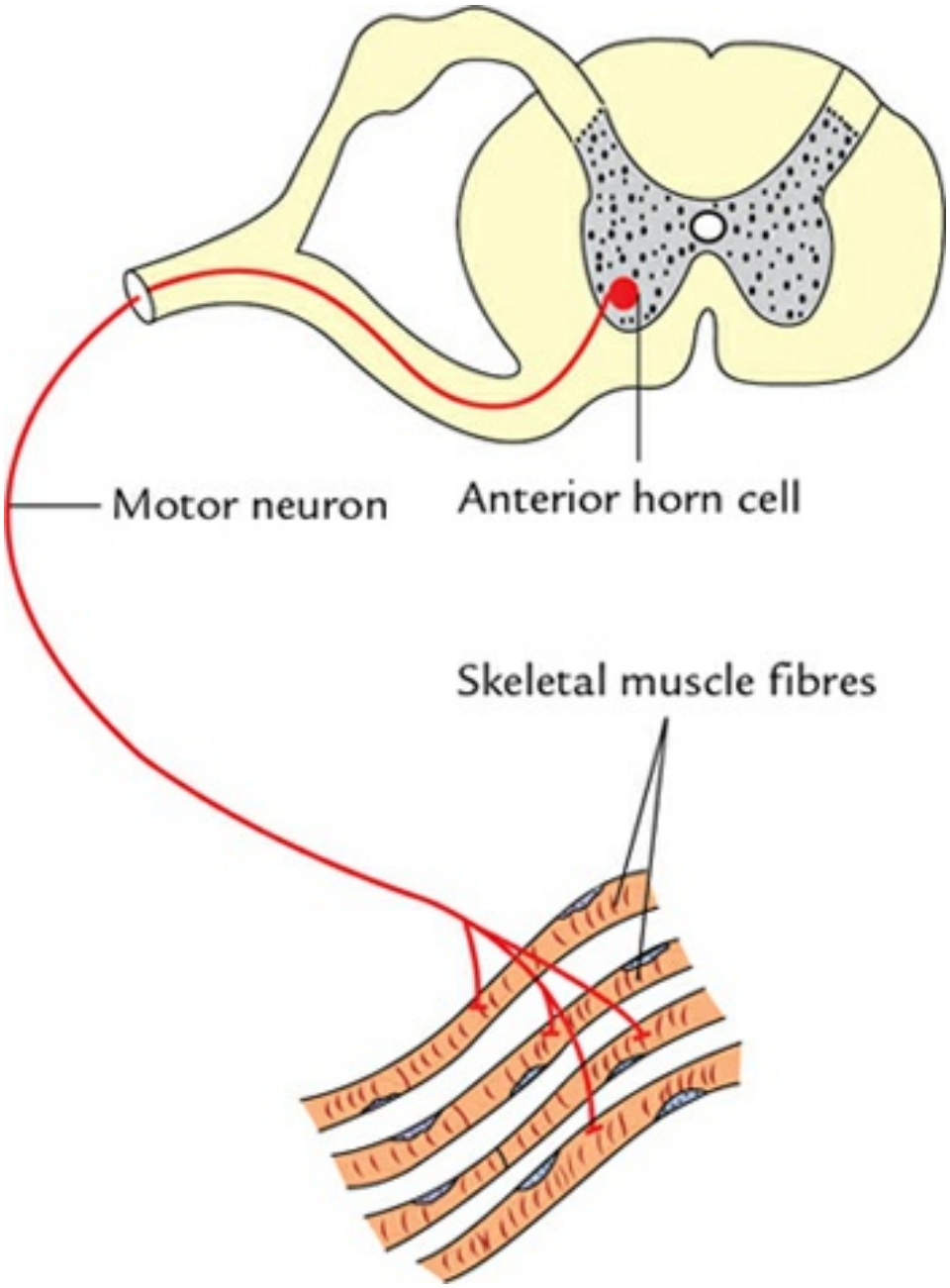


FIG. 9.14 ■ Motor unit. It consists of a single motor neuron and all the muscle fibres that it innervates. Most muscles have an innervation ratio of one motor neuron per 100–150 muscle fibres. Muscles capable of precise movements have an innervation ratio of 1:10, whereas muscles responsible for gross body movement have an innervation ratio exceeding 1:500.

The muscles that have precise and accurately controlled action, viz. extraocular muscles have smaller motor units with an innervation ratio of 1:10. But muscles that have generalized functions (gross body movements), such as those in the gluteal region and thigh, have very large motor units with an innervation ratio exceeding 1:500.

Neuromuscular junction [motor end plate (Fig. 9.15)]

The junction between the expanded terminal end of the axon-**presynaptic knob** and receptive region of a muscle fibre **sole plate,** is called the **neuromuscular junction**.

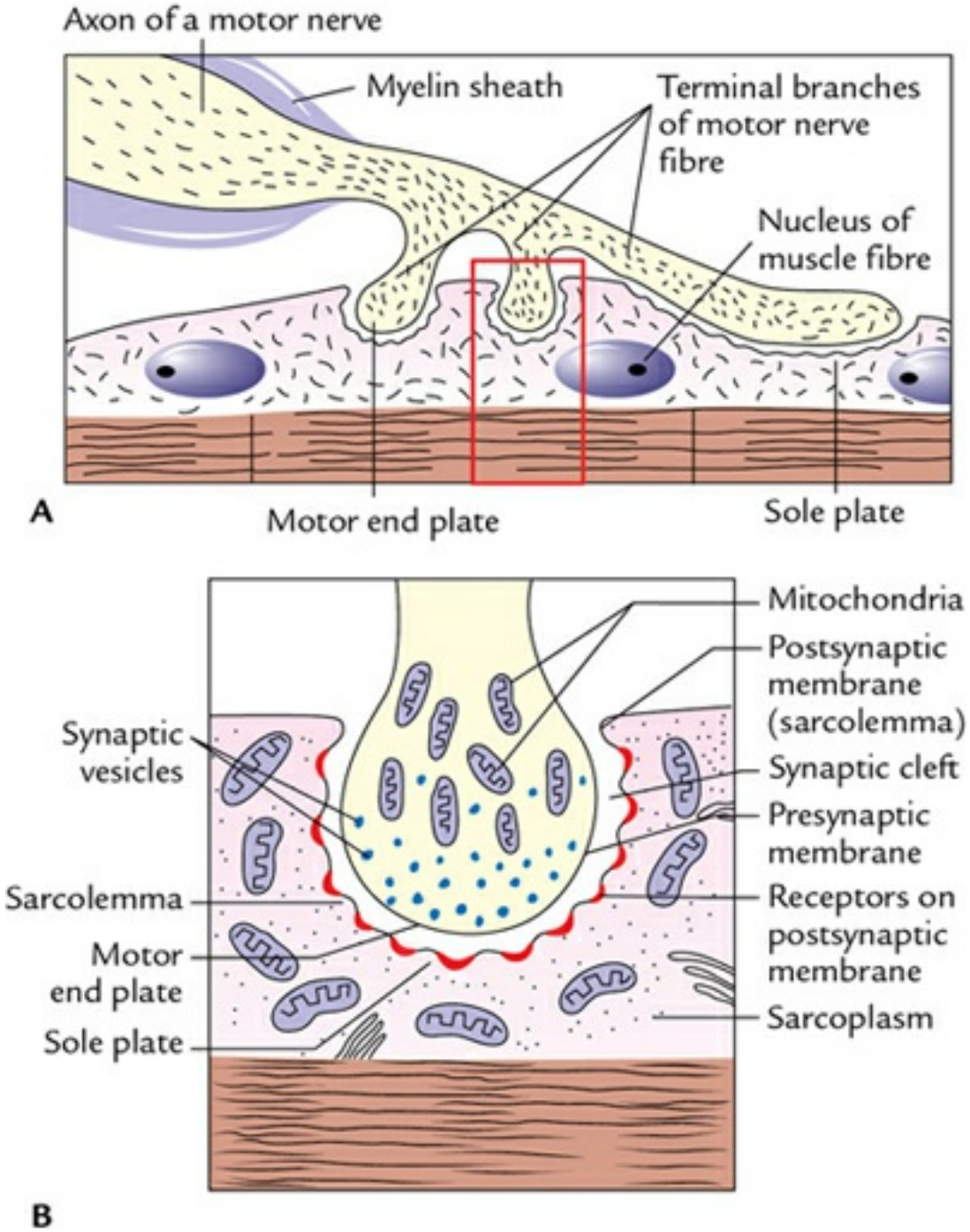


FIG. 9.15 ■ Neuromuscular junction: **(A)** site where nerve fibre and muscle fibre meet and **(B)** showing presynaptic knob, synaptic cleft and sole plate. The sole plate is the sarcolemma and underlying sarcoplasm.

When a motor nerve penetrates a muscle, it divides into a number of branches or axons. The terminal end of each branch expands to form a synaptic knob, which contacts the sarcolemma of muscle fibre. The axon may branch to serve a number of muscle fibres.

Presynaptic knob

It is the expanded terminal end of the axon (also called the presynaptic terminal). It is not covered by Schwann sheath as the terminal part of nerve fibre loses myelin sheath and Schwann sheath spreads over the surface of the sarcolemma.

The **synaptic knob** contains numerous small synaptic vesicles containing a neurotransmitter called **acetylcholine (Ach)**.

Sole plate

The region of muscle fibre that comes in contact with presynaptic knob is called *sole plate*. Here sarcolemma is folded and bear many receptors, the sarcoplasm underneath the sarcolemma contains many muscle nuclei and mitochondria.

Synaptic cleft (neuromuscular cleft)

It is a small gap between the plasma membrane of the axon terminal (presynaptic membrane) and the plasma membrane of the sarcolemma (postsynaptic membrane).

Mechanism of transmission of impulse

As the nerve impulse reaches the axon terminal, it causes the release of acetylcholine into the synaptic cleft of the neuromuscular junction which soon binds with the receptors on the postsynaptic membrane leading to its depolarization (i.e. production of an action potential) and, consequently, the muscle contracts. As the action potential is produced, acetylcholine is immediately destroyed by an enzyme called acetylcholinesterase present in a

high concentration on motor end plate.

Clinical correlation

- **Formation of new motor end plate:** When a nerve fibre is cut, the nerve terminal degenerates but the *sole plate* persists for a year or so. When the nerve fibre regenerates, a new *motor end plate* is formed.
- **Organophosphorus poisoning:** In ***organophosphorus poisoning*** (a commonly ingested poison to commit suicide), the organophosphates bind with and inhibit the action of acetylcholinesterase (AchE); as a result, the Ach is not destroyed in the synaptic cleft, leading to the continuous production of action potential and contraction of muscles, viz. respiratory muscles. Consequently, there occurs spastic paralysis of respiratory muscles and death.
- ***Myasthenia gravis*** results from the *production of autoimmune antibodies* that bind to acetylcholine receptors on the postsynaptic membrane of sole plate of muscle fibre and destroy them, thus reducing their number. Therefore, when they are activated by acetylcholine, the muscle cannot contract properly and exhibit a degree of flaccid paralysis.
- The acetylcholine receptors are also blocked by a poison called *curare*. Fortunately, curare is not a common poison to which people are exposed.

Muscle receptors

Neuromuscular spindles (muscle spindles)

These are spindle-shaped sensory end organs within the skeletal muscles that provide sensory information to the CNS to control the tone of the muscle (Fig. 9.16).

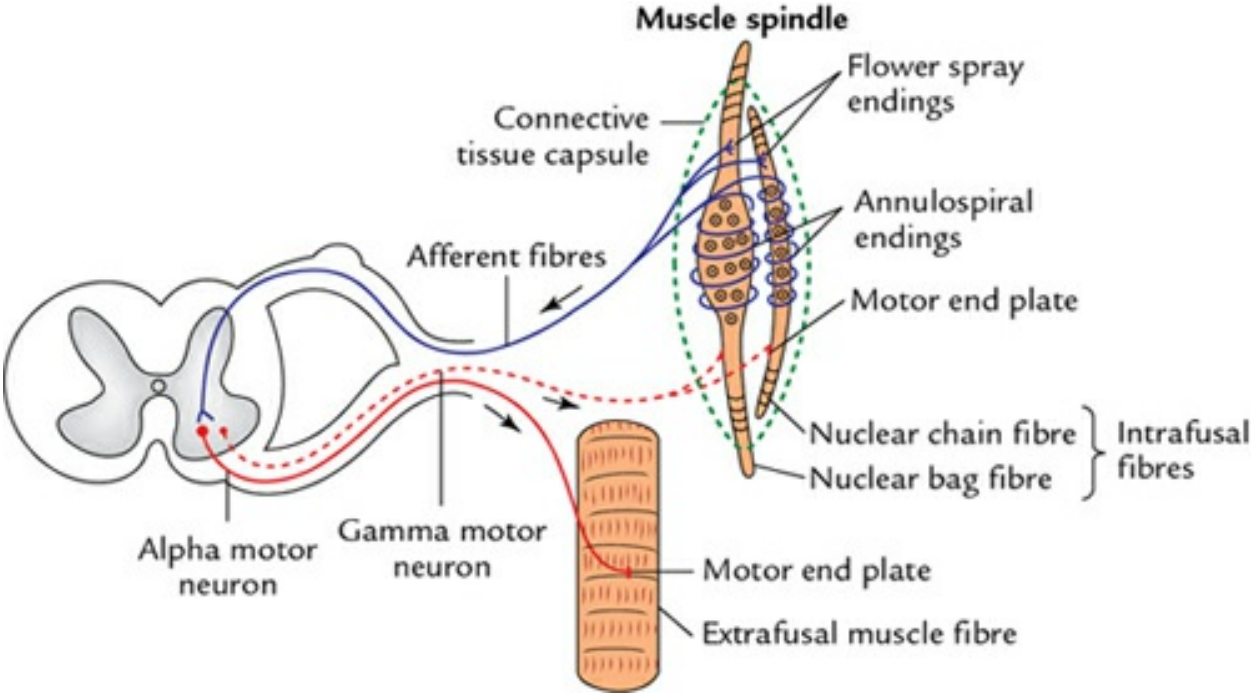


FIG. 9.16 ■ Schematic structure of neuromuscular spindle and its nerve supply.

Each spindle consists of a bundle of small specialized skeletal muscle fibres, surrounded by a fusiform connective tissue capsule. These fibres are called **intrafusal fibres**. The unspecialized muscle fibres outside the spindle are called **extrafusal fibres**.

The intrafusal muscle fibres are of two types: **nuclear chain fibres** and **nuclear bag fibres**. In nuclear chain fibres, the nuclei form a single longitudinal chain in the central unexpanded part, whereas in the nuclear bag fibres, nuclei are aggregated in the central expanded region.

The extrafusal fibres are supplied by large alpha (α) motor fibres, whereas intrafusal fibres are supplied by small gamma (γ) motor fibres.

The sensory innervation of the muscle spindle is by two types of sensory nerve endings:

1. Annulospiral
2. Flower spray.

The **annulospiral nerve endings** wind spirally the central nuclear region of the intrafusal muscle fibres.

The **flower spray nerve endings** terminate at the ends of the intrafusal fibres away from the central nuclear region, resembling a spray of the

flowers.

N.B.

The nuclear bag fibres are thicker and longer than the nuclear chain fibres and project beyond the spindle-shaped fibrous capsule to be attached with the extrafusal connective tissue.

Stretch reflex/myotatic reflex

It refers to contraction of a muscle in response to passive stretching, i.e. when a muscle is stretched, the stretch reflex automatically regulates the length of the muscle. It is a monosynaptic reflex. The **perfect example of a monosynaptic reflex** is the knee jerk or patellar reflex (Fig. 9.17).

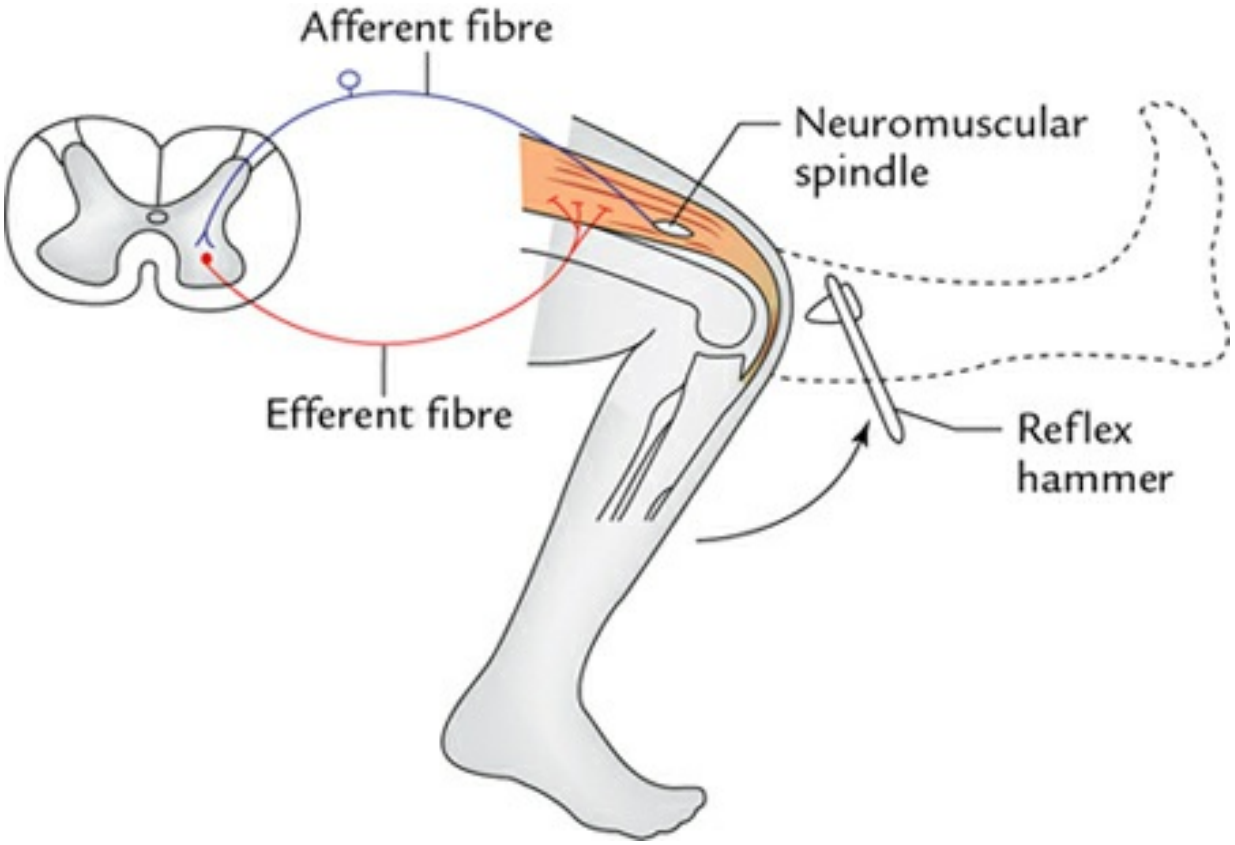


FIG. 9.17 ■ Stretch reflex (monosynaptic reflex).

When the muscle is stretched, the intrafusal muscle fibres are elongated, thus stimulating the sensory nerve endings around them. The sensory nerve fibres carrying the information synapse with alpha (α) motor neuron, which,

in turn, causes quick contraction of stretched muscle fibres (the stretch reflex) thus reducing tension in the intrafusal fibres (Fig. 9.17).

N.B.

- The muscle spindles regulate the degree and rate of contraction of extrafusal fibres.
- The stretch reflex is used by clinicians to elicit the tendon jerks.

Golgi tendon organs (neurotendinous spindles)

These are sensory organs located near the musculotendinous junctions.

The neurotendinous spindle is spindle-shaped, consisting of loosely arranged collagen fibres surrounded by a fibrous capsule. The collagen fibres (also called **intrafusal tendon fibres**) are innerved by myelinated nerve fibres which lose their myelin sheath before piercing the capsule of the spindle and terminate in club-shaped endings.

Golgi tendon reflex (Fig 9.8)

They monitor the tension produced on the tendon during muscle contraction and prevent its damage from excessive stresses put on it.

Clinical correlation

Golgi tendon organ reflex: When the collagen fibres (intrafusal tendon fibres) within the neurotendinous spindle are stretched, the sensory fibres carrying this information stimulate inhibitory interneurons that synapse with alpha-1 motor neurons, which in turn cause relaxation of muscles to which the particular tendon is attached. This is termed as *Golgi tendon organ reflex* (Fig. 9.18). The opposing actions of neuromuscular spindles (excitatory) and neurotendinous spindles (inhibitory) are in balance during stretch reflex activity.

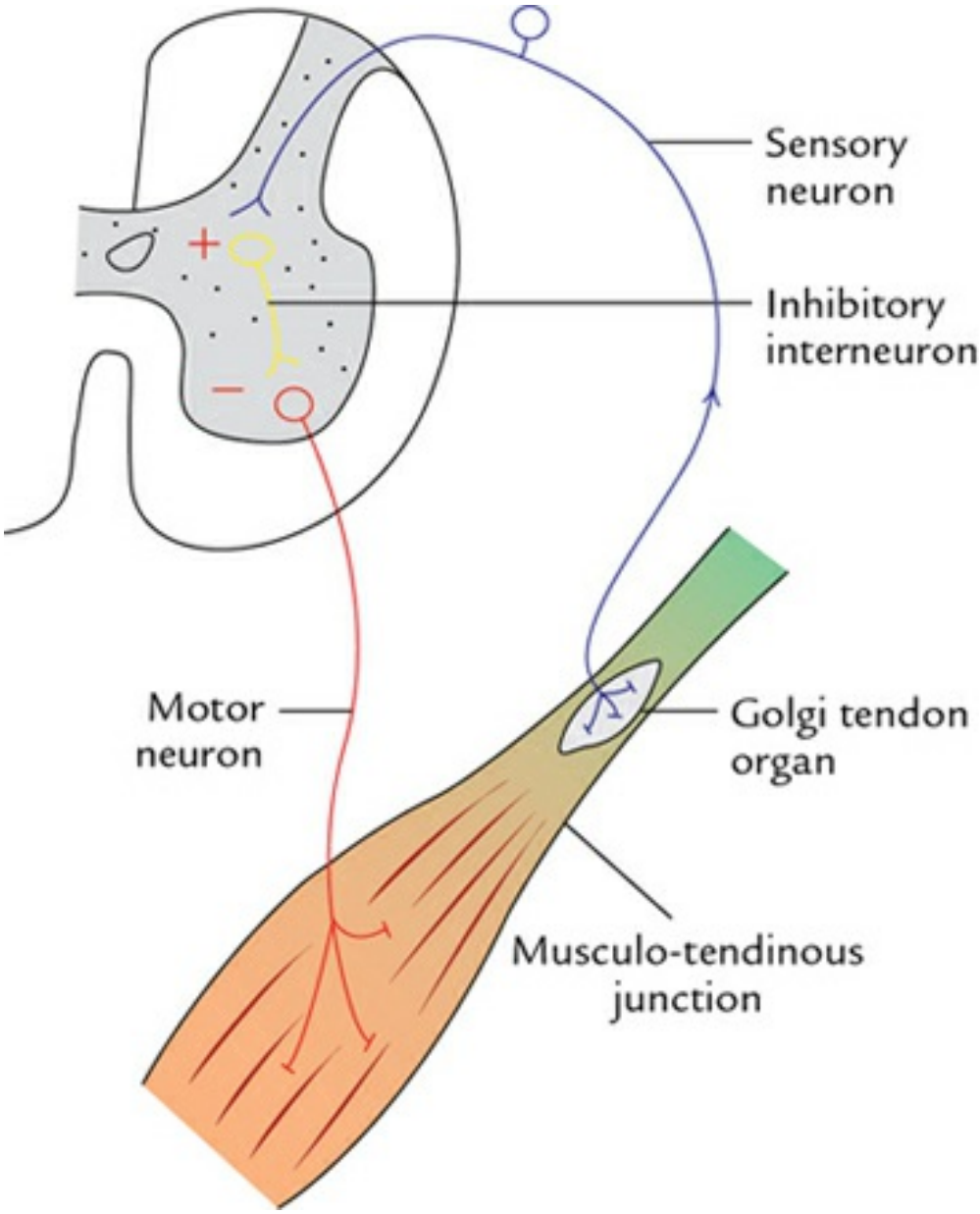


FIG. 9.18 ■ Golgi tendon organ reflex. The golgi tendon organ gives rise to afferents which end on an inhibitory interneuron. This reflex inhibits contraction in the same muscle.

Segmental innervation of muscles

Most of the skeletal muscles are supplied by more than one spinal segment (hence more than one spinal nerve).

It is important to note the following facts regarding segmental innervations:

1. Most of the muscles are supplied by two spinal segments (intrinsic muscles of the hand are unisegmental).

2. Muscles sharing a common primary action are supplied by the same spinal segments, and the antagonist muscles (i.e. opposing primary action) are supplied by the same number of spinal segments but one segment lower **en bloc**.

For example, the muscles flexing the elbow joint are supplied by C5 and C6 spinal segments, and muscles extending the elbow joint are supplied by C7 and C8 spinal segments.

It is neither necessary nor possible to remember the segmental innervation of all the muscles but students should remember the segmental innervation of muscles which are tested clinically by eliciting tendon jerks in patients.

The segmental innervation of these muscles is given in Table 9.5.

TABLE 9.5

Segmental innervation of muscles commonly used for eliciting tendon jerks/reflexes

Muscle	Segmental innervation	Tendon jerk/reflex
Biceps brachii	C5, C6 (musculo-cutaneous nerve)	**Biceps jerk** (flexion of the elbow by tapping the tendon of biceps brachii)
Triceps brachii	C7, C8 (radial nerve)	**Triceps jerk** (extension of elbow joint by tapping the tendon of triceps brachii)
Brachio-radialis (earlier called supinator longus)	C5, C6 (radial nerve)	**Supinator jerk** (flexion of elbow joint and supination of radio-ulnar joints by tapping the insertion of brachio-radialis tendon)
Quadriceps femoris	L2, L3, L4, etc. (femoral nerve)	**Knee jerk** (extension of the knee joint by tapping the tendon of quadriceps femoris)
Triceps surae	S1, S2 (tibial nerve)	**Ankle jerk** (plantar flexion of the ankle joint by tapping the Achilles tendon)

Clinical correlation

Paralysis of muscles: The loss of innervation of muscle leads to loss of its motor power, i.e. power to produce movements is called *paralysis*. It occurs due to damage to motor pathway consisting of upper and lower motor neurons. Damage to upper motor neurons causes *spastic paralysis* with exaggerated tendon jerks whereas damage to lower motor neurons causes *flaccid paralysis* with loss of tendon jerks. **AN 7.6**

Action of muscles

When muscle contracts, it brings about a movement. The range of movement depends on the length of fibres in the fleshy part and the power generated during contraction.

Muscle tone

It refers to the constant tension produced by muscles for long periods of time. Muscle tone is responsible for keeping our back and leg straight. The muscle tone is maintained by a small percentage of motor units. The motor units that are contracting are stimulated in such a way that tension produced in a muscle remains constant.

N.B.

The same motor units are not contracting all the time.

Length–tension relationship in muscles

The tension refers to the force built-up within the muscle, which is necessary for a muscle to contract. Stretching a muscle builds up tension within the muscle which is released when the muscle contracts.

A muscle is capable of being shortened to one-half of its normal resting

length. Also, the muscle can be stretched twice as far as it can be shortened. The excursion of a muscle is the distance between maximum elongation and maximum shortening (Fig. 9.19). The action of the muscle is strongest when it is slightly stretched.

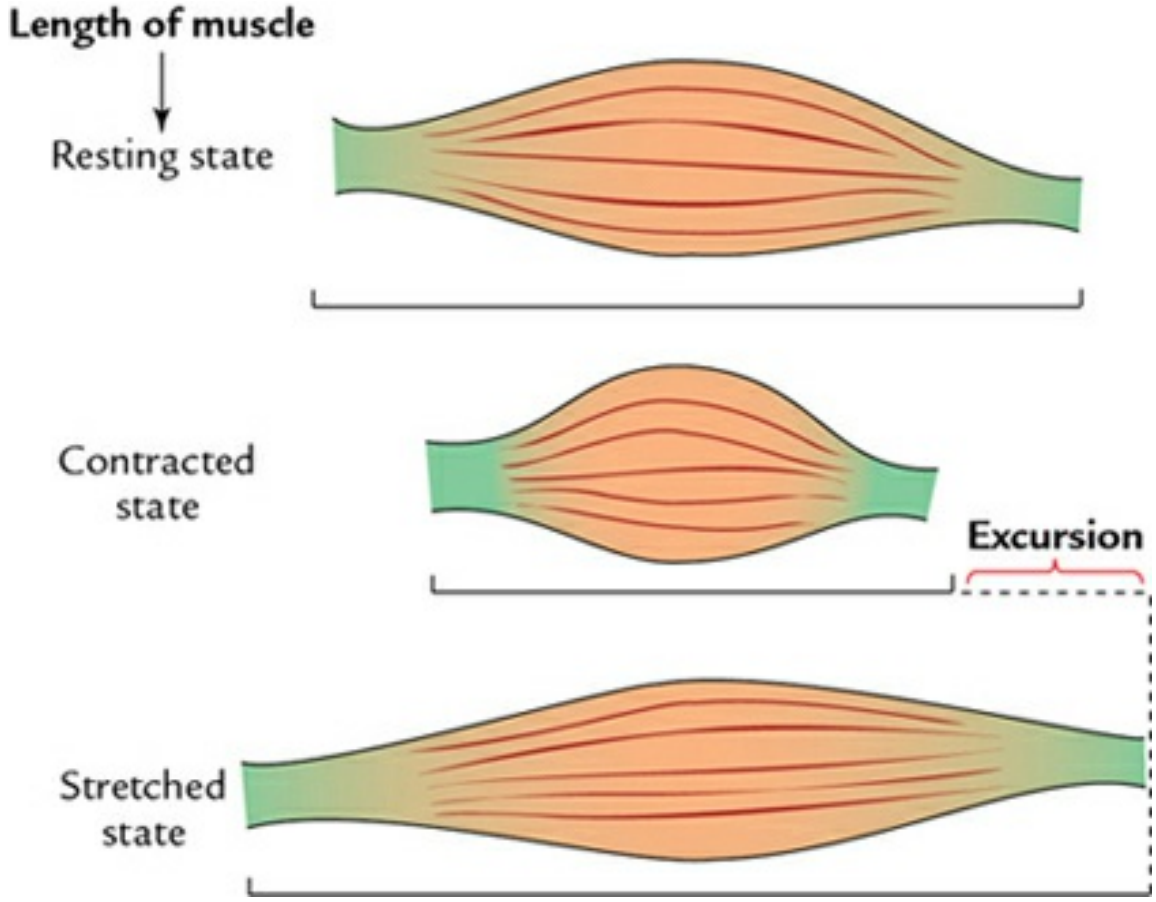


FIG. 9.19 ■ Excursion of muscle.

Types of muscle contraction

Muscle contractions are of the following types:

1. **Isometric contractions:** In isometric contractions, length of the muscle does not change, but the tension does increase, e.g. holding the arm outstretched.
2. **Isotonic contractions**: In isotonic contractions, amount of tension produced by the muscle is constant during contraction, but length of the muscle changes. The length of the muscle is reduced by one-third or more, e.g. movements of fingers and hands.

3. **Concentric contractions:** The muscle produces increasing tension as it shortens. A large percentage of movements produced by muscle contractions are concentric contractions.
4. **Eccentric contractions:** In eccentric contractions the tension is maintained in muscle while muscle increases in length, e.g. lowering the arm to the side of the body.

Active and passive insufficiency of muscles

In muscles acting on one joint, the excursion of muscle will be greater than the range of motion allowed by the joint. However, for muscles acting on two or more joints, the muscle excursion is less than the combined range of motion allowed by the joints.

Active insufficiency: When muscle reaches a point where it cannot shorten further, it is termed **active insufficiency**. It occurs in the agonist muscle that is contracting.

Passive insufficiency: When the muscle cannot be elongated any farther without damage to its fibres, it is termed **passive insufficiency**. It occurs in the antagonist muscle that is relaxed during the movement and is on the opposite side of a joint.

Think of how much you are hurt when slapped with a loose and stretched hand by someone.

Shunt and spurt muscles (Fig. 9.20) AN 3.3

Shunt muscle: It is a skeletal muscle with its proximal attachment near the joint at which it acts while its distal attachment is some distance away from the joint. So that it causes a greater range of joint movement, e.g. brachioradialis.

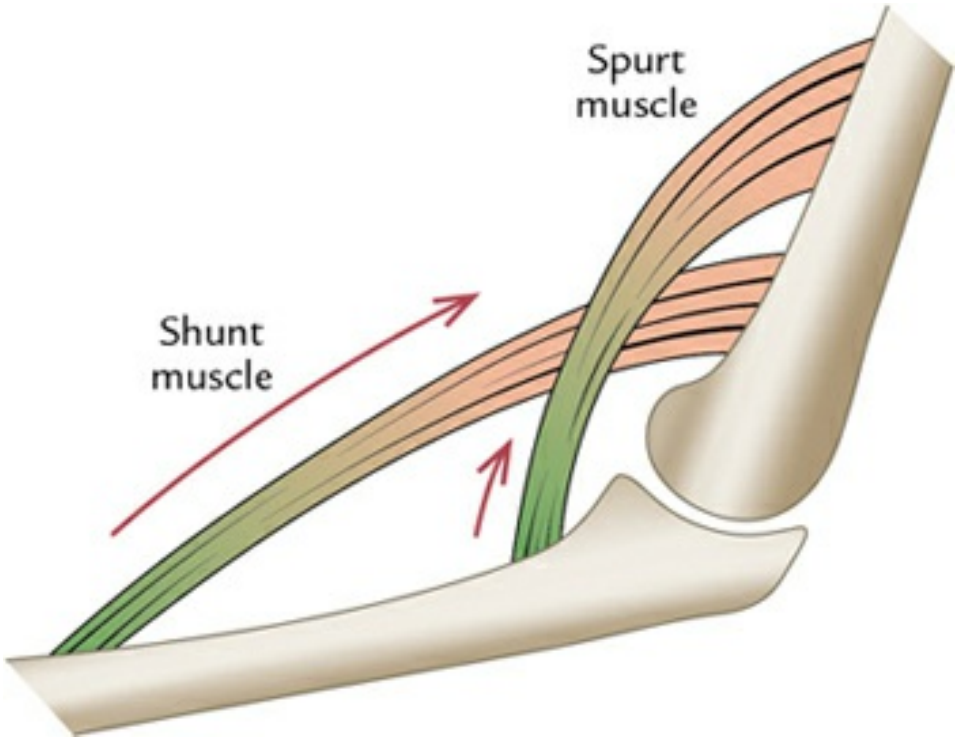


FIG. 9.20 ■ Shunt and spurt muscles.

Spurt muscle: It is a skeletal muscle with its proximal attachment away from the joint at which it acts while its distal attachment is near the joint. So that it causes less range of joint movement, e.g. brachialis. It actually stabilizes the joint.

Group action of muscles

With a few exceptions, a single muscle does not contract alone. Whole movements rather than individual muscles are represented in the cerebral cortex. Therefore, each movement requires the contraction or relaxation of a whole group of muscles.

Further, each movement is brought about by the coordinated activity of a different group of muscles. These muscle groups are classified according to the role played by them in the occurrence of a particular action:

1. **Prime movers (agonists):** These muscles are primarily responsible for producing the desired movement, e.g. biceps brachii is acting as a **prime mover** when it produces flexion at the elbow joint. Prime movers simply bring the insertion near its origin (Fig. 9.21).
2. **Antagonists:** An antagonist is a muscle that can produce movement opposite to a prime mover. Usually, however, the two muscles **agonist**

and **antagonist** act in unison so that when the prime mover contracts, its antagonist undergoes a simultaneous relaxation. In this way, an accurate controlled movement is carried out, e.g. flexion of the elbow, the biceps acts as a prime mover while the triceps 'pays out' and acts as an **antagonist** (Fig. 9.21). These muscles reverse role, of course, in the extension of the elbow.

N.B.

This is possible due to reciprocal innervation of an opposite group of muscles regulated by the spinal cord through the stretch reflex.

3. **Fixators:** A muscle is said to act as a **fixator** when it contracts to stabilize the origin of the prime mover so that it can act efficiently, e.g. the muscles attaching the shoulder girdle to the trunk to contract as fixators to allow the deltoid to act on the shoulder joint to produce abduction.
4. **Synergists:** When the prime mover crosses more than one joint to reach the joint where its main action takes place, the undesired movement at the proximal joint is prevented by certain muscles known as **synergists**, e.g. the long flexors of fingers crossover the wrist joint and can flex it but this movement is disadvantageous if it is desired to clench the fist. The extensors of the wrist, therefore, contract as **synergists** to prevent wrist flexion (Fig. 9.22).

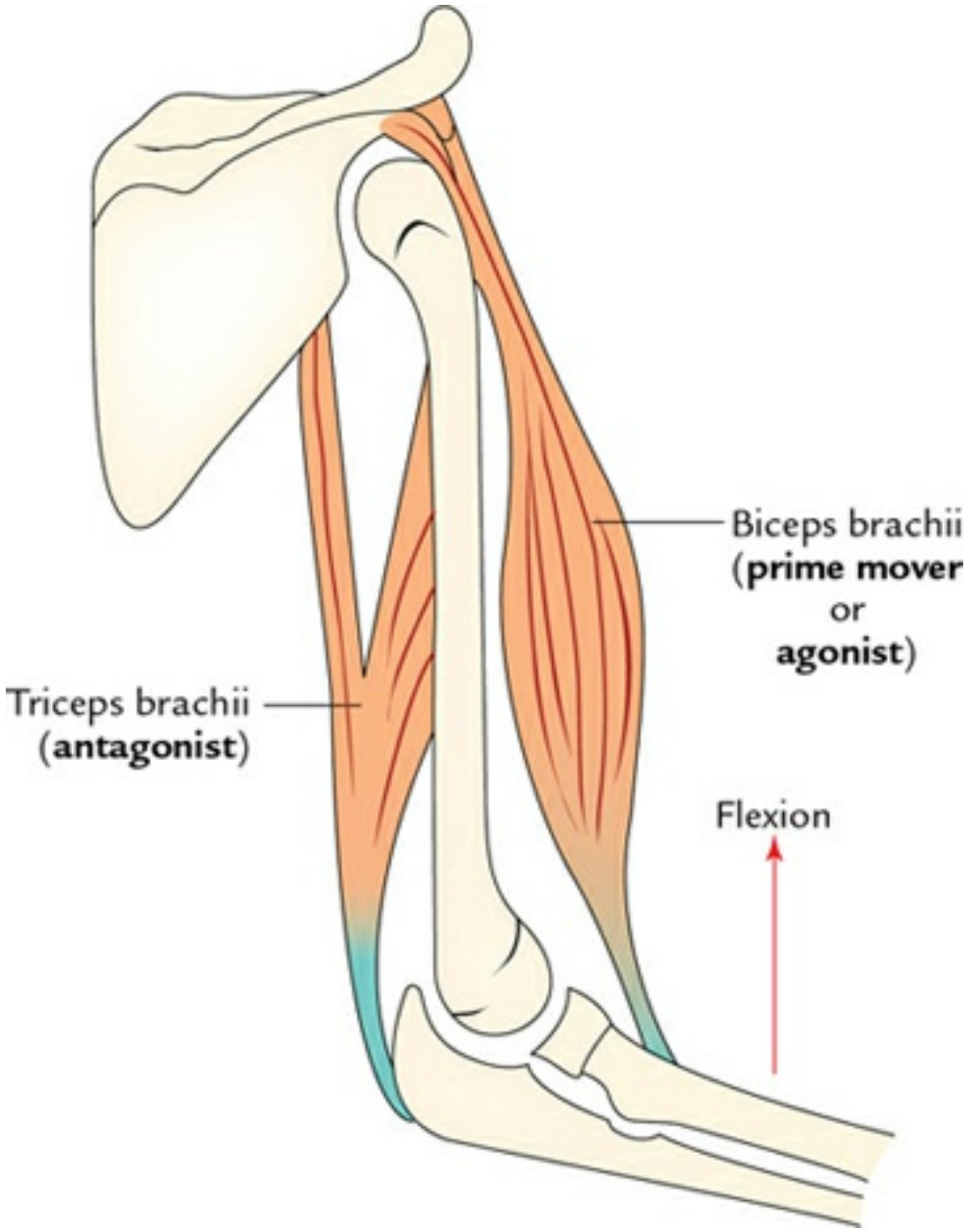


FIG. 9.21 ■ Diagram to show prime mover and antagonist muscles. For flexion at the elbow biceps brachii muscle acts as the prime mover, whereas the triceps brachii acts as the antagonist. (At the same joint, during extension, the triceps acts as a prime mover and the biceps acts as an antagonist.)

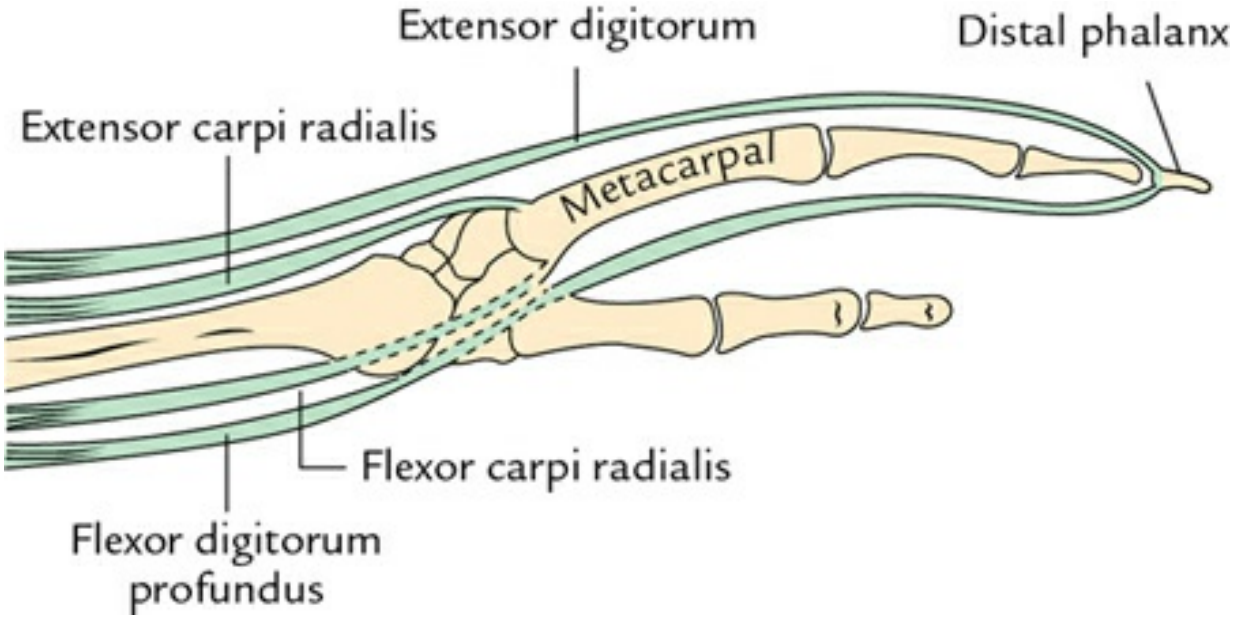


FIG. 9.22 ■ The flexor and extensor muscles of the corpus act as synergists to stabilize the corpus so that the long flexor and extensor of the hand can flex and extend fingers.

These terms are applied to a particular muscle during a particular movement. Many muscles can act as prime movers, an antagonist, a fixator or a synergist depending upon the movement to be accomplished.

Golden Facts to Remember

• **Total number of muscles in the body**	About 400
• **All the muscles of body develop from mesenchyme except**	Arrector pili, muscles of iris and myoepithelial cells which develop from ectoderm
• **Largest muscle in the body**	Gluteus maximus
• **Longest muscle in the body**	Sartorius
• **Smallest muscle type in the body**	Stapedius
• **Most important property of a muscle**	Contractility
• **Most abundant muscle type in the body**	Skeletal muscles
• **Functional contractile unit**	Motor unit

of a muscle	
• Structural and functional unit of a muscle fibre	Sarcomere
• Most variable muscle in the body	Palmaris longus (in the forearm)
• Longest tendon in the body	Plantaris (in the leg)
• Largest tendon in the body	Achilles tendon (tendocalcaneus)
• Most important reflex for maintaining the health of a muscle	Stretch reflex
• Most commonly used muscle for intramuscular injection	Deltoid (in shoulder region)
• Muscles with smallest motor unit	Extraocular muscles
• Muscles with largest motor unit	Muscles of lower limb; e.g. gluteus maximus
• Most common involuntary movements of skeletal muscles	Myokymia
• Most commonly ruptured tendon in the body	Tendocalcaneus
• Most differentiated muscle in the body	Cardiac muscle
• All the muscles need nerve stimulus to contract except	Cardiac muscle that can contract without nerve stimulus (myogenic contraction)
• Most common type of muscle contraction	Concentric contractions
• Type of muscle fibres most suited for long-distance running	Slow-twitch fibres (red-fibres)
• Sites where faradic stimulation of nerve is most effective	Nerve points
• In most of the muscles in the body, the nerve enters in its deep aspect except	Serratus anterior in which the nerve enters in its superficial aspect
• Skeletal muscles can repair themselves to some extent	Due to proliferation of satellite cells which fuse to

	form new skeletal muscle fibres
• Damaged cardiac muscle (e.g. myocardial infarction) is replaced by fibrous tissue, because	Cardiac muscle repair (regeneration) is nonexistent for it does not contain satellite cells
• Type of muscle with highest regenerative capacity	Smooth muscle
• Hardest working muscle in the body	Cardiac muscle

Multiple choice questions

1. **The skeletal muscle presents all of the following features *except:***
   (a) Its fibres present cross-striations.
   (b) Its fibres are unbranched and multinucleated.
   (c) Its actions are involuntary.
   (d) It possesses stretch receptors.
2. **All of the following muscles have pennate fasciculi *except:***
   (a) Flexor pollicis longus
   (b) Flexor hallucis longus
   (c) Deltoid
   (d) Trapezius
3. **Regarding stretch reflex, all of the following statements are true *except:***
   (a) It is a monosynaptic reflex
   (b) It involves alpha (α) motor neuron
   (c) It is used to elicit tendon jerks
   (d) It regulates the rate of contraction of intrafusal fibres
4. **In the movement of flexing the elbow joint, the biceps brachii acts as:**
   (a) Synergist
   (b) Antagonist
   (c) Fixator
   (d) Prime mover
5. **All of the following features, regarding red muscle fibres are true *except:***
   (a) Speed of contraction is slow

(b) Are fatigue resistant
(c) Have few mitochondria
(d) Have high glycogen content

6. **The muscles capable of highly dextrous movements contain:**
(a) One motor unit per muscles fibre
(b) Many muscle fibres per motor unit
(c) Few muscle fibres per motor unit
(d) Many motor units per muscle fibre

7. **Select the *incorrect statement*** about the tendon:
(a) It attaches the muscle belly to the periosteum of bone
(b) It is made of dense regular connective tissue
(c) It serves to support the weight
(d) It heals quickly if ruptured

8. **In clenching the fist, which of the following muscles acts as synergists:**
(a) Flexors of the wrist
(b) Extensors of the wrist
(c) Adductors of the wrist
(d) Abductors of the wrist

Answers

1. *c*, **2.** *d*, **3.** *d*, **4.** *d*, **5.** *c*, **6.** *a*, **7.** *d*, **8.** *b*

Chapter 10: Cardiovascular system

Specific learning objectives

After studying this chapter, the student should be able to:

- Define the cardiovascular system and enumerate its functions.
- Define thrombosis, infarction and aneurysm. **AN 5.8**
- Describe structure and functions of arteries, veins and capillaries.
- Explain functional differences between elastic arteries, muscular arteries and arterioles. **AN 5.4**
- List general differences between the arteries and veins. **AN 5.3**
- Differentiate between pulmonary and systemic circulation. **AN 5.2**
- Describe portal systems by giving examples. **AN 5.5**
- Discuss arteriovenous anastomosis and its functional significance.
- Describe the concept of anastomoses and collateral circulation with the significance of end arteries. **AN 5.6**
- Explain functions of meta-arterioles and precapillary sphincters. **AN 5.7**
- Describe foetal circulation and tell how it differs from the adult circulation.
- Correctly solve the Multiple choice questions given at the end of the chapter.

The cardiovascular system consists of heart and blood vessels. The heart pumps the blood and blood vessels circulate it. The system supplies

nutrients to and removes waste products from various tissues of the body. The conveying medium is blood which flows through tubular channels called *blood vessels*. It is thus a closed system and blood in it serves as a medium for transportation of various agents such as nutrients, O_2, CO_2, etc.

The heart pumps the blood and provides the major force that causes the blood to circulate, whereas blood vessels carry blood to all the tissues of the body and back to the heart. In addition, the blood vessels participate in the regulation of blood pressure. The vessels which carry the blood away from the heart are called **arteries** (Fig. 10.1), while the vessels which bring back the blood to the heart are called **veins** (Fig. 10.2).

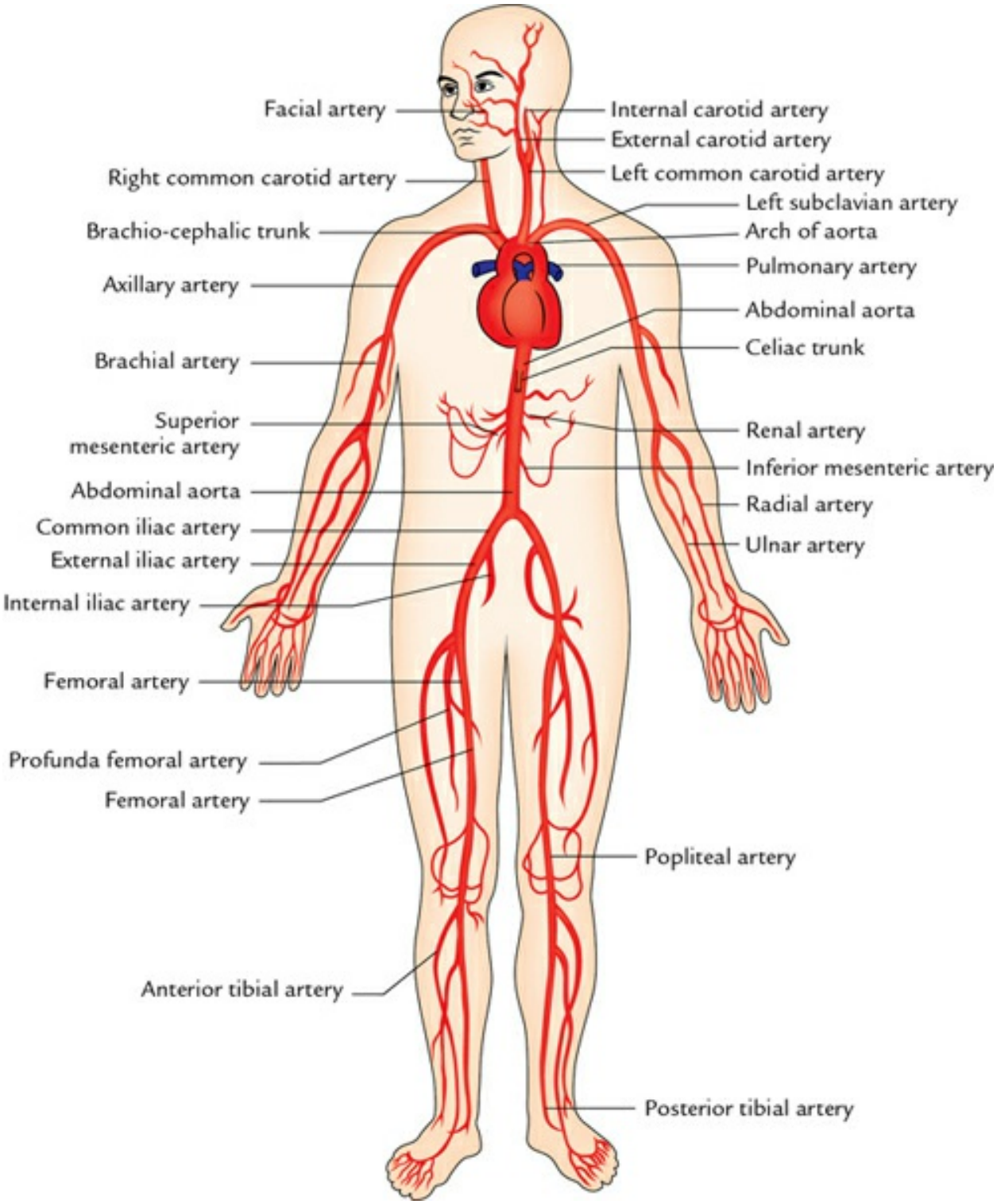


FIG. 10.1 ■ Arteries of the body.

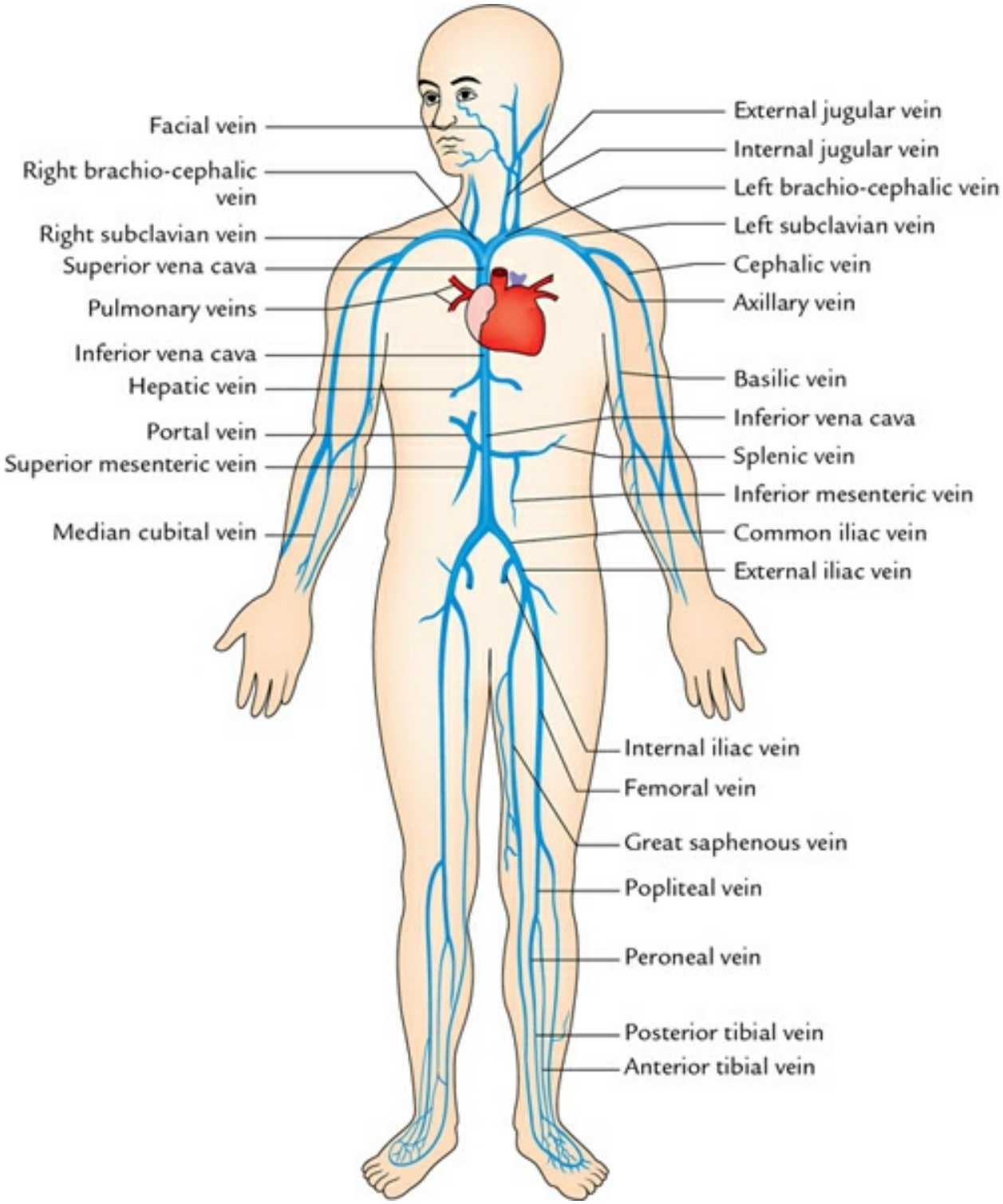


FIG. 10.2 ■ Veins of the body.

The microscopic vessels connecting the arteries and veins are called **capillaries**. These vessels allow easy exchange of nutrients, metabolites, and respiratory gases (O_2 and CO_2).

Functions:

The cardiovascular system performs the following functions:

1. Transports nutrients to different parts of the body.
2. Removes waste products of metabolism from organs and tissues of the body.
3. Is responsible for gaseous exchange in the lungs, i.e. intake of O_2 and elimination of CO_2.
4. Carries hormones and other regulatory molecules from their site of origin to distant target tissues.
5. Helps to protect (by leukocytes and their products) the body from infection.

Components of cardiovascular system AN 5.2, AN 5.4, AN 5.5, AN 5.6, AN 5.7

The cardiovascular system comprises:

1. Blood
2. Heart
3. Blood vessels.

Blood

Blood is taught in detail in physiology; at the same time, it is important to have some knowledge of blood before discussing other components of the cardiovascular system.

Blood is a highly specialized connective tissue consisting of **blood cells** and **plasma**.

Blood cells

The blood cells are of three types:

1. Erythrocytes
2. Leukocytes
3. Thrombocytes (platelets).

1. Erythrocytes

The erythrocytes (red blood cells, RBCs) are disc-shaped cells that lack nuclei and mitochondria. They get energy from anaerobic respiration and transport O_2 and CO_2.

2. Leukocytes

The leukocytes (white blood cells, WBCs) are of two types:

1. *Granulocytes*, i.e. they have granules in their cytoplasm.
2. *Agranulocytes*, i.e. they do not have granules in their cytoplasm.

Types of granulocytes

1. **Neutrophils:** They are called *neutrophils* because their granules have no affinity either to eosin (pink to red) stain or haematoxylin (blue to purple) stain. They have a multilobed nucleus and play an important role in the phagocytosis of bacteria and dead cells; they thus impart natural (innate) immunity. Neutrophils are the first to arrive at an area of tissue damage.
2. **Eosinophils**: They are called so because their granules stain with eosin. They have a bilobed nucleus. They play a role in reducing the severity of allergic reactions by secreting **histaminase.** Their level in blood increases in allergic reactions (e.g. eosinophilia).
3. **Basophils**: They are so named because their granules stain blue with haematoxylin. They release anticoagulant heparin, histamine, and 5-hydroxytryptamine. Basophils play a role in the immediate (type I) hypersensitivity reaction (*anaphylactic reactions*) causing allergic rhinitis, asthma, urticaria and anaphylaxis.

Types of agranulocytes

1. **Monocytes:** They are phagocytic cells and members of the monocyte-macrophage system. They respond to inflammation by leaving the peripheral blood to enter the tissue and are called **macrophages**.
2. **Lymphocytes:** They are only slightly larger than RBCs. The nucleus nearly fills the cells. Lymphocytes are of two types:
   (a) B lymphocytes
   (b) T lymphocytes.

B lymphocytes differentiate in the bone marrow. In response to antigens, they proliferate and produce plasma cells which secrete *immunoglobulins/antibodies*, namely, IgG, IgA, IgM and IgD. The B cells, plasma cells and immunoglobulins are the basis of the **humoral response**. Therefore, B lymphocytes are responsible for *antibody-mediated (humoral) immunity*.

T lymphocytes are the lymphocytes which mature, become immunocompetent in the thymus, and then enter the blood to reach the lymph nodes and spleen. T-lymphocytes are responsible for *cell-mediated immunity*.

Lymphocytes and immunity are described in detail on page 161 in Chapter 11.

Clinical correlation

Basis of immunization: During foetal development, B lymphocytes differentiate in the bone marrow. Mature (or virgin) cells express antigen-specific IgM and IgD on the cell surface. Mature B cells migrate to the spleen, lymph nodes and gut-associated lymph tissue and wait for antigen exposure. When exposed to antigens, they differentiate into plasma cells which produce antibodies (immunoglobulins). B cells, plasma cells and immunoglobulins together constitute the *humoral response*.

B memory cells are programmed to react to the same antigen. Upon re-exposure to that antigen, it results in a faster immune response called the *secondary immune response*.

The immunoglobulins secreted by B memory cells have a higher affinity for antigen than that produced during the initial exposure. This is the basis for *immunization*.

3. Thrombocytes (platelets)

These are in fact the fragments of large cells called **megakaryocytes** found in the bone marrow. The platelets play an important role in blood clotting. They constitute the major portion of the mass of the clot. Platelets that attach together in the blood clot also release a chemical called **serotonin** which causes constriction of blood vessels, thus reducing the flow of blood to the injured area.

Plasma

The plasma is the fluid portion of the blood. Ninety per cent of it is made up of water and the remaining is made up of proteins, inorganic salts, lipids, etc.

There are three types of plasma proteins:

1. Albumins
2. Globulins
3. Fibrinogen.

Albumins are produced in the liver and provide the necessary viscosity to the blood to maintain and regulate blood pressure.

Globulins are of three types: (1) alpha globulin, (2) beta globulin, and (3) gamma globulin. The alpha and beta globulins are synthesized within the liver and transport fat- and lipid-soluble vitamins. The gamma globulins are produced in lymphoid tissue and are called **antibodies**. They play an important role in immunity.

Fibrinogen is synthesized in the liver and plays an important role along with thrombocytes in the clotting of blood.

N.B.

If fibrinogen is removed from plasma, it is called *serum*.

Clinical correlation

The blood can also serve to transport disease-causing bacteria, viruses and other toxins. However, drugs given to treat the diseases are also transported through the blood.

Heart

The heart is a four-chambered, hollow muscular organ, roughly the size of a clenched fist. It is situated in the mid-thoracic cavity behind sternum between the lungs.

About two-thirds of the heart is located on the left of the midline and one-third on the right of the midline. The heart is enclosed in a serous sac (*serous*

pericardium) which in turn is enclosed in a dense fibrous connective tissue called the **fibrous pericardium**. The serous pericardium consists of the inner visceral and outer parietal layers with a potential cavity between the two layers called the **pericardial cavity**. The heart acts as a central muscular pump that pumps about 5 L of blood/min. It takes about 1 min for the blood to reach the most distal parts of the body and back to the heart.

Measurements:

- **Size:** Size of one's own fist.
- **Weight of the heart:** 280–340 g in adult males
  230–280 g in adult females.

Wall of the heart

The wall of the heart consists of three distinct layers. From superficial to deep, these are:

1. **Epicardium** is made up of visceral pericardium.
2. **Myocardium** is made up of cardiac muscle.
3. **Endocardium** is made up of endothelial cells. It is continuous with the endothelial lining of blood vessels.

Chambers of the heart (Fig 10.3)

The interior of the heart is divided into four chambers: right and left atria and right and left ventricles (Fig. 10.3):

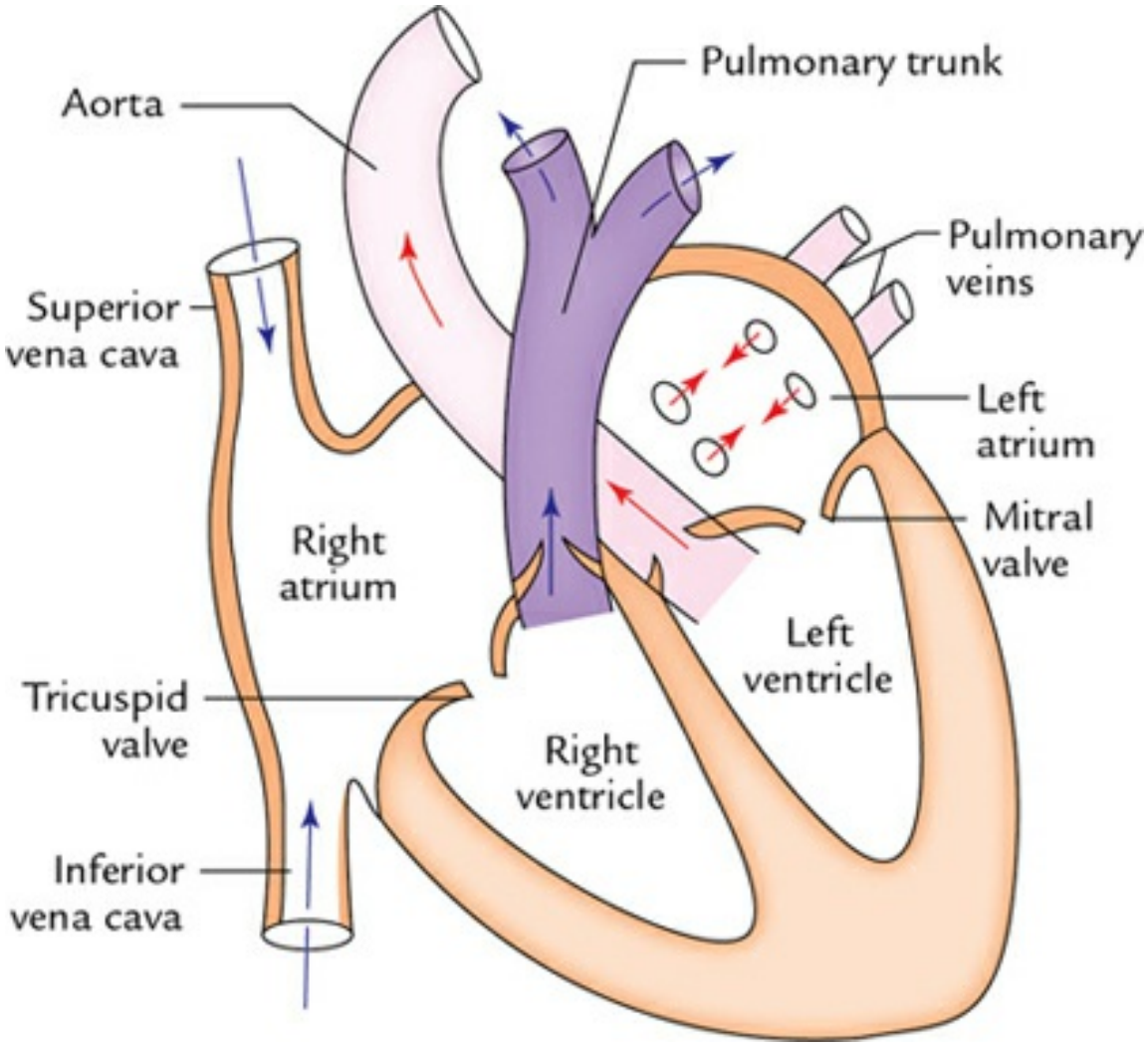


FIG. 10.3 ■ Chambers of the heart.

Right and left atria are above and **right and left ventricles** are below. Each atrium has an ear-shaped appendage called an *auricle*.

The atria are separated from each other by the interatrial septum while ventricles are separated from each other by the interventricular septum.

The **right atrium receives the deoxygenated blood** from systemic circulation through the superior and inferior vena cavae. Blood from the right atrium passes through the right atrioventricular valve (*tricuspid valve*) into the right ventricle. The right ventricle pumps the blood into the lungs for oxygenation. The **left atrium receives the oxygenated blood** from pulmonary circulation through four pulmonary veins. Blood from the left atrium passes through the left atrio-ventricular valve (mitral valve or bicuspid valve) into the left ventricle.

Base of the heart

It lies opposite the middle, four thoracic vertebrae (i.e. T5–T8) in a supine position. The right one-third of the base is formed by the right atrium and the left two-thirds by the left atrium. The atria are receiving chambers, whereas the ventricles are pumping chambers.

Apex of the heart

It is a cone-shaped lower and outer end of the heart formed by the left ventricle.

Functions of the heart (Fig 10.4)

The heart functions as a **double pump** (Fig. 10.4):

1. The right half of the heart receives deoxygenated blood, i.e. blood is low in oxygen and pumps it to the lungs through the pulmonary trunk and pulmonary arteries.
2. The left half of the heart receives oxygenated blood, i.e. oxygen-rich blood from the lungs and pumps it to the rest of the body through the aorta and its branches.

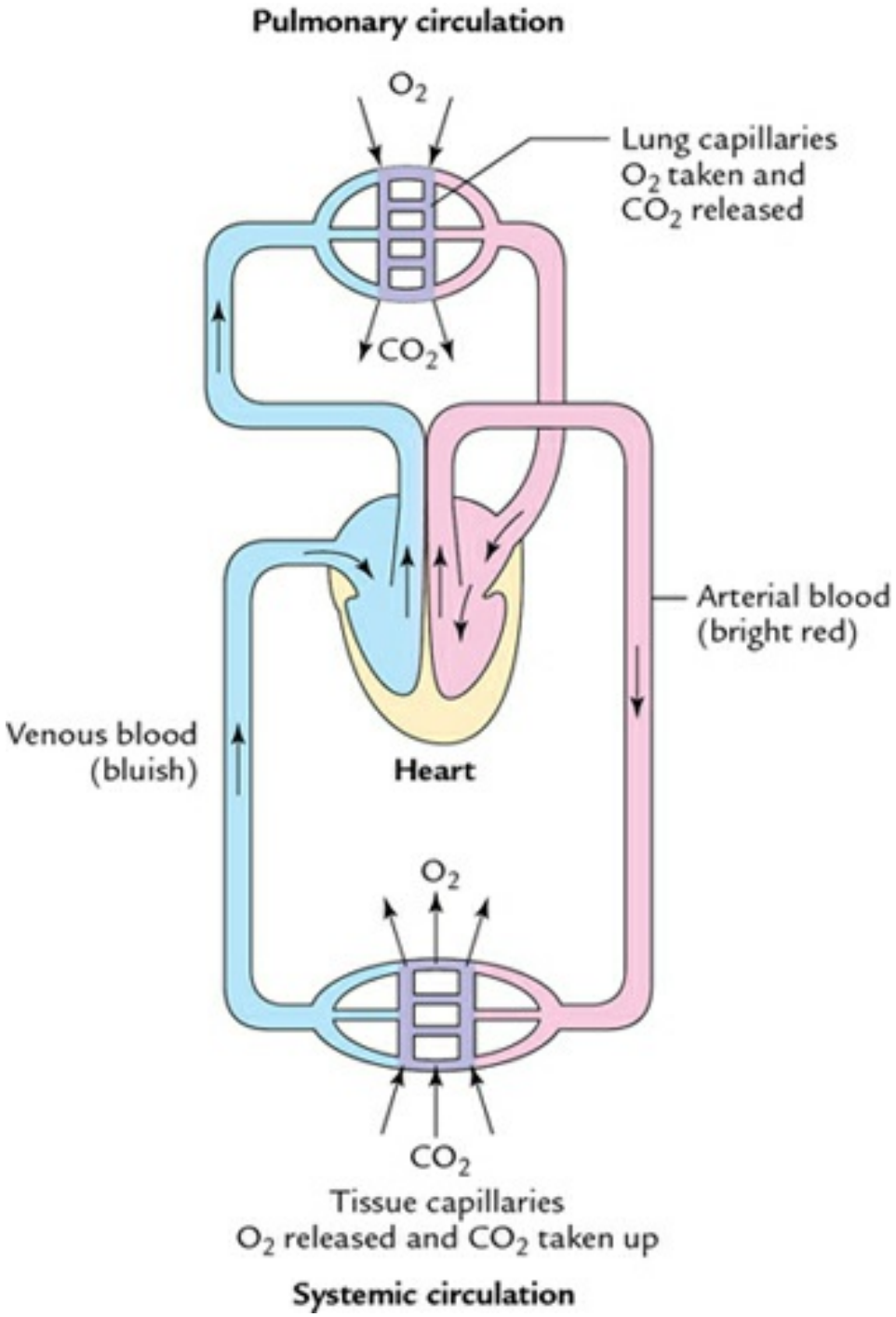


FIG. 10.4 ■ Double pump action of heart (Transport of gases through circulatory systems).

Thus, the heart regulates two circuits of blood flow:

- Pulmonary circulation
- Systemic circulation.

Apex beat

When the heart contracts, the thrust of the heart is felt in the left precordium. The outermost and the lowermost thrust on the front of the left half of the chest felt by a flat hand is called *apex beat. In adults, it is felt in the left fifth intercostal space, half-inch medial to the mid-clavicular line. In children, it is felt in the left second or third intercostal space, half-inch lateral to the midclavicular line.*

N.B.

Frequency of heartbeats

On average, the heart beats about 70 times in males and 75 times in females.

Normal heart rate

(a) In infants = 130–150/min
(b) In children = 100–130/min
(c) In adults = 60–90/min

Arterial supply

The heart is supplied arterial blood by the **right and left coronary arteries** (Fig. 10.5), which arise from ascending aorta immediately above the aortic orifice in the heart. The coronary arteries receive about 5% of the blood pumped from the heart, although the heart comprises only a small proportion of body weight. The large blood supply, especially to the left ventricle, is in keeping with the importance of the heart to the body functions.

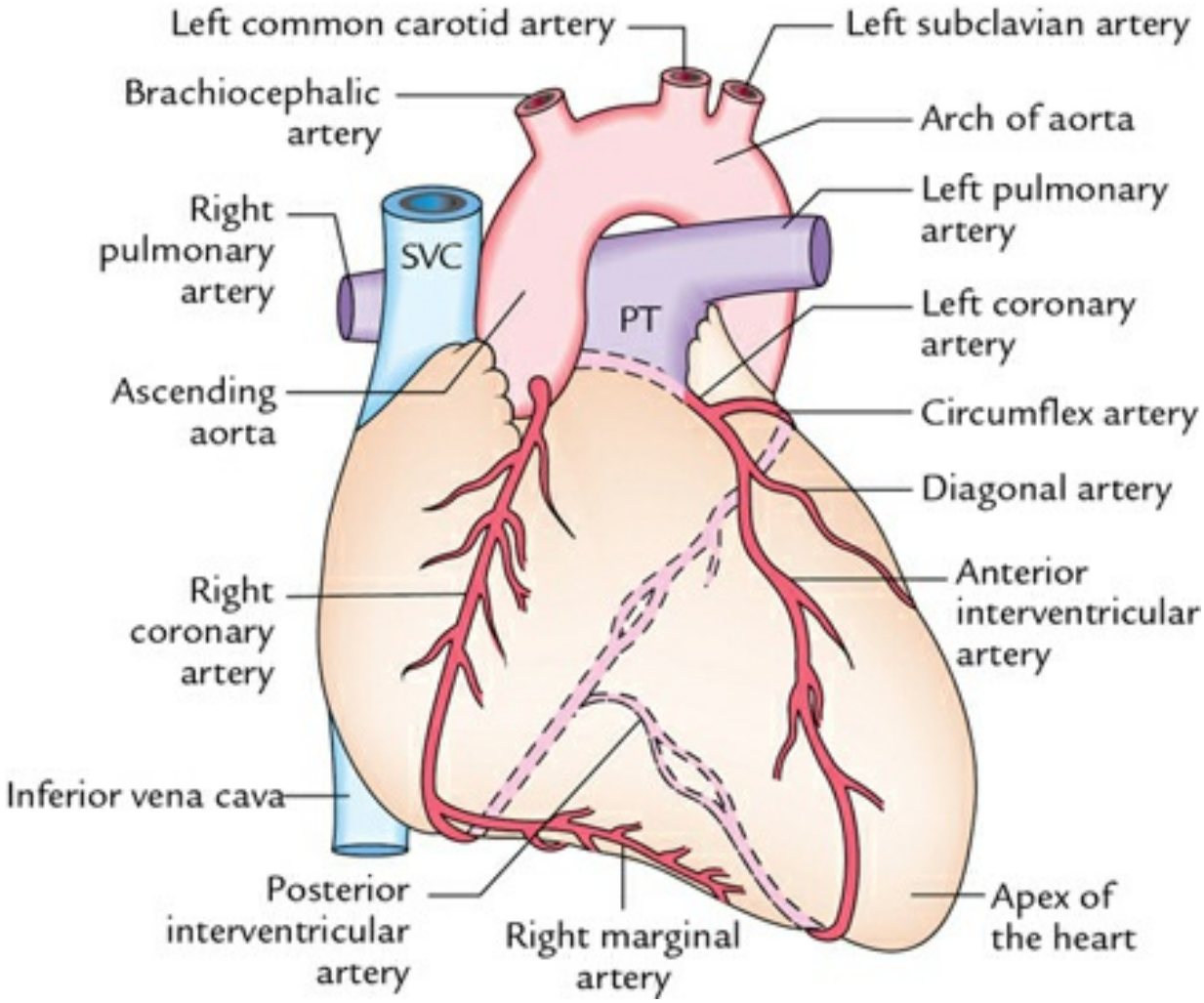


FIG. 10.5 ■ Arterial supply of the heart. SVC, superior vena cava; PT, pulmonary trunk.

N.B.

The coronary arteries are unique in the sense that they are filled during diastole.

Clinical correlation

- **Angina pectoris:** If coronary arteries are narrowed, there will be reduced blood and O_2 supply to cardiac muscle. As a result, the individual feels pain in his/her left precordium, medial side of the left arm and forearm. The pain typically occurs on exertion and is relieved by rest. This clinical condition is called *angina pectoris*.
- **Myocardial infarction:** If coronary arteries are blocked, there will be

myocardial ischaemia leading to cellular necrosis. This clinical condition is called *myocardial infarction* or *heart attack*. It typically occurs at rest and the pain lasts longer than 10 min. It is not relieved by rest.

- **Heart attacks:** These are one of the most common causes of death these days. They occur when blood clot blocks blood flow to the heart.
  The risk of attack can be minimized by: (1) reducing excess weight, (2) avoiding high blood pressure (hypertension), (3) taking a low cholesterol diet, (4) avoiding smoking, and (5) doing regular exercises.

Venous drainage

The venous blood from the heart is drained into the ***coronary sinus*** through its tributaries, viz. *great cardiac vein*, *middle cardiac vein*, *small cardiac vein*, *posterior vein of the left ventricle*, *oblique vein of the left atrium* and *right marginal vein*. The coronary sinus in turn opens into the right atrium. The other small veins (also called *venae cordis minimae* or *Thebesian veins*) drain directly into the chambers of the heart.

Nerve supply

The heart is supplied by both sympathetic and parasympathetic fibres. The stimulation of sympathetic fibres results in increase in heart rate and force of contraction of heart rate.

The stimulation of parasympathetic fibres (vagus nerve) results in a decrease in heart rate and force of contraction of the heart.

N.B.

All the cardiac branches of the sympathetic chain and vagus nerve contain both sensory and motor fibres *except the cardiac branch* from the superior cervical sympathetic ganglion, which contains only postganglionic motor nerves.

Conducting system of the heart

The conduction system sends electrical signals to your heart to contract (heartbeat) in order to pump blood into the body.

The cardiac muscle has the property of being stimulated automatically by its own conducting system formed of cardiac fibres which are specialized for the initiation and conduction of cardiac impulses. This phenomenon is known as automaticity. The automaticity of the heart is further regulated by nerve impulses from the brain or circulating metabolites and hormones either increase or decrease the heart rate.

Conducting system of the heart is made up of nodes, and bundles of specialized cardiac muscle fibres which generate and conduct electrical impulses for cardiac muscle. It consists of the following components (Fig. 10.6):

1. **Sinoatrial (SA) node.** It is located in the right atrium in the upper part of the sulcus terminalis. It initiates impulses; hence it is also called a *pacemaker of the heart*.
2. **Atrioventricular (AV) node.** It is located in the lower part of the interatrial septum. It also generates impulses but at a slower rate than the SA node.
3. **Atrioventricular bundle.** It connects atrial and ventricular musculature.
4. **Right and left bundle branches.** They are located in the muscular part of the interventricular septum.
5. **Purkinje fibres.** They are the terminal branches of bundle branches.

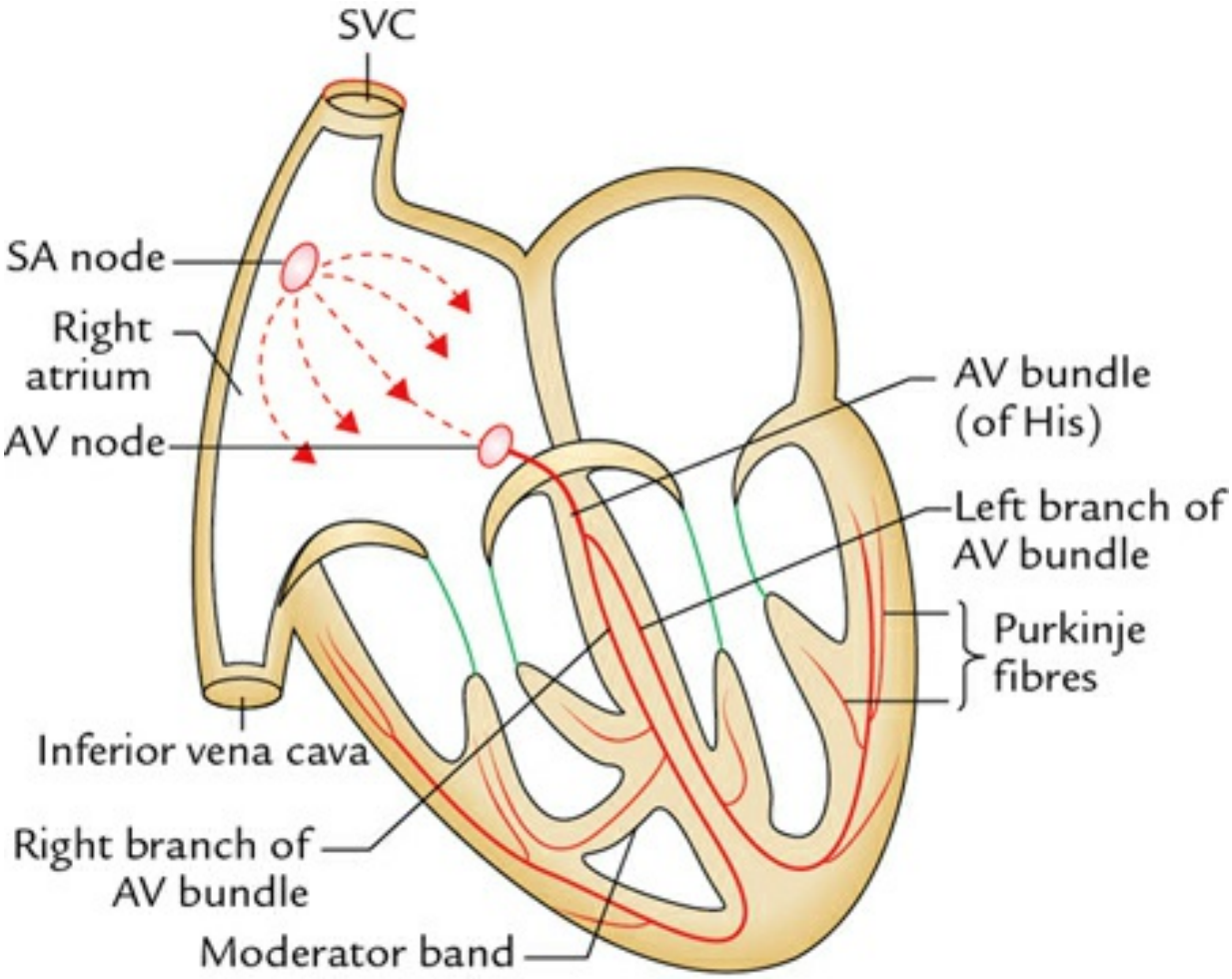


FIG. 10.6 ■ Conducting system of the heart. (Source: Fig. 21.20, p. 272, Textbook of Anatomy: Upper Limb and Thorax, 2e, Vishram Singh. Copyright Elsevier 2018. All rights reserved.)

N.B.

Cardiac muscle can contract without nerve stimulus (myogenic contraction), whereas other muscles of the body need nerve stimulus to contract.

Blood vessels

The blood vessels form a closed system of tubes that carry blood away from the heart to the tissues of the body and then return it back to the heart.

The blood vessels include:

1. Arteries
2. Capillaries

3. Veins.

Arteries (distributing channels) are thick-walled tubes that carry blood away from the heart. The blood leaving the heart passes through the vessels of progressively smaller diameters referred to as arteries and arterioles (Fig. 10.15).

N.B.

The word '*artery*', meaning *air tube,* was first used by Aristotle because after death when **rigor mortis** (stiffening of muscles of body a few hours after death) passes over, the liquid blood is collected in the dilated veins and arteries become empty. Sometimes air bubbles appear within arteries due to decomposition.

- **Capillaries** are microscopic vessels that connect arterioles and venules. They are responsible for exchange of gases (O_2, CO_2), and nutrients between blood and interstitial fluid.
- **Veins** (draining channels) are thin-walled tubes that carry blood from tissues of different parts of the body back to the heart. The blood returning to the heart from the capillaries passes through the vessels of progressively larger diameters, termed veins and venules (Fig. 10.2).

N.B.

Except for the capillaries and the venules, the blood vessel walls consist of three layers.

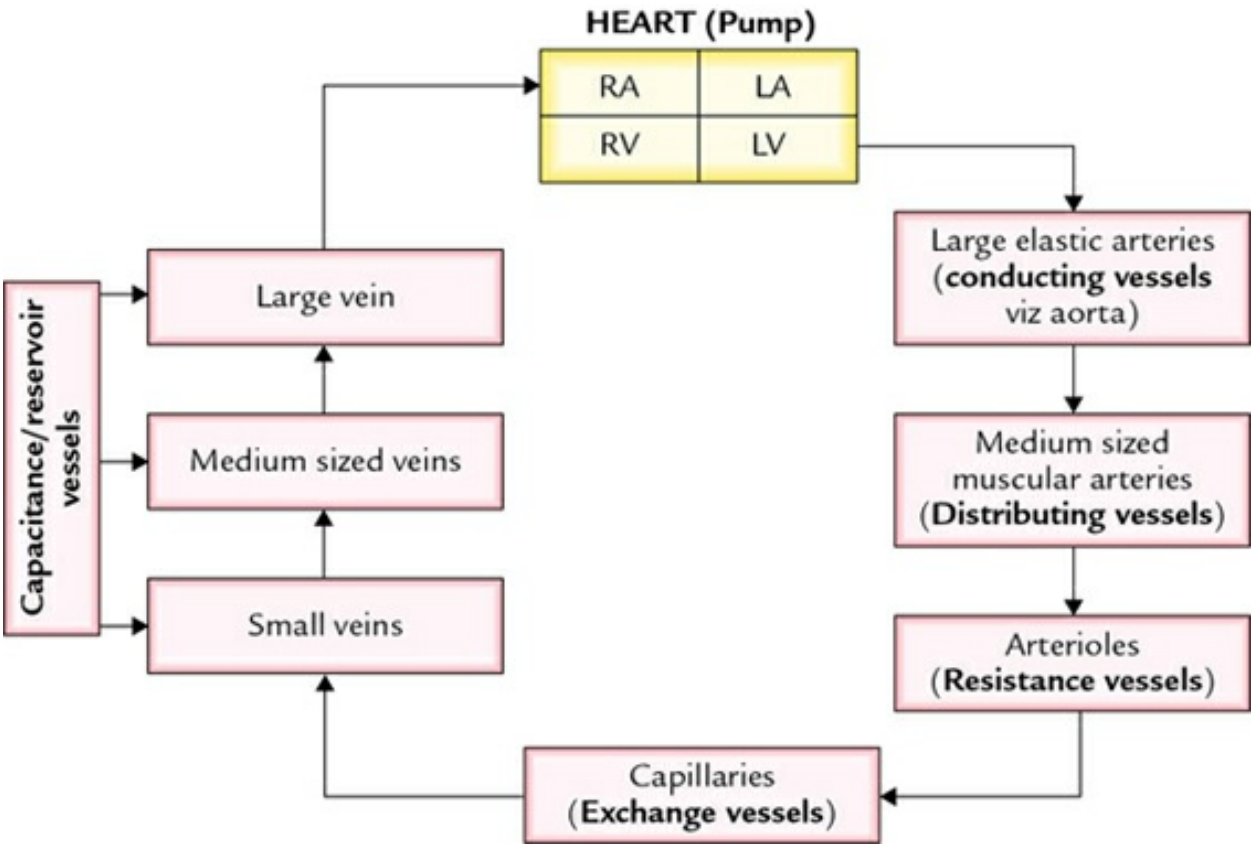
Classification of blood vessels (Fig 10.1)

Functionally the blood vessels are classified into five types:

1. **Conducting vessels**, e.g. large (elastic) arteries (for details, see arteries).
2. **Distributing vessels**, e.g. medium-sized (muscular) arteries (for details, see arteries).

3. **Resistance vessels**, e.g. arterioles (for details, see arteries).
4. **Exchange vessels**, e.g. capillaries, sinusoids and postcapillary venules.
5. **Capacitance or reservoir vessels**, e.g. small, medium and large veins. These are low-pressure, large-volume vessels. The high capacitance of these vessels is because they are thin-walled and have the capacity to dilate.

These vessels are shown in Figure 10.5 and Flowchart 10.1.



FLOWCHART 10.1 ■ Classification of blood vessels.

Arteries

Characteristic features

The salient features of arteries are as follows:

1. They are thick-walled vessels and carry blood from the heart to capillaries.
2. They are often accompanied by vein/veins and nerve/nerves; three of

them together form the neurovascular bundle.
3. Their lumen is smaller than that of accompanying vein/veins.
4. They do not have valves in their lumen.
5. They divide repeatedly like a branch of a tree and gradually become smaller in size.

Microscopic structure

The arterial wall is made up of three layers/coats (Fig. 10.7A and B). From within outwards, these are:

1. Tunica intima
2. Tunica media
3. Tunica adventitia.

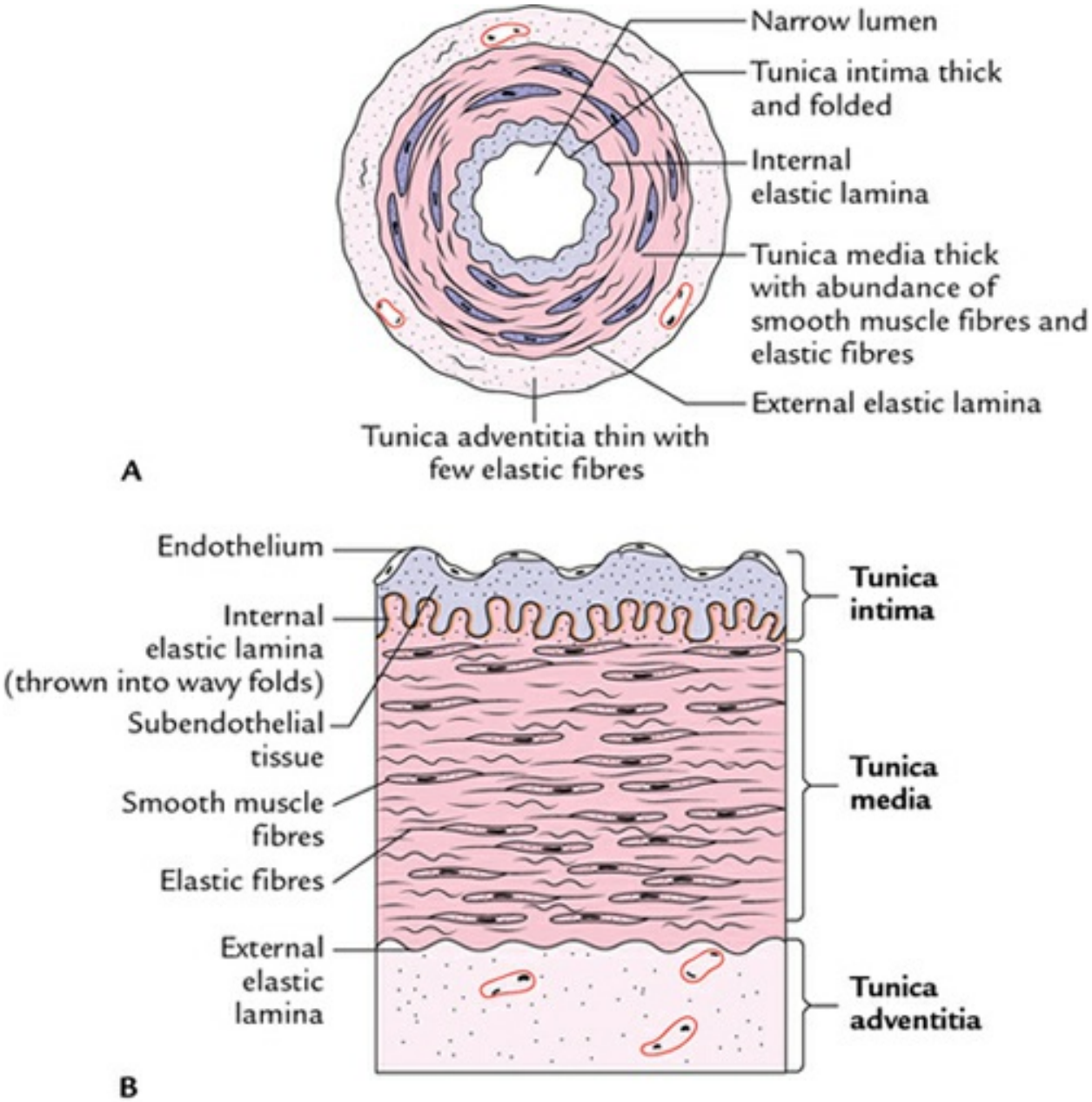


FIG. 10.7 ■ Microscopic structure of a medium-sized artery: **(A)** cross-section showing three different layers in the wall and the lumen and **(B)** magnified view of the small portion of wall to show the 3 layers or coats in the wall.

Tunica intima is made of the endothelium, consisting of flattened cells and basal lamina. Externally, the endothelium is supported by subendothelial loose connective tissue and a fenestrated membrane of elastic tissue called the **internal elastic lamina**.

Tunica media is the thickest layer and is made up of layers of circularly arranged smooth muscle fibres. It also contains elastic fibres and a few collagen fibres present in between layers of muscular fibres. The tunica media is limited externally by a fenestrated membrane of elastic tissue called

the **external elastic lamina**.

Tunica adventitia is thin but strongest of all coats. The tunica adventitia is made of longitudinally arranged connective tissue fibres (both elastic and collagen) and connective tissue cells. It merges with the perivascular sheath.

The structure of the artery is summarized in Table 10.1.

TABLE 10.1

Structure of artery

Name of the layer	Composition
Inner layer (*Tunica intima*)	• Endothelium • Subendothelial tissue • Internal elastic lamina
Intermediate layer (*Tunica media*)	• Circular smooth muscle fibres • Elastic fibres • External elastic lamina
Outer layer (*Tunica adventitia*)	• Fibroelastic tissue

Clinical correlation

- **Arteriosclerosis (or hardening of the arteries):** It is the age-related progressive generalized degenerative disorder of arterial walls usually seen after middle age. There is generally a slow loss of elasticity and thickening of tunica intima due to an increase in collagen and accumulation of lipid. Consequently, it leads to diffuse narrowing of the lumen of blood vessels. Ischaemia of the tissue supplied by affected arteries occurs. In the lower limb, it is seen in the form of *intermittent claudication*, characterized by pain and weakness in muscle at work, especially during walking that is almost immediately relieved by rest. In the brain, it is seen in the form of mental function.
- **Thrombosis/atherosclerosis:** It is a blood clot that forms on a vessel wall when platelets, proteins and cells stick together. It may block the flow of blood. The details are as under: **AN 5.7**

It is arteriosclerosis in which plaques (patchy accumulation) of lipid,

fibrous tissue and macrophages called *atheroma* accumulate in the tunica intima, which make the luminal surface of the artery uneven that can initiate the formation of a blood clot called a *thrombus* which may occlude the lumen, e.g. if it occurs in coronary artery it may lead to *myocardial infarction (heart attack).*

- **Infarction:** It is a tissue death (necrosis) due to an inadequate blood supply to the tissues in the affected area, due to blockages and rupture of arteries etc. **AN 5.7**
- **Aneurysm:** It is a ballooning of a segment of an artery due to the weakening or thinning of its wall. Sometimes arterial wall becomes thin enough to rupture.

Ruptured aneurysm can cause internal bleeding or stroke. It can sometimes be fatal. **AN 5.7**

N.B.

An *embolus* is a *thrombus* that has dislodged from the wall of the vessel and moves into the bloodstream. Both thrombus and embolus can occlude flow. An embolus lodged in the coronary artery (coronary embolism) is called *coronary thrombus* in a vessel of the *lung*, it is called a *pulmonary thrombus* and if in a vessel of the *brain,* it is called *cerebral thrombus*.

Classification of arteries AN 5.4

Functionally, arteries are classified into three types:

1. Elastic (conducting) arteries
2. Muscular (distributing) arteries
3. Arterioles (resistance vessels).

N.B.

- As the arteries become smaller and smaller there is a gradual change in their diameter, the thickness of the wall, amount of elastic tissues and smooth muscle fibres in their wall from larger sized elastic arteries to smallest arteries—the arterioles.
- Thus **large arteries** have maximum elastic fibres in their wall, hence they

are also termed as *elastic arteries*. While **medium-sized arteries** have minimum elastic fibres in their wall, hence they are termed **muscular arteries**.

- The **smallest arteries**—the arterioles have only a muscular wall, hence they are the primary site of peripheral vascular resistance to regulate blood pressure.

- **Elastic arteries (conducting vessels)** are large arteries arising from the heart and their main branches, e.g. aorta, brachiocephalic trunk, common carotid artery and the subclavian artery. They are called *elastic arteries* because the tunica media of these arteries is predominantly made up of elastic fibres. They are also called **conducting vessels** as their main function is to conduct blood from the heart to the muscular arteries. **AN 5.4**
- **Muscular arteries (distributing vessels)** are medium-sized arteries supplying individual organs and various parts of the limbs, e.g. renal, testicular, uterine, radial, posterior and anterior tibial arteries, etc. They are also called **distributing vessels**. There is a gradual change from elastic to muscular arteries; the elastic material decreases and muscular tissue becomes the main constituent of tunica media (75%). These arteries regulate the flow of blood to an organ or part, as the smooth muscle of tunica media can alter the size of its lumen by contraction or relaxation.
- **Arterioles** are the smallest divisions of the muscular arteries with 100 mm or less in diameter. Their narrow lumen is surrounded by abundant muscle tissue. They are the main source of peripheral resistance to the blood flow; hence they are also called **resistance vessels**. They play an important role in regulating **diastolic blood pressure**.

Divisions of arteriole

As the arterioles progressively divide into smaller branches, their walls become thinner and form successively **terminal arterioles** and **meta-arterioles:**

1. The **large arterioles** (i.e. arterioles at their arterial end) have all three

coats. **AN 5.7**

2. The **terminal arterioles** (15–20 mm in diameter) are devoid of the internal elastic lamina and have a continuous coat of muscle, cells arranged in one or two layers.
3. In **meta-arterioles**, smooth muscles are replaced by discontinuous non-contractile cells called pericytes or Rouget cells. The meta-arterioles terminate into capillaries.

Thoroughfare Channels

In some vascular beds, a meta-arteriole is directly connected with a venule by a **thoroughfare channel** or **preferred channel**, and the capillaries take origin as side branches of the thoroughfare channel to form a capillary network (Fig. 10.8). The entry of blood through the capillary is regulated by precapillary sphincters.

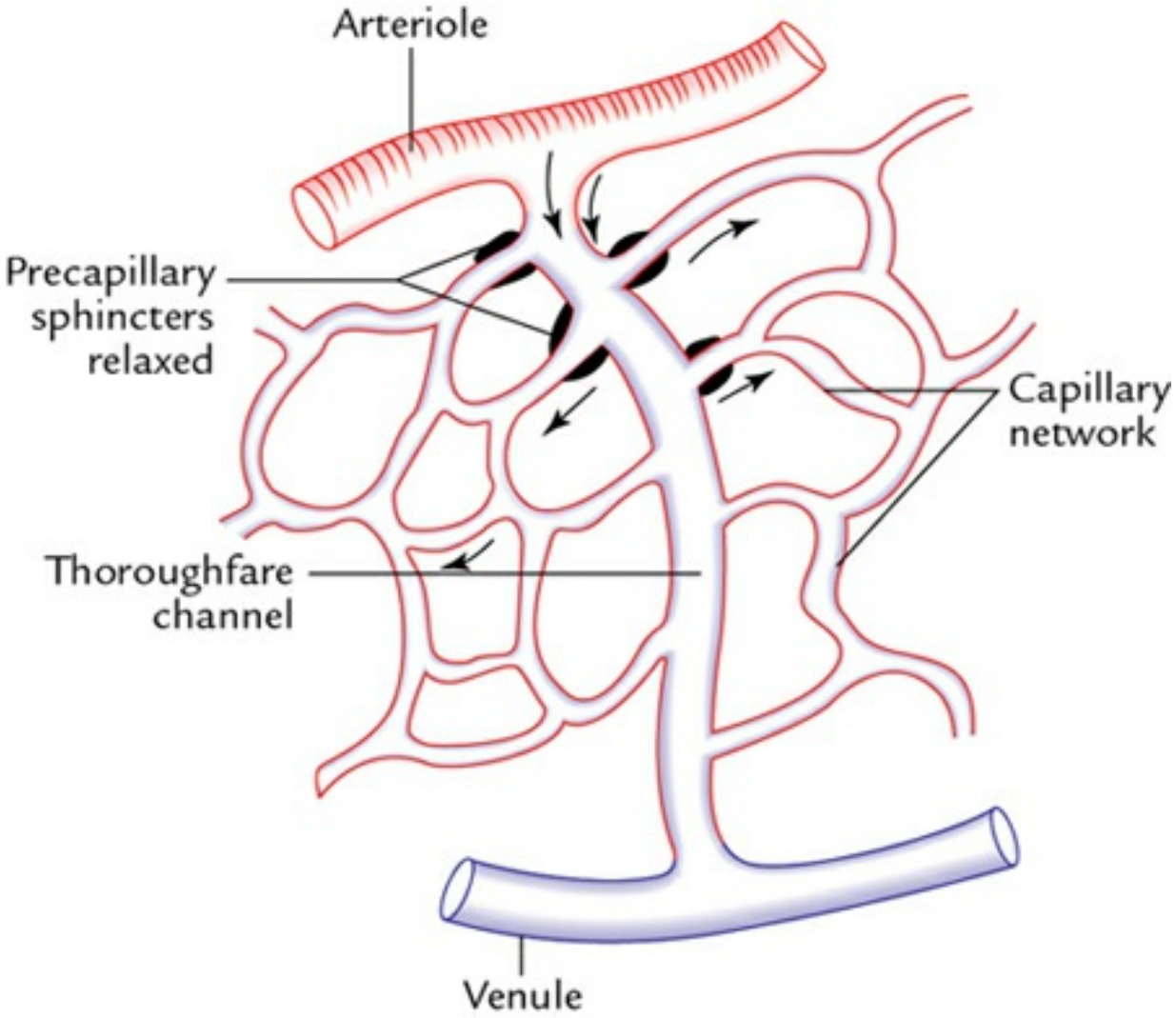


FIG. 10.8 ■ Thoroughfare channels.

Blood flowing through the 'thoroughfare channels' bypasses the capillary bed.

Functional differences between different types of arteries

The functional differences between elastic arteries, muscular arteries and arterioles are given in Table 10.2. **AN 5.4**

TABLE 10.2

Differences between elastic arteries, muscular arteries and arterioles

Elastic arteries	Muscular arteries	Arterioles

Receives blood directly from heart and can stretch in response to each heartbeat and recoil thereafter	Transport blood to different types of organs and tissues in the body	• Provides peripheral resistance to maintain mean arterial pressure and tissue perfusion • Regulate blood flow in tissues and organs

Blood supply of the arteries

Tunica adventitia and the outer two-thirds of tunica media are supplied by **vasa vasorum**.

Tunica intima and inner one-third of tunica media are supplied by **luminal blood through diffusion**.

Minute veins accompanying arteries drain the blood from the arterial wall.

Lymphatics are also present in the tunica adventitia.

N.B.

Vasa vasorum (nutrient vessels) supply only large arteries and some medium-sized arteries (more than 1 mm in diameter). They form dense capillary plexus in the tunica adventitia and may penetrate up to the middle of tunica media.

Clinical correlation

Syphilitic aneurysm: The vasa vasorum are involved in *tertiary syphilis*, leading to the poor blood supply of the tunica adventitia and the outer two-thirds of tunica media. As a result, these layers undergo ischaemic degeneration. Consequently, weakness of these layers leads to *syphilitic aneurysms*. Nowadays tertiary syphilis is more or less non-existent.

Nerve supply

The arteries are mostly supplied by nonmyelinated *sympathetic nerve fibres* called **nervi vasorum/nervi vascularis**.

The sympathetic fibres supplying arteries generally cause vasoconstriction (i.e. constriction of smooth muscles in the wall of arteries) *except* in the heart, brain and skeletal muscles where they cause vasodilatation.

N.B.

A few myelinated sympathetic fibres also supply the arteries. They are said to be sensory in nature (pain sensations).

Filling of the arteries

All the arteries are filled with blood during systole *except* coronary arteries (supplying the heart) which are filled during diastole.

Arterial pulse

The force exerted by blood against the wall of vessels is called **blood pressure**. The normal blood pressure of an adult is about 120/80 mmHg (120 stands for systolic pressure and 80 stands for diastolic pressure). The systolic pressure results due to contraction of the heart during ventricular systole, whereas diastolic pressure results due to contraction of the smooth muscle of the arterial wall. The difference between systolic and diastolic pressure is called **pulse pressure**.

A pulse is a palpable impulse of pressure wave of blood flow initiated by ventricular systole.

Clinical correlation

Sites where the arterial pulses are routinely palpated: A pulse is a palpable impulse of pressure wave of blood flow initiated by ventricular systole.

The student must know the sites where the arterial pulses are routinely palpated by the clinicians. These seven sites are listed in Table 10.3 and illustrated in Figure 10.9.

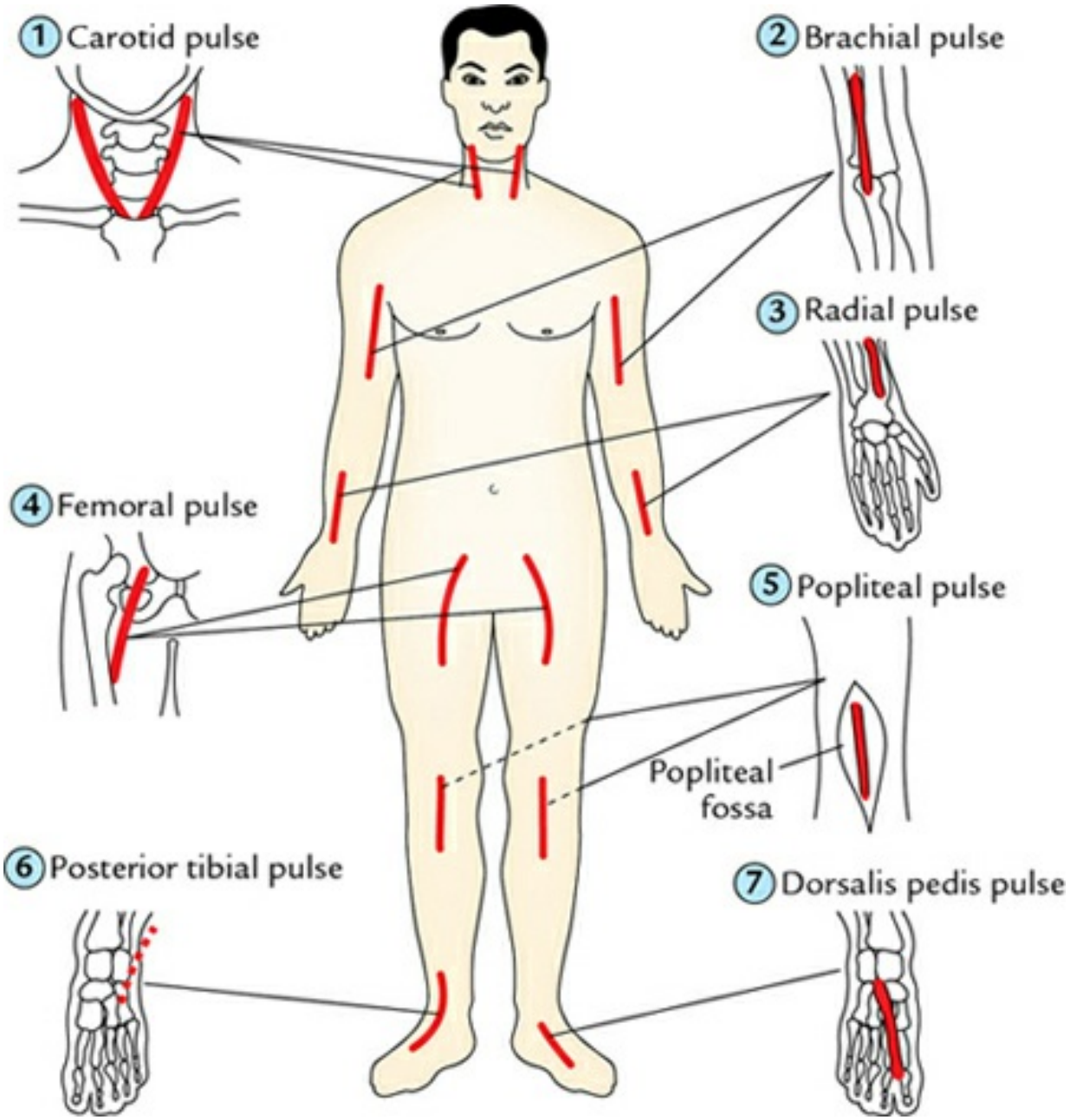


FIG. 10.9 ■ Seven sites where arterial pulses are routinely palpated.

TABLE 10.3

Seven routinely palpated sites of arterial pulse

Pulse	Site	Assessment criteria
Carotid pulse	Along the anterior border of sternocleidomastoid muscle in neck at the level of the cricoid cartilage	*Most reliable pulse* in physiological shock or cardiac arrest, when pulses at other sites are not

		palpable
Brachial pulse	Medial to the tendon of biceps brachii in front of elbow	***To auscultate the blood pressure***
Radial pulse	Radial side of front of forearm at wrist lateral to the tendon of flexor carpi radialis	***Most commonly felt pulse*** to assess the character and rate of the pulse
Femoral pulse	Below the inguinal ligament midway between pubic symphysis and anterior superior iliac spine	To locate femoral vein for venipuncture, which lies just medial to it
Popliteal pulse	Behind the knee in the popliteal fossa	To assess the status of circulation in the lower limb
Posterior tibial pulse	Medial side of ankle midway between medial malleolus and tendocalcaneous	To assess the status of circulation in the foot
Dorsalis pedis pulse	Over the dorsum of the foot just medial to the tendon of extensor hallucis longus	To assess the status of circulation in the foot

Capillaries and sinusoids

Capillaries

The capillaries are thin-walled and endothelium-lined thin microscopic vessels that connect arterioles and venules. There are over 40 billion capillaries in the body with an extensive network of vessels almost in every tissue of the body. The capillaries provide a total surface area of 1000 sq miles for exchange between blood and tissue fluid. The average diameter of the capillary is 6–8 mm. As the diameter of erythrocytes is about 7 mm, only one erythrocyte passes at a time. Thus RBCs pass through a capillary in a single 'file'.

Unlike the vessels of the arterial and venous system, the walls of capillaries are made up of only one cell layer of squamous epithelium called the

endothelium.

Functions

These are *exchange vessels* that allow the exchange of gases and nutrients between blood and tissue fluids.

N.B.

The flow of blood through capillaries is called *microcirculation*.

Types

According to the nature of endothelial lining, the capillaries can be classified into the following two types:

1. Continuous capillaries
2. Fenestrated capillaries.

Continuous capillaries

In **continuous capillaries,** the endothelial cells form a continuous tube. The cells are held together by tight junctions. The main feature of continuous capillaries is the pinocytic vesicles in endothelial cells. This indicates that the transport of material takes place through the cytoplasm of endothelial cells and may account for the selective nature of transport.

Sites: Continuous capillaries are found in skin, muscle, lung, and brain.

Fenestrated capillaries

Fenestrated capillaries are characterized by the wide pores between the endothelial cells. These pores are closed by a layer of mucoprotein called the **diaphragm**. The diffusion of substance takes place through these diaphragms.

Sites: Fenestrated capillaries are found in the pancreas, endocrine glands, intestinal villi, choroid plexus, ciliary processes of the eye, etc.

N.B.

The renal glomeruli also have fenestrated (discontinuous) capillaries but pores are not closed by diaphragms.

Sinusoids

The sinusoids are large irregular vascular spaces that connect arteriole with venule or venule with venule. They replace capillaries in certain organs such as the liver, spleen, bone marrow, suprarenal glands, parathyroid glands, etc.

The lumen of sinusoids is irregular and wide (about 30–40 mm in diameter). The walls of sinusoids are thin and made up of endothelial cells with large pores or slits which are not closed by diaphragms. The wall of sinusoids may be incomplete and contain phagocytic cells; namely, sinusoids in the liver contain Kupffer cells which remove bacteria and other foreign particles from the blood. The sinusoids are closely surrounded by the parenchyma of the organ.

Functions

Due to irregular lumen, the flow of blood is sluggish in sinusoids that allow sufficient time for the exchange of substances between blood and tissue fluid.

The differences between capillaries and sinusoids are highlighted in Table 10.4.

 **TABLE 10.4**

Differences between capillaries and sinusoids

Features	Capillaries	Sinusoids
Lumen	Smaller (5–8 mm)	Larger (30–40 mm)
	Regular	Irregular
Wall	Made up of endothelial cells	Made up of endothelial cells and may contain phagocytic cells
	Continuous or fenestrated with small pores closed by diaphragms	Fenestrated with large pores or may be incomplete
Location in circulatory system	Connect arterioles and venules	Connect arterioles with venules or venules with venules

Veins

Characteristic features

The salient features of veins are as follows:

1. They are thin-walled vessels that carry blood from capillaries to the heart.
2. The large veins are formed by the union of smaller veins like tributaries of a river.
3. They have a larger lumen as compared to arteries and less amount of muscular and elastic tissue in their walls.
4. Their lumen is often provided with valves, which prevent the reflux of the blood and thus, maintain a unidirectional flow of blood even against gravity.
5. Large veins have **dead space** around them for their dilation during increased venous return.

General structure

The general structural features of the veins are similar to those of arteries, i.e. their wall is also made up of three layers but they are ill-defined and seen clearly only in large veins (Fig. 10.10). The *tunica adventitia is the thickest and the best developed layer*. It contains collagen, elastic and muscle fibres. However, the bundles of smooth muscle fibres in this layer are arranged longitudinally.

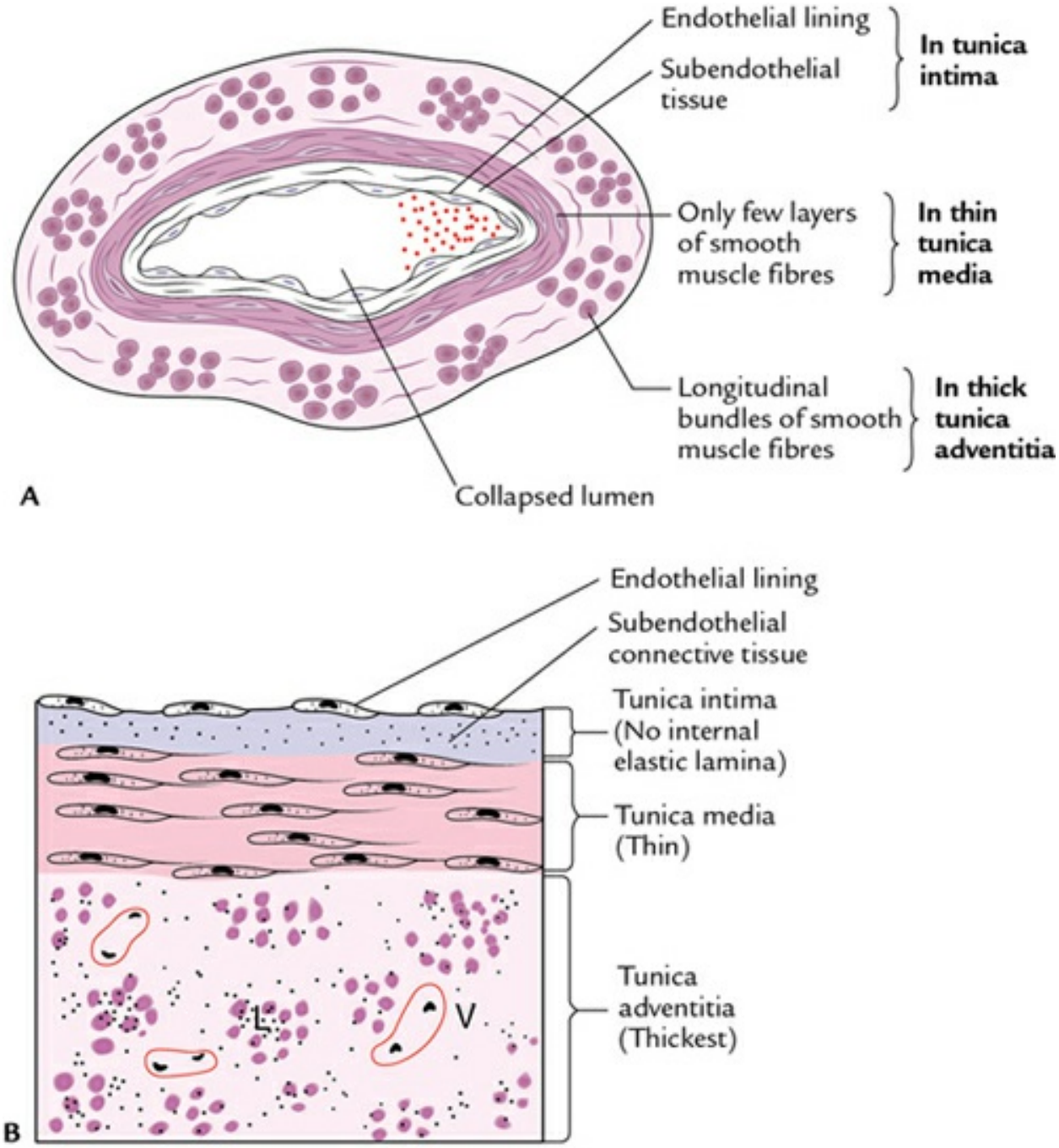


FIG. 10.10 ■ Microscopic structure of a large-sized vein: **(A)** cross-section showing different wall layers and the lumen and **(B)** magnified view of the wall layers. V = vasa vasorum, L = longitudinal bundles of muscle fibres.

The tunica media is poorly developed. The lumen of veins, being thin-walled is often collapsed and contains some blood. The proper internal elastic lamina in the tunica intima is absent.

The differences between arteries and veins are enumerated in Table 10.5.

TABLE 10.5

Differences between arteries and veins AN 5.3

Arteries	Veins
Thick-walled	Thin-walled
More muscular	Less muscular
More elastic	Less elastic
Smaller lumen (always remain patent)	Larger lumen (may be collapsed)
Tunica media thicker than tunica adventitia	Tunica media thinner than tunica adventitia
No valves in the lumen	Valves mostly present in the lumen

N.B.

Thickest coat in arteries is tunica media, whereas the thickest coat in veins is tunica adventitia.

Classification of veins

The veins are classified into the following three types:

1. Large
2. Medium-sized
3. Small (also called venules).

- **Large veins:** All three layers of wall, i.e. tunica intima, tunica media and tunica adventitia are well differentiated. The tunica adventitia is always thicker than tunica media.
  The walls of large veins have some elastic tissues that resist the pressure of the right atrial systole, e.g. inferior vena cava (IVC) and superior vena cava.
- **Medium-sized veins:** These veins also have all three layers in their wall but it becomes gradually difficult to distinguish the three layers with decreasing size of medium-sized veins, splenic vein, testicular vein, etc.
- **Small veins or venules:** These veins are of two types:
  1. **Postcapillary venules:** They are the smallest veins and receive blood from capillaries. Their wall is made up of endothelium.

These veins have special permeability, i.e. diffusion of fluid and white blood cells into the surrounding tissue and absorption of intercellular fluid from the tissue into the venules.

2. **Muscular venules:** They are called so because of the presence of one or two layers of smooth muscle cells outside the endothelium.

N.B.

The veins are *capacitance vessels* because they return varying quantities of venous blood towards the heart and have the capacity to distend or collapse.

Blood supply

The larger vein-like arteries are also supplied by nutrient vessels called **vasa vasorum**, but in the veins, they penetrate up to the tunica intima.

Nerve supply

It is same as arteries, but nerve fibres innervating the veins are fewer in number than arteries.

Pattern of distribution of arteries and veins in body

The venous patterns are far more variable than arterial patterns. For example,

1. *Large veins* are usually single, viz. SVC, IVC, etc.
2. *Medium-sized veins* are usually double, lying on either side of a medium-sized artery, namely, deep veins distal to elbow and knee, hence they are called **venae comitantes**.
   These veins are united to each other by short channels which form a network around the artery.
3. *Small veins/veinules* are located at the venous end of capillaries.

N.B.

In several regions, the venous patterns are quite different from those of arterial patterns, namely, in the brain, liver and lungs.

Venous valves

The inner lining of most medium- and small-sized veins are thrown at intervals into delicate semilunar folds called **cusps**. With the wall of the vein, each cusp forms a bulging pocket or **sinus**.

The cusps are arranged in pairs facing each other to form **valves** (Fig. 10.11). The valves open only in one direction, i.e. towards the heart.

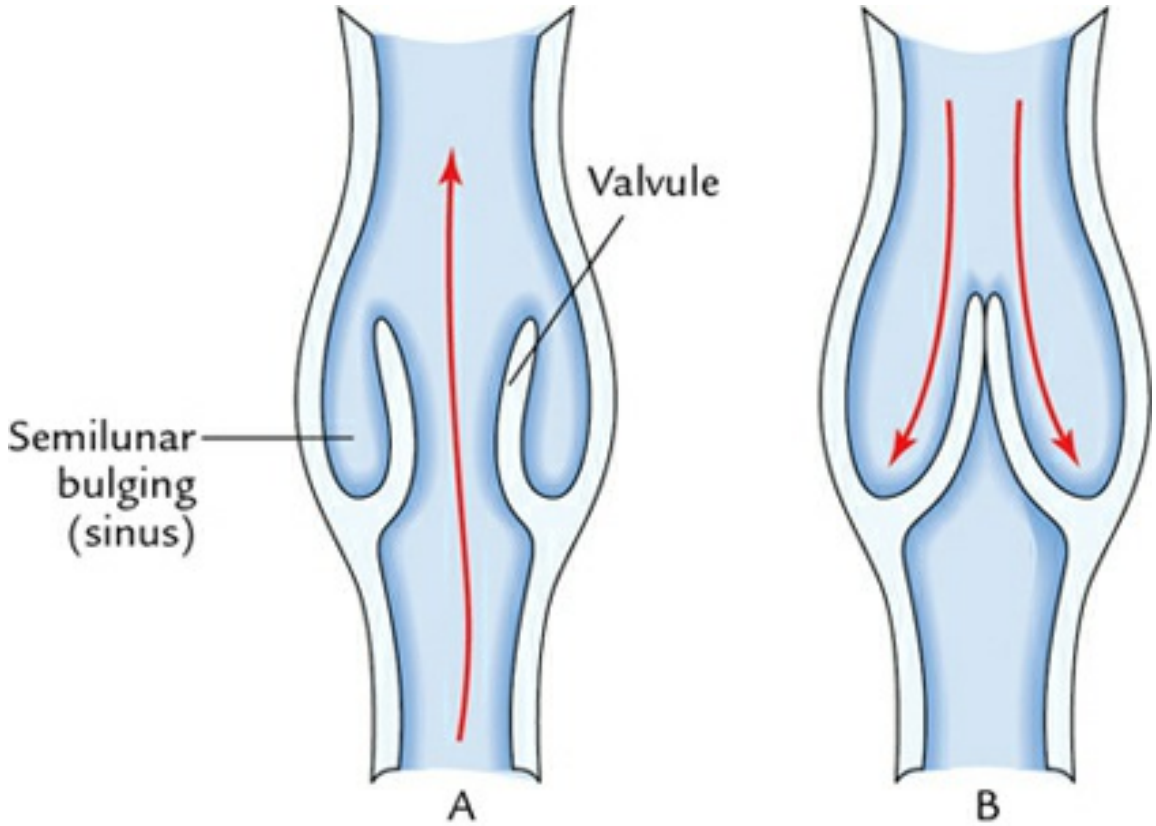


FIG. 10.11 ■ Opening and closing of venous valves: **(A)** the valve opens by forward pressure towards the heart and **(B)** the valve closes by backward pressure.

N.B.

Venous valves are bicuspid and consist of two valvule.

The valves present near the termination of the internal jugular, subclavian and femoral veins prevent the venous blood from being forced back into the

head, neck and limbs during increased intra-thoracic pressure (e.g. during deep inspiration) and during increased intra-abdominal pressure (e.g. during defaecation; Fig. 10.12).

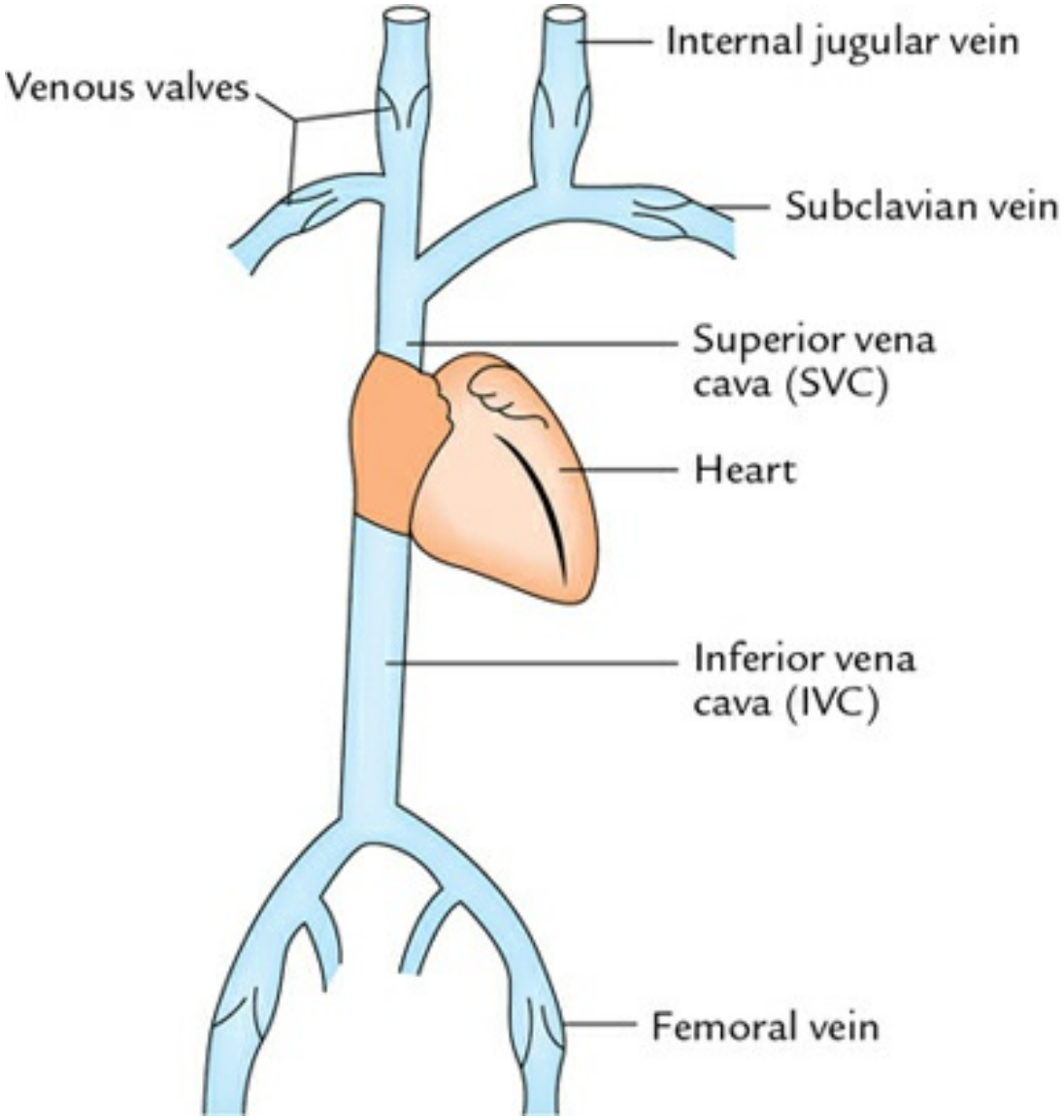


FIG. 10.12 ■ Venous valves near the heart.

N.B.

- The valves are most numerous in the veins of the limbs, and they are commonly placed just before the mouth of a tributary.
- The muscle fibres in the venous wall tend to arrange in a loop near the point of drainage of a tributary to act as a *sluice gate.*

Veins which do not have valves in their lumen are as follows:

1. Superior vena cava
2. Inferior vena cava
3. Hepatic veins
4. Renal veins
5. Uterine veins
6. Ovarian veins
7. Facial veins
8. Pulmonary veins
9. Umbilical veins
10. Emissary veins
11. Portal veins
12. Veins less than 2 mm in diameter.

Veins which do not have muscular tissue in their wall are as follows:

1. Dural venous sinuses
2. Pial veins
3. Retinal veins
4. Veins of the erectile tissue of the penis
5. Veins of spongy bone.

Clinical correlation

Sites of venepuncture: The superficial veins are commonly used for obtaining blood samples or giving intravenous injections, transfusions and infusions.

The common sites of venepuncture are:

(a) **Cubital fossa** (into *median cubital, cephalic, and basilic veins*)

(b) **Dorsal aspect of hand** (into a *dorsal venous arch*)

(c) **In front of the ankle joint** (into the *great saphenous vein*)

Factors helping venous flow

Although the venous pressure is low (i.e. 2 mmHg) than the arterial pressure (i.e. 100 mmHg), venous blood is pumped by the following factors:

1. Mass action of skeletal muscles (one-way flow of blood to the heart is ensured by the presence of *venous* valves).
2. Negative intrathoracic pressure created during inspiration sucks the blood from the great veins into the thorax.
3. Pulsations of the arteries.

N.B.

The effect of the massaging action of skeletal muscles on the venous blood flow is often described as the *skeletal muscle pump*.

Clinical correlation

- **Varicose veins:** The accumulation of blood in the veins of the legs over a long period of time, as may occur in people whose profession requires standing for long period, viz. traffic police personnel can cause the veins to stretch to the point where the venous valves are no longer efficient. Consequently, due to the backflow of blood, the superficial veins become dilated and tortuous, a condition called *varicosity of veins*. The great saphenous vein of the lower limb is most commonly affected.
- **Spread of tumour/cancer:** The veins are one of the three ways through which the tumour or cancer cells can spread to distant organs. Actually, the cancer cells can break off from the tumour and travel through venous blood. **AN 6.3**

Anastomosis of blood vessels AN 5.6

Anastomosis is the communication/connection between the two blood vessels forming collateral channels.

Arterial anastomosis

The arteries do not always end in capillaries rather their branches join/unite with branches of the other arteries forming **anastomosis** (Fig. 10.13). Anastomosis provides a *collateral channel for circulation* when one of these arteries is blocked.

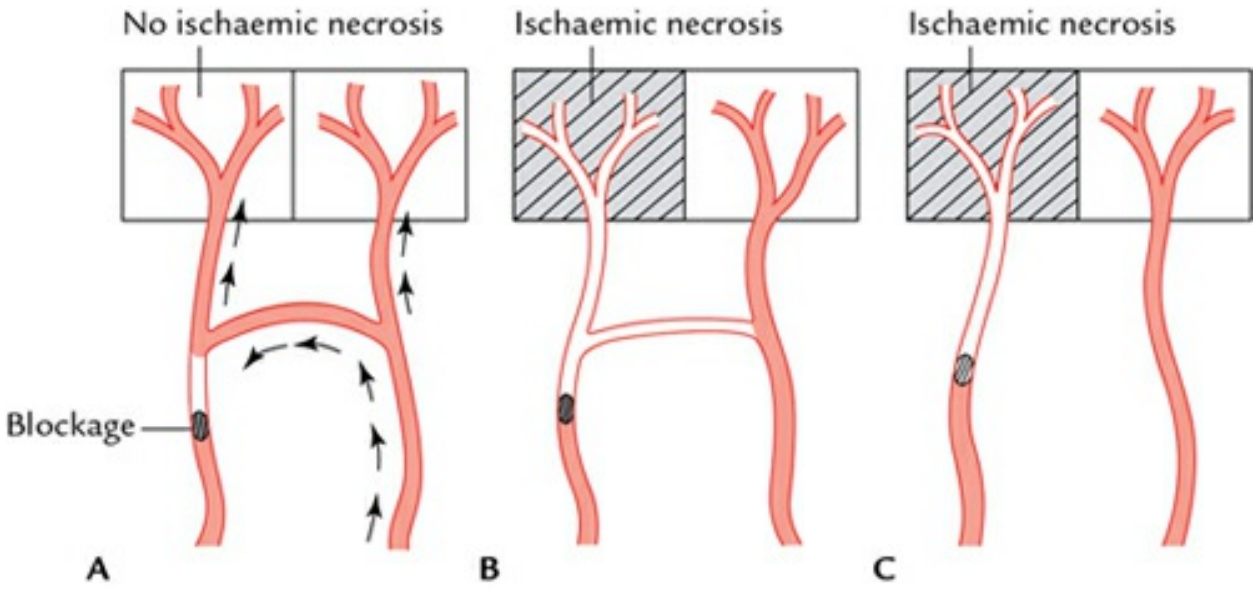


FIG. 10.13 ■ Arterial anastomosis and end arteries: **(A)** functional anastomosis; **(B)** functional end artery (nonfunctional anastomosis) and **(C)** anatomical end artery.

Different types of anastomosis

Anastomosis is of two types (Fig. 10.13):

1. **Actual anastomosis:** It may occur in the following ways:
   (a) *End-to-end anastomosis*: when arteries join end to end, e.g. labial arteries, facial arteries, arterial arches in palms and soles.
   (b) *Convergent anastomosis*: When two arteries converge and join each other to form a larger artery, e.g. two **vertebral arteries** unite to form a larger **basilar artery.**
2. **Potential anastomosis:** The potential anastomosis takes place between terminal arterioles. In such a type of anastomosis, collateral circulation cannot take place if one of the arteries is suddenly blocked. However, if sufficient time is given, the arterioles can dilate and establish collateral circulation, e.g. coronary arteries (for details see N.B. given below).

End arteries

These are the arteries whose branches do not anastomose with branches of other adjacent arteries, e.g. (1) central artery of retina, (2) arteries of spleen, liver, kidneys, metaphyses of long bones and (3) central (medullary) branches of cerebral arteries.

If these arteries are blocked, the area supplied suffers from ischaemia that may lead to cell necrosis.

N.B.

Functional end arteries are not the actual (anatomical) end arteries because they anastomose at the level of arterioles (potential anastomosis) but if they are blocked, the tissues supplied become ischaemic, e.g. coronary arteries and cortical branches of cerebral arteries.

Arteriovenous anastomoses

The direct connections between the arteries and veins without the intervention of capillaries are termed **arteriovenous anastomoses** or **shunts**. The terminal arteriole or its side branch joins the venule. The *AV (arteriovenous) shunts* have a thick muscular wall and are abundantly supplied with vasomotor sympathetic nerves, and thereby may act as a sphincter.

Sites

Arteriovenous anastomoses are found at the following sites:

1. Skin of nose, lips and external ear
2. Mucous membrane of alimentary canal and nose
3. Erectile tissue of sex organs
4. Thyroid gland
5. Tongue.

Functions

Arteriovenous anastomoses permit the direct transfer of blood from arterial to venous channels, bypassing the capillary bed when sphincters are relaxed (Fig. 10.14). The functions of arteriovenous anastomoses include:

1. Regulation of temperature
2. Regulation of regional blood flow
3. Regulation of blood pressure.

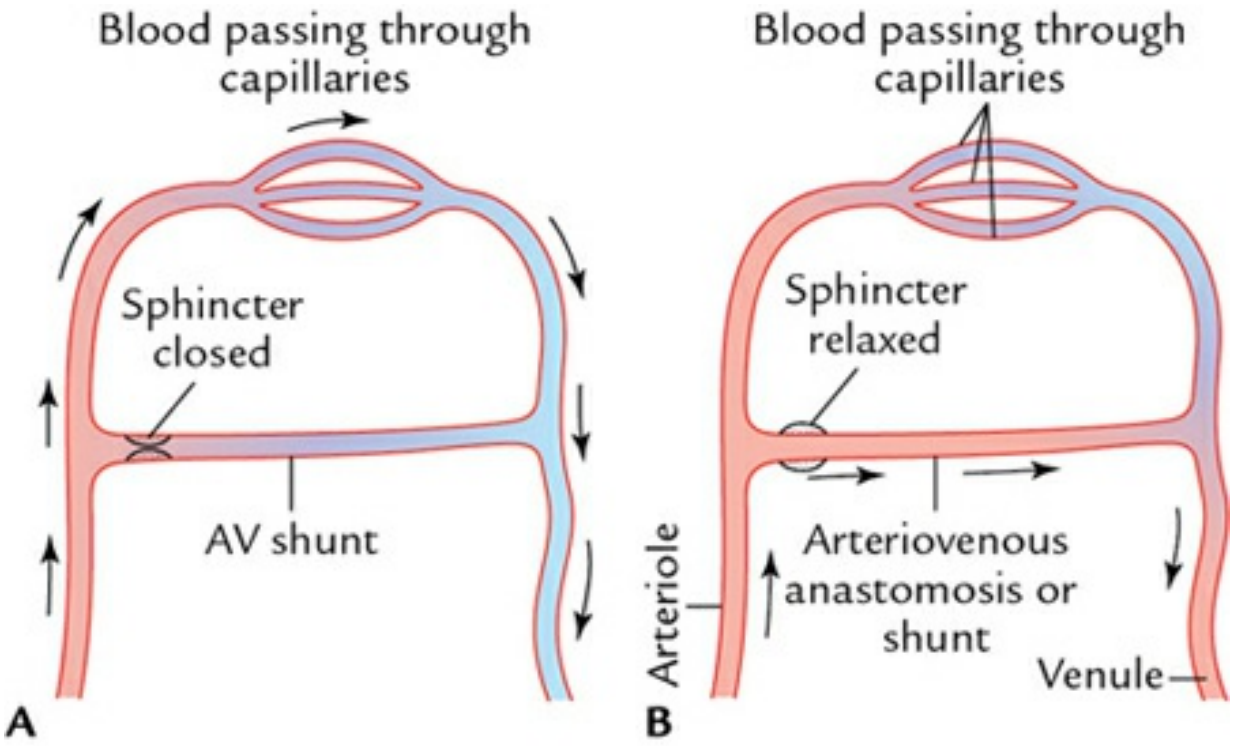


FIG. 10.14 ■ Functioning of arteriovenous anastomoses (or shunt): **(A)** blood not passing through the shunt because the sphincter is closed, hence it is passing through capillaries (when tissue or organ is active) and **(B)** blood passing through the shunt because the sphincter is relaxed, hence little or no blood is passing through capillaries (when tissue or organ is at rest).

Clinical correlation

Anuria after severe road accidents: In organs like kidneys and intestine, arteriovenous anastomoses open up following massive haemorrhage during road accidents or war injuries. This allows the blood to bypass the capillary bed of the kidney and intestine, thus making blood available to vital organs such as heart and brain. For this reason, anuria often occurs after accidents but once the volume of blood in general circulation

improves, the AV shunts gradually close, allowing the blood to pass through the glomerular capillaries. Consequently, the output of urine improves, which is a good clinical sign after the accident.

Circulation of blood

In adult individuals, the blood circulates through an estimated 60,000 miles of vessels throughout the body to provide food and oxygen to trillions of living cells in the body. At the same time, it removes the waste products of their metabolism.

Types of blood circulation AN 5.2. AN 5.5

Blood circulation in the body can be categorized into the following three types (Fig. 10.15):

1. **Pulmonary circulation:** The deoxygenated blood entering the right atrium passes to the right ventricle which pumps it through the pulmonary trunk and pulmonary arteries to the capillaries of the lungs (where it is oxygenated), then through the pulmonary veins it returns to the left atrium.
2. **Systemic circulation:** The oxygenated blood from left atrium passes to the left ventricle which pumps it through aorta and its branches to the capillaries of the rest of the body.
   The capillaries join to form veins that become increasingly larger till finally the superior and inferior vena cavae and cardiac veins return the deoxygenated blood to the right atrium.
   The right atrium receives same amount of deoxygenated blood that was pumped by the left ventricle, and at the same rate.

N.B.

Students must note that blood appears red when oxygen content is high and appears blue when oxygen content is low. Therefore, blood is 'red' in pulmonary veins, on the left side of the heart, and in systemic arteries, whereas the blood is 'blue' in systemic veins, right side of the heart, and in pulmonary arteries. These structures, therefore, should be coloured red and blue accordingly in anatomical illustrations.

Difference between pulmonary and systemic circulation **AN 5.2**

The difference between pulmonary and systemic circulation is given in Table 10.6.

3. **Portal circulation:** It is in fact a part of the systemic circulation. ***It begins with capillaries and ends with capillaries,*** i.e. blood passes through two sets of capillaries before draining into a systemic vein.

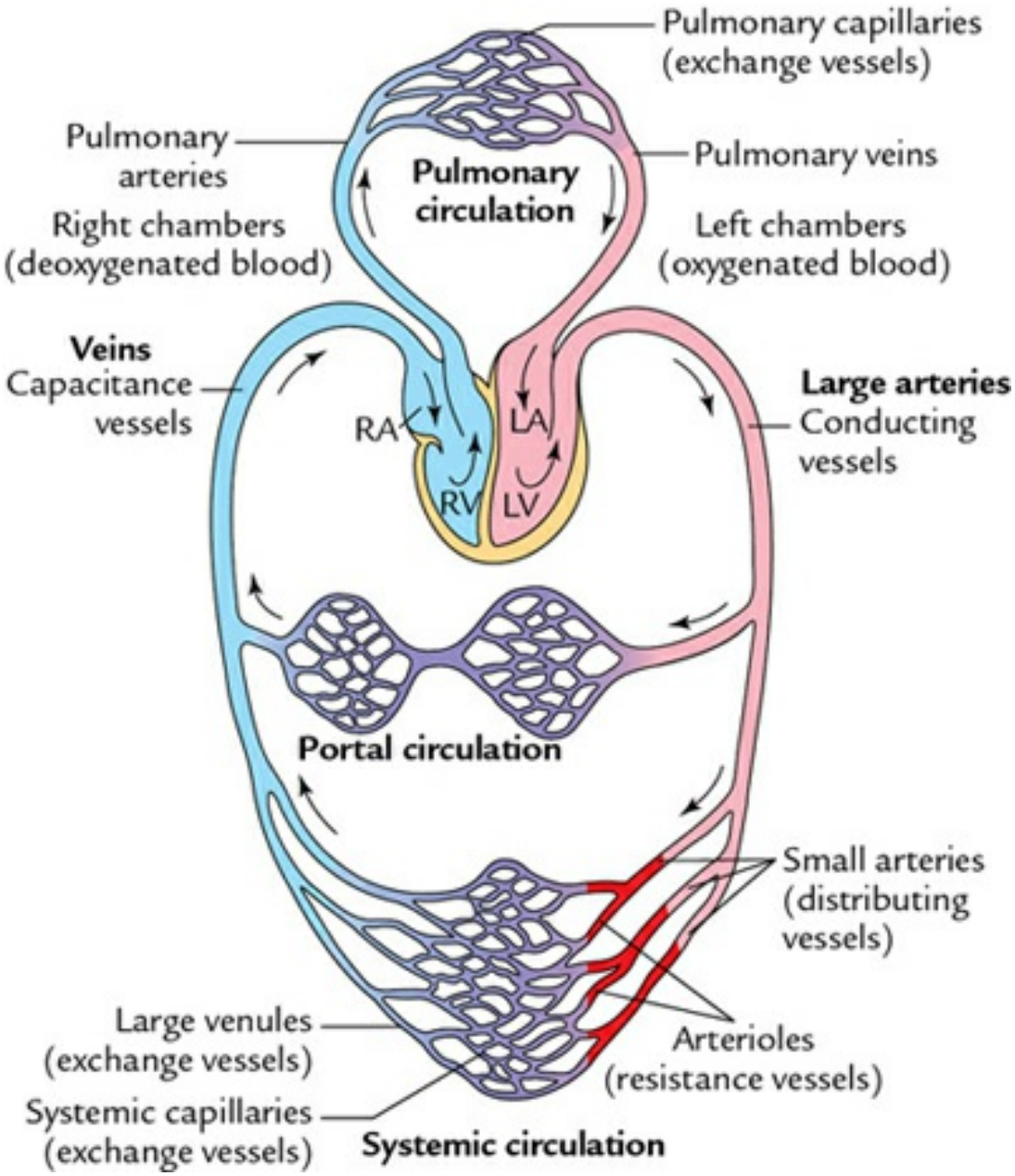


FIG. 10.15 ■ Types of circulation: pulmonary, systemic and portal.

TABLE 10.6

Difference between pulmonary and systemic circulation

Pulmonary circulation	Systemic circulation
Sends deoxygenated blood from the heart to lungs through pulmonary arteries for oxygenation and receives oxygenated blood from the lungs to the heart through pulmonary veins	Sends oxygenated blood from heart to rest of the body, through aorta and its branches to whole body and returns deoxygenated blood from body to the heart through superior and inferior vena cava

The ***portal vessels*** are the vessels that connect the two sets of capillaries at their two ends.

The vessel draining the first capillary network is known as a portal vessel, which branches like an artery to form the second set of capillaries or sinusoids. Such type of circulation is seen in the liver **(hepatic portal circulation)**, hypophysis cerebri **(hypothalamo-hypophyseal portal circulation),** kidney **(renal portal circulation),** etc.:

(a) ***Hepatic portal circulation*** (Fig. 10.16):

The venous blood passes from the capillary bed of GIT, spleen and pancreas through the portal vein to the liver. In the liver, it passes through a secondary capillary bed, the hepatic sinusoids, before entering the general circulation via the inferior vena cava.

In this way, blood with a high concentration of nutrients absorbed from the stomach and intestines goes to the liver first, where certain modifications take place before it is supplied to the other parts of the body.

N.B.

Hepatic portal system is essentially concerned with the transport of absorbed nutrients from food to the liver and their subsequent metabolism.

(b) ***Hypothalamo-hypophyseal portal circulation*** (Fig. 10.17*):*

The blood passes from the capillary network in the hypothalamus through portal vessels into the capillary network in the anterior pituitary. The vein/veins arising from the capillary network in the

anterior pituitary then merge with the general circulation.

The neurohormones produced and secreted by the hypothalamus enter the capillary network within the hypothalamus to reach the anterior pituitary where they act on the cells of the anterior pituitary to either increase or decrease their secretion. The hormones secreted by the anterior pituitary enter the capillary network within the anterior pituitary and then are carried by the general circulation to the target tissue.

N.B.

Through hypothalamo-hypophyseal portal system, the hypothalamus regulates the activities of adenohypophysis (anterior pituitary) by means of neurohormone (releasing or inhibiting hormones).

(c) ***Renal portal circulation*** (Fig. 10.18):

The afferent arterioles supply blood to the glomerular capillaries of the renal corpuscle. Efferent arterioles (portal vessels) arise from glomerular capillaries and carry the blood away from the glomerulus. The efferent arteriole gives rise to the plexus of capillaries around the proximal and distal convoluted tubules (peritubular capillaries). The peritubular capillaries drain into general circulation through the interlobular vein.

Thus, the renal portal system connects the glomerular capillaries with the peritubular capillaries. This mechanism helps reabsorption of some essential constituents of glomerular filtrate back into the blood.

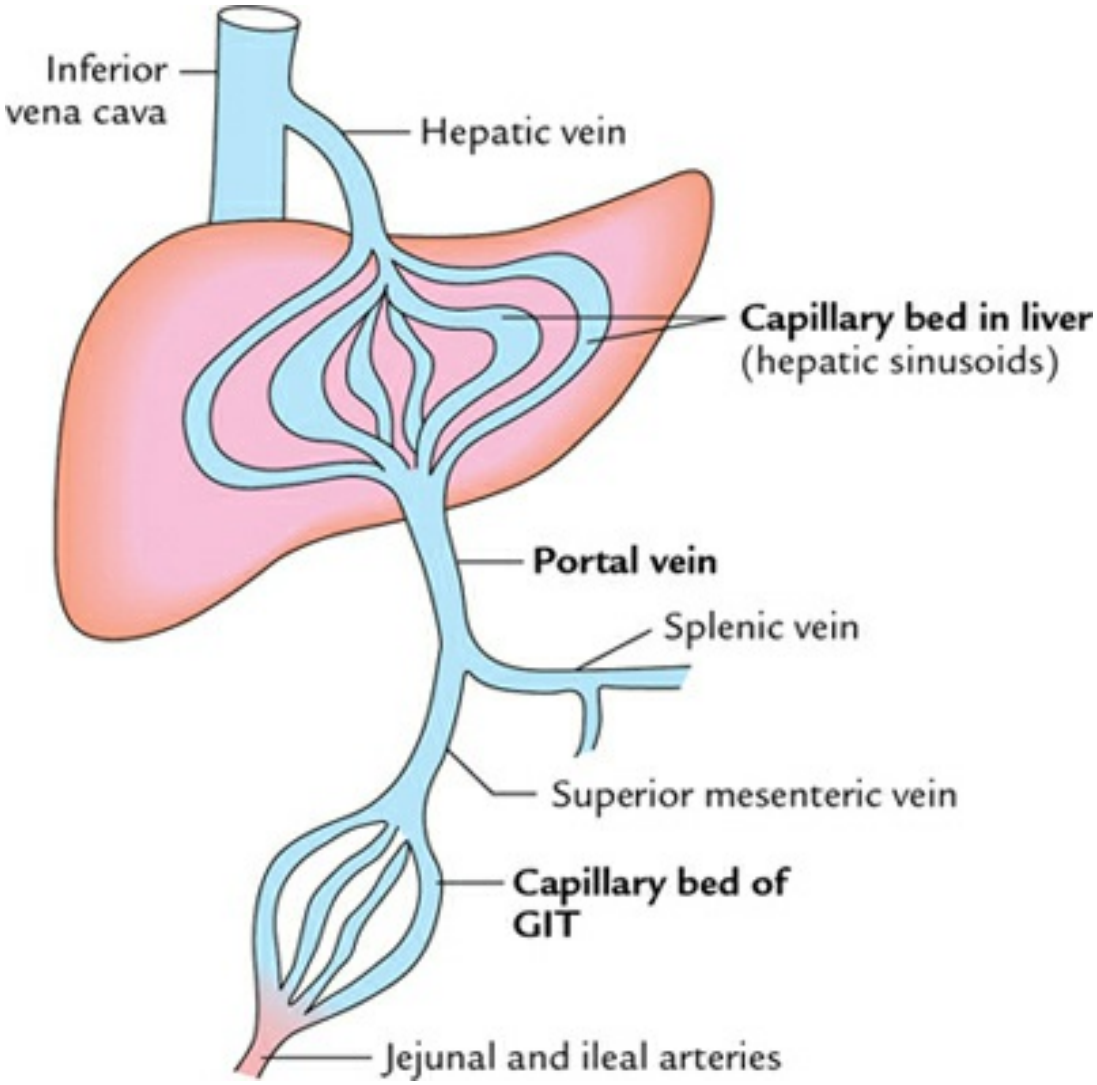


FIG. 10.16 ■ Hepatic portal circulation.

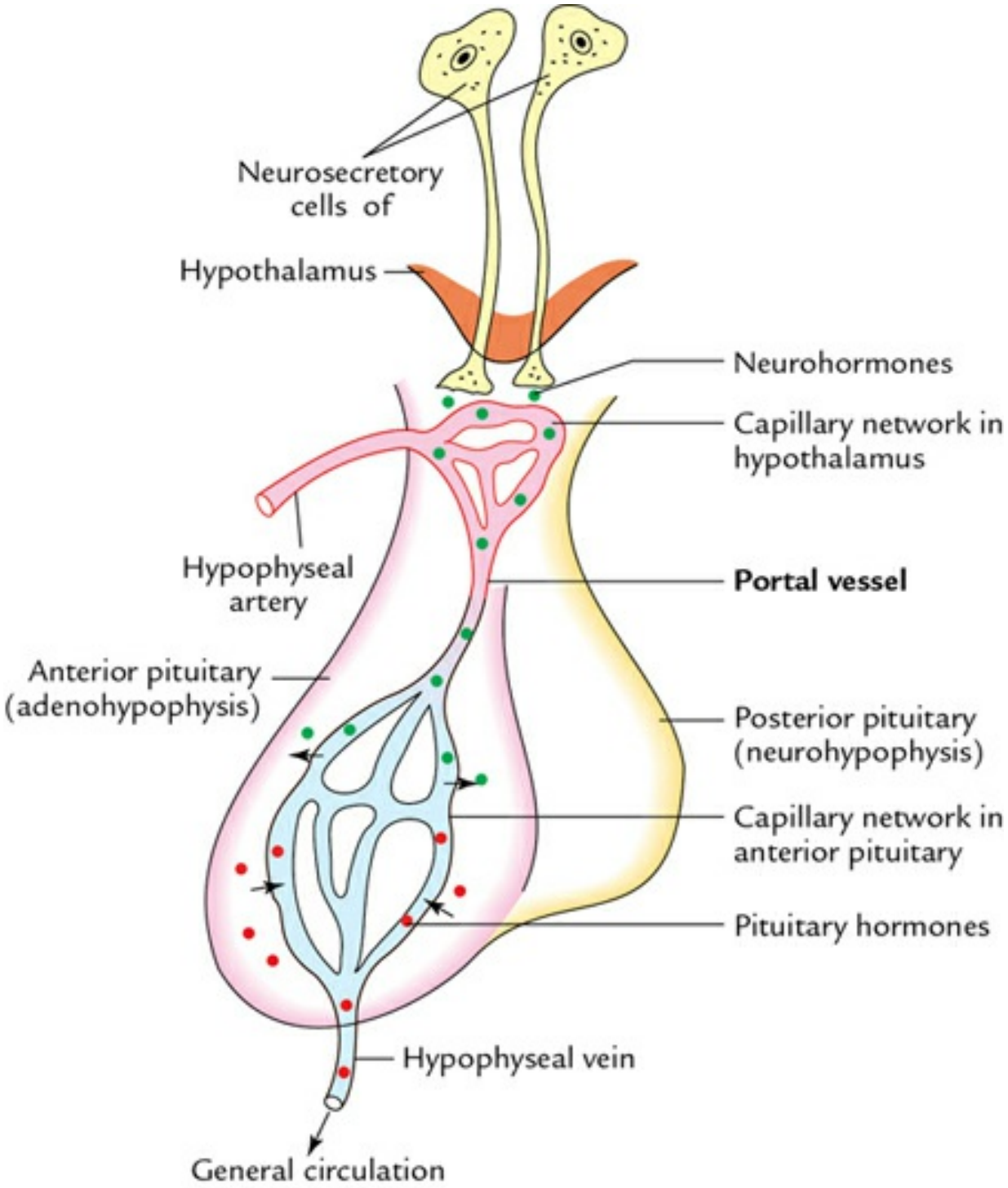


FIG. 10.17 ■ Hypothalamo-hypophyseal portal circulation.

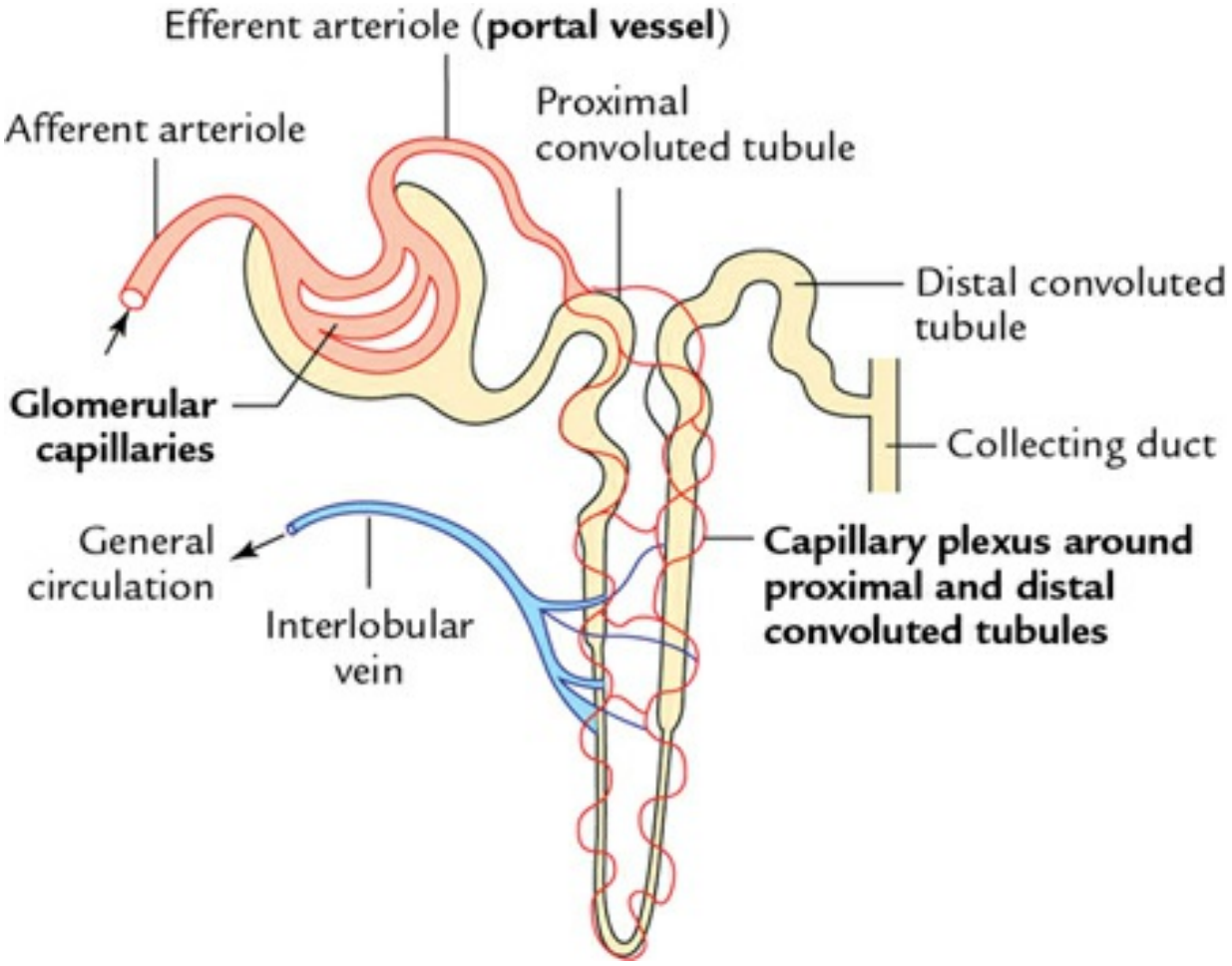


FIG. 10.18 ■ Renal portal circulation.

Foetal circulation

The foetal circulation is different from circulation in the adult (Fig. 10.19). This is because of the following factors in the foetus:

1. The collapsed foetal lungs are nonfunctional.
2. The portal circulation is of little significance.
3. The oxygenation of blood occurs in the placenta.

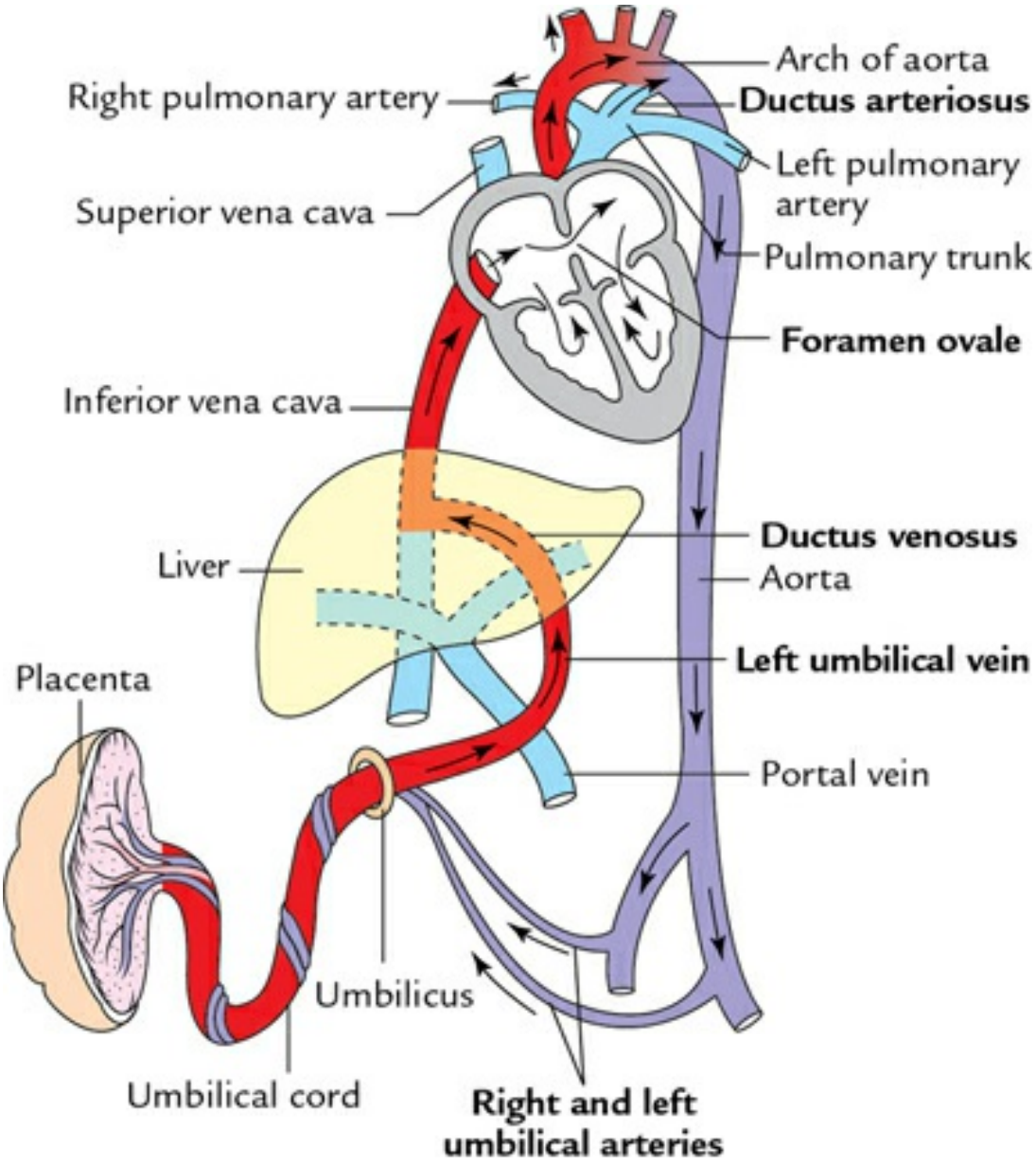


FIG. 10.19 ■ Foetal circulation.

The three cardinal features of foetal circulation are:

1. The right heart pumps very little blood to the collapsed lungs.
2. The left heart pumps blood through systemic circulation and the placenta.
3. A system of three shunts operates to bypass partially the lungs and liver. These shunts close down postnatally and adult circulation is established:
   (a) The **ductus venosus** shunts the blood from the umbilical vein to the IVC, bypassing the liver.
   (b) The **foramen ovale** shunts the blood from the right atrium to the

left atrium, bypassing the pulmonary circulation.

(c) The **ductus arteriosus** shunts the blood from left pulmonary artery to the aorta, bypassing the pulmonary circulation.

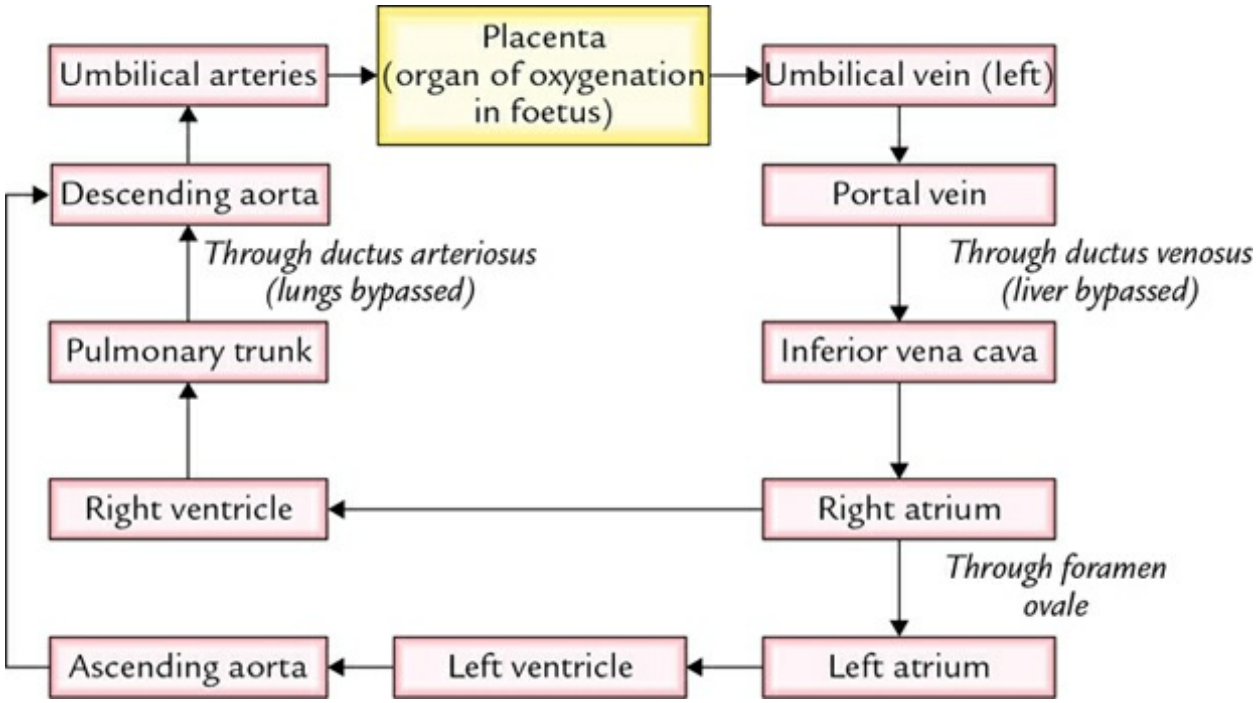
The foetal blood charged with nutritive material and oxygen leaves the placenta to enter the left umbilical vein, which traverses the umbilical cord to end in the left branch of the portal vein.

Only some amount of blood from the left portal vein flows through the liver; however, most of the blood bypasses the liver via **ductus venosus** to the inferior vena cava which opens into the right atrium.

Most of the blood brought into the right atrium by the IVC is shunted through the foramen ovale (opening in the interatrial septum) into the left atrium, thereby short-circuiting the pulmonary circuit. It then passes through the left ventricle into the ascending aorta and aortic arch, and by their branches, it is distributed to the heart, head and neck and upper limbs. The blood from the head and neck and upper limbs returns to the right atrium through the superior vena cava. From the right atrium, it passes to the right ventricle and then into the pulmonary trunk. From here, most of the blood is short-circuited to the aorta by the ductus arteriosus that connects the left pulmonary artery to the aortic arch just beyond the origin of the left subclavian artery. Then the blood is distributed by the aorta and common iliac arteries to the abdomen, lower limbs and placenta.

The umbilical arteries, one on each side, pass by the sides of the bladder and up the anterior abdominal wall to the umbilicus and then through the umbilical cord to the placenta.

The foetal circulation is summarized in Flowchart 10.2.



FLOWCHART 10.2 ■ Foetal circulation.

The remnants formed by the closure of foetal circulatory structures after birth, following the start of neonatal circulation are presented in Table 10.7.

TABLE 10.7

Remnants that result from the closure of foetal circulatory structures

Foetal circulatory structures	Adult remnants
Ductus venosus	Ligamentum venosum
Foramen ovale	Fossa ovalis
Ductus arteriosus	Ligamentum arteriosum
Left umbilical vein	Ligamentum teres hepatis
Right and left umbilical arteries	Medial umbilical ligaments

N.B.

- Since the functions of the placenta are concerned with: (1) nutrition, (2) excretion and (3) respiration, in foetus, the portal, renal and pulmonary circulations are of little significance. The placental circulation is paramount.
- The placenta is the organ of oxygenation in foetus.

- Foetal circulation compensates for nonfunctional foetal lungs.

Differences between blood vascular and lymphatic system

These are described in Ch 12 on page 165.

Golden Facts to Remember

• First organ in the body to start functioning	Heart
• Largest artery in the body	Aorta
• Largest vein in the body	Inferior vena cava (IVC)
• Longest vein in the body	Great saphenous vein
• Largest portal vessel in the body	Portal vein
• Most commonly used artery for measuring blood pressure	Brachial artery
• Most commonly felt arterial pulse in the body	Radial pulse
• Most reliable pulse in the body	Carotid pulse
• Best example of an end artery in the body	Central artery of the retina of the eye
• Best example of functional end arteries	Coronary arteries
• Most commonly used vein for intravenous injection	Median cubital vein (in the cubital fossa)
• Total number of capillaries in the body	40 billion
• Total surface area of capillaries involved in the exchange of gases, nutrients, etc.	1000 square miles
• Total length of all capillaries joined end to	60,000 miles

end	
• Total amount of blood in the vascular system	5 L
• Most abundant leukocytes in peripheral circulation	Neutrophils
• All the cells of the blood are nucleated except	Mature red blood cells (RBCs)
• All arteries in the body contain oxygenated blood except	Pulmonary arteries in adults and umbilical arteries in the foetus, which contain deoxygenated blood
• All veins in the body contain deoxygenated blood except	Pulmonary veins in adults and umbilical veins in the foetus, which contain oxygenated blood
• All the arteries in the body are filled during systole except	Coronary arteries which are filled during diastole
• Vessels responsible for maximum peripheral vascular resistance	Arterioles

Multiple choice questions

1. **All of the following are examples of elastic arteries *except*:**
   (a) Aorta
   (b) Common carotid artery
   (c) Subclavian artery
   (d) Radial artery
2. **All of the following are examples of distributing vessels *except*:**
   (a) Common carotid artery
   (b) Renal artery
   (c) Testicular artery
   (d) Uterine artery
3. **Arterioles are the examples of:**
   (a) Distributing vessels
   (b) Conducting vessels
   (c) Resistance vessels

(d) Capacitance vessels

4. **Fenestrated capillaries are found in all of the following sites *except*:**
   (a) Pancreas
   (b) Lung
   (c) Intestinal villi
   (d) Ciliary processes of the eye
5. **Veins are an example of:**
   (a) Conducting vessels
   (b) Distributing vessels
   (c) Capacitance vessels
   (d) Resistance vessels
6. **All of the following are examples of end arteries *except*:**
   (a) Central branches of cerebral arteries
   (b) Central artery of retina
   (c) Facial artery
   (d) Splenic artery
7. **All of the following are veins without valves in their lumen *except*:**
   (a) Inferior vena cava
   (b) Saphenous veins
   (c) Emissary veins
   (d) Veins less than 2 mm in diameter
8. **All of the following veins do not have muscular tissue in their wall *except*:**
   (a) Retinal veins
   (b) Veins of spongy bone
   (c) Venules
   (d) Veins of the erectile tissue of the penis
9. **Which of the following arteries are examples of functional end arteries:**
   (a) Central branches of cerebral arteries
   (b) Coronary arteries
   (c) Arteries of spleen, liver and kidneys
   (d) Arteries supplying metaphyses of long bones
10. **Arteriovenous anastomoses are found at all of the following sites *except*:**
    (a) Skin of lips
    (b) Erectile tissue of sex organs
    (c) Thyroid gland

(d) Liver

11. **All of the following are features of veins *except*:**
    (a) Thin walls
    (b) Thin tunica adventitia
    (c) Thin tunica media
    (d) Wider lumen
12. **Stimulation of sympathetic fibres causes vasodilatation of all of the following arteries *except*:**
    (a) Arteries of heart
    (b) Arteries of GIT
    (c) Arteries of the brain
    (d) Arteries of skeletal muscles
13. **Nerve supply of arteries is mostly derived from:**
    (a) Myelinated sympathetic nerve fibres
    (b) Nonmyelinated sympathetic nerve fibres
    (c) Myelinated parasympathetic nerve fibres
    (d) Nonmyelinated parasympathetic nerve fibres
14. **All of the following are examples of portal circulation *except*:**
    (a) Pulmonary circulation
    (b) Hepatic circulation
    (c) Renal circulation
    (d) Circulation in hypophysis cerebri
15. **Which of the following arteries are filled mainly during diastole:**
    (a) Common carotid arteries
    (b) Hepatic arteries
    (c) Coronary arteries
    (d) Renal arteries

Answers

1. *d*, 2. *a*, 3. *c*, 4. *b*, 5. *c*, 6. *c*, 7. *b*, 8. *c*, 9. *b*, 10. *d*, 11. *b*, 12. *b*, 13. *b*, 14. *a*, 15. *c*.

Chapter 11: Lymphatic system

Specific learning objectives

After studying this chapter, the student should be able to:

- Define the lymphatic system and discuss its functions and clinical significance.
- List the components and functions of the lymphatic system. **AN 6.1**
- Differentiate between blood vascular and lymphatic systems. **AN 5.1**
- Describe the structure of lymph capillaries and the mechanism of lymph circulation. **AN 6.2**
- Explain the concept of lymphoedema and the spread of tumours via lymphatics. **AN 6.3**
- Describe the location, structure and functions of lymph nodes, spleen and thymus.
- Describe the location and functions of mucosa-associated lymphoid tissue (MALT).
- Discuss the role of T lymphocytes in providing cell-mediated immunity.
- Discuss the role of B-lymphocytes in providing antibody-mediated immunity.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

The lymphatic system basically consists of an extensive network of extremely

variable **lymph vessels and lymph nodes** through which lymph circulates (Fig. 11.1). In addition, it also includes other lymphoid organs (viz. spleen, thymus and bone marrow) and lymphoid tissues (viz. mucosa associated lymphoid tissue—MALT). The lymphatic system defends the body from bacteria, viruses, and other harmful agents, hence a very important part of the **immune system**.

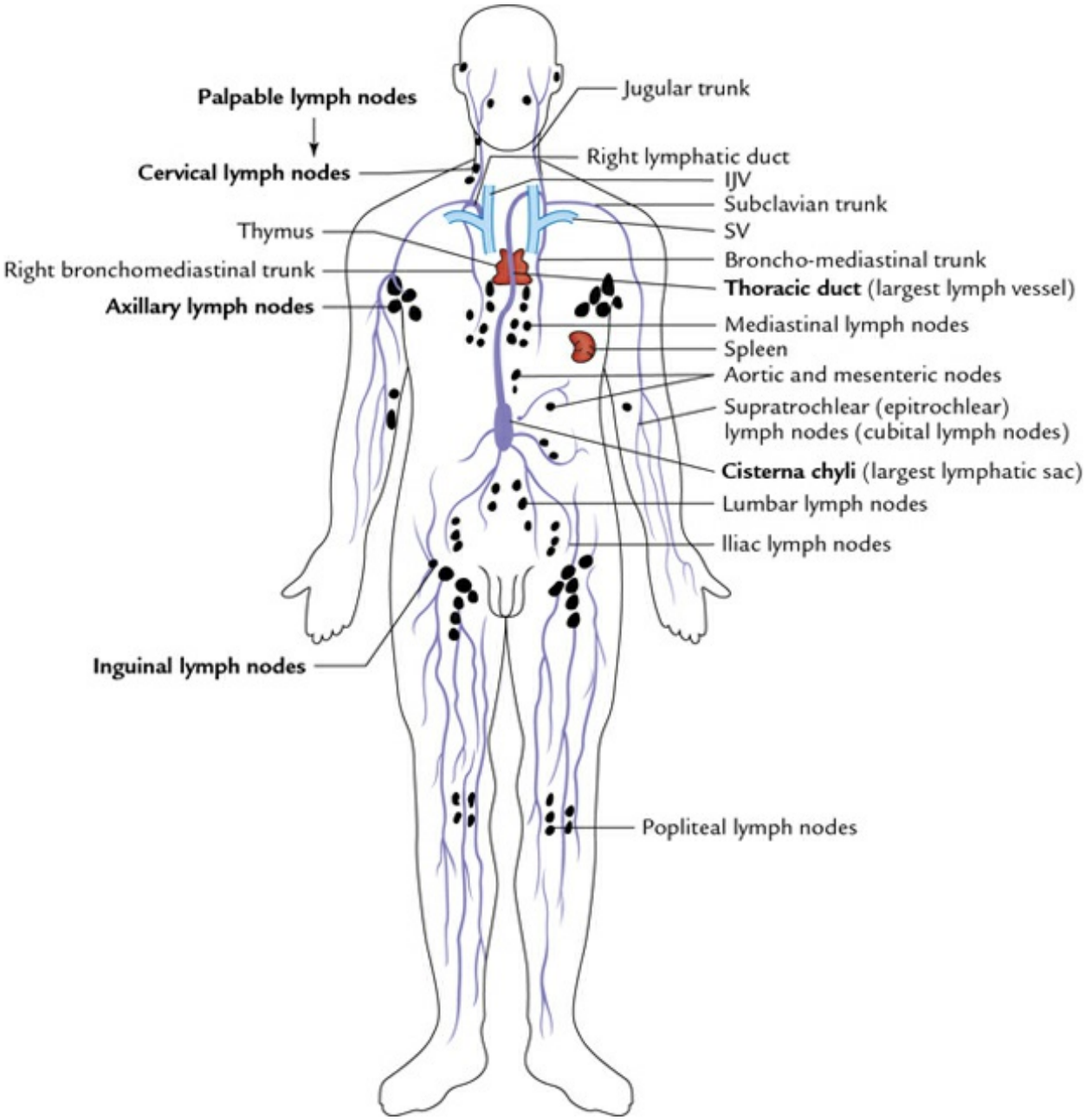


FIG. 11.1 ■ Schematic diagram of a human being showing major locations of lymph nodes, thoracic duct, right lymphatic duct and other lymph vessels. Commonly enlarged and palpated lymph nodes are labelled with bold font. IJV = internal jugular vein, SV = subclavian vein.

The *lymphatic system is essentially a drainage system that is accessory to the venous system* (Fig. 11.2) because it drains the interstitial fluid (containing macromolecules) which cannot be drained by the venous system. The details are as under.

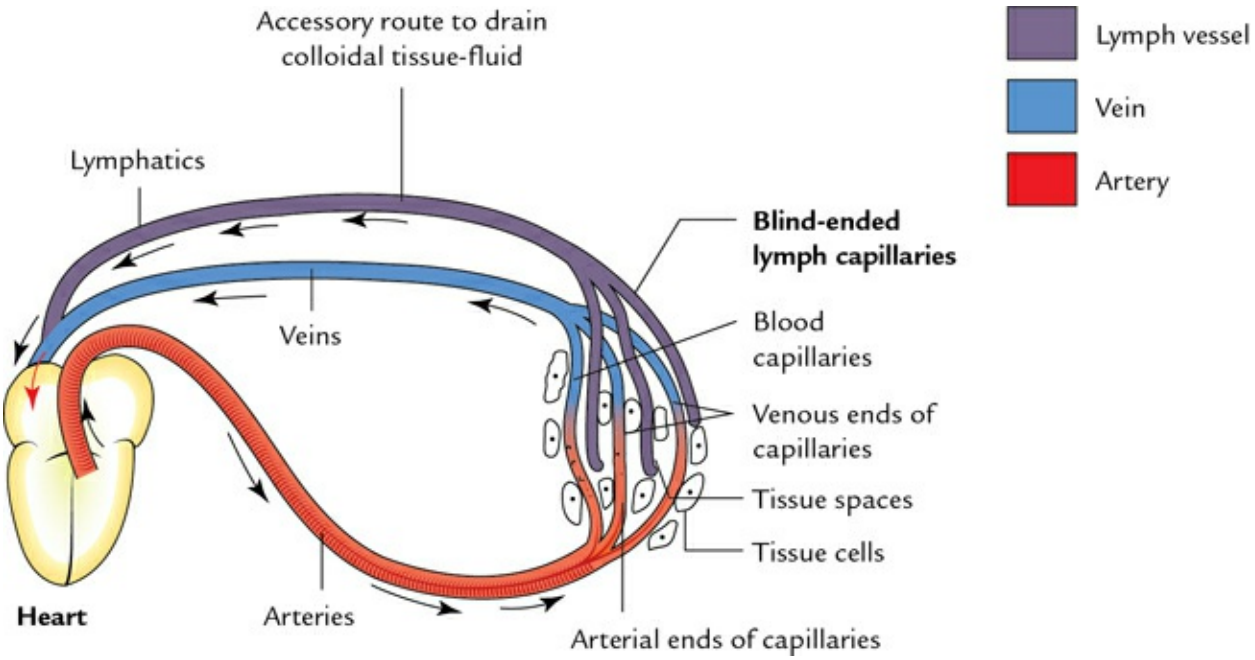


FIG. 11.2 ■ Schematic diagram showing the relationship between the lymphatic system and cardiovascular system.

Most of the tissue fluid (80%–90%) formed at the arterial ends of the capillaries is absorbed back into the blood by the venous ends of the capillaries. The remaining 10%–20% of tissue fluid containing large molecules of proteins, fat droplets, fat-soluble substances and particulate matter, namely, bacteria etc. cannot be absorbed by venous ends of blood capillaries. This remaining fluid is absorbed by lymph capillaries which begins blindly in the tissue spaces and is sent back to the blood.

Functions and role

The functions of the lymphatic system are as follows:

1. Drains excess tissue fluid containing macromolecules of protein, lipid,

etc. to the venous system, i.e. tissue fluid which could not be drained by the venous system.
2. Absorbs fat from the intestine (called **chyle**) and transports it to the blood.
3. Helps to provide immunological defence against disease-causing agents.
4. Provides routes for the spread of infection or cancer cells.

Components of the lymphatic system AN 5.1, AN 5.8, AN 6.1

The lymphatic system consists of:

1. Lymph
2. Lymph capillaries
3. Lymph vessels
4. Lymphoid organs
   (a) Lymph nodes
   (b) Spleen
   (c) Thymus
5. Epitheliolymphoid system
6. Bone marrow.

Lymph

The tissue fluid (interstitial fluid) that enters the lymph capillaries is called **lymph**. Generally, it is a clear watery fluid similar in composition to plasma, with the important exception of plasma proteins. However, the lymph from the small intestine is milky white (called **chyle**) because it contains large droplets of fat absorbed from the intestine. The lymph transports the plasma proteins that seep out of the capillary beds back to the bloodstream. It also carries away larger particles, e.g. bacteria and cell debris which are then filtered out and destroyed by the lymph nodes. *Thus, the lymph contains lymphocytes, macromolecules of protein, fat droplets and particulate matter such as dust particles, carbon particles, bacteria, etc.*

To an extent, the constitution of lymph is similar to that of plasma.

Clinical Correlation AN 6.3

Lymphoedema: About 30 L of fluid passes from the arterial ends of capillaries into the intercellular space every day. Out of this, about 27 L of fluid consisting of micromolecules are absorbed back by the venous ends of the capillaries. The remaining 3 L of fluid consisting of macromolecules of protein, fat droplets and particulate matter such as bacteria is absorbed by lymph capillaries. For this reason, the **lymphatic system is regarded as** a '**drainage system of the coarse type**' and **venous system as** a '**drainage system of the fine type**'. If an extra 3 L of fluid is not drained by the lymphatic system, the accumulation of this fluid in the tissue will cause oedema (swelling).

Lymph capillaries AN 6.2

The lymph capillaries are microscopic blind-ended lymph vessels that begin in the intercellular spaces. They form a vast network in intercellular spaces of most of the tissues of the body (Fig. 11.2).

Structure and mechanism of lymph circulation AN 6.2

The walls of the lymph capillaries like those of blood capillaries are made up of a single layer of endothelial cells but they are permeable to tissue fluid containing large molecules such as proteins, bacteria, particulate matter and colloidal material.

This fluid from the lymph capillaries is then transported back into the bloodstream via lymph vessels. While passing through lymph vessels it is filtered by lymph nodes to remove bacteria, particulate matter etc. Lymph nodes are placed in groups in the passageways of lymph vessels. Note lymph only moves in one direction i.e. towards the heart.

N.B.

- Lymph capillaries are most numerous in the *skin, glands and mucous and*

serous membranes.

- Lymph capillaries within the villi of the small intestine are called *lacteals*. They absorb fat and transport it to the blood.

The lymph capillaries differ from blood capillaries in the following respects:

1. Begin blindly in intercellular spaces.
2. Have a bigger lumen which is less regular.
3. Are permeable to bigger molecules, hence absorbing tissue fluid-containing particulate matter and colloid material.

N.B.

The sites where lymph capillaries are absent are:

1. Epidermis
2. Hair
3. Nails
4. Cornea
5. Articular cartilage
6. Brain and spinal cord
7. Bone marrow
8. Splenic pulp.

Lymph vessels

The lymph capillaries unite to form lymphatic vessels. They are thin-walled vessels, 0.5–1.0 mm in diameter, and have a beaded appearance due to the presence of numerous valves within their lumen. The flow of lymph in lymphatic vessels is unidirectional towards the large veins at the root of the neck due to the presence of these valves. The lymphatic vessels pass through a series of lymph nodes before the lymph is drained into the venous system (Fig. 11.3). The lymph nodes filter the lymph to make it free from pathogens and harmful agents.

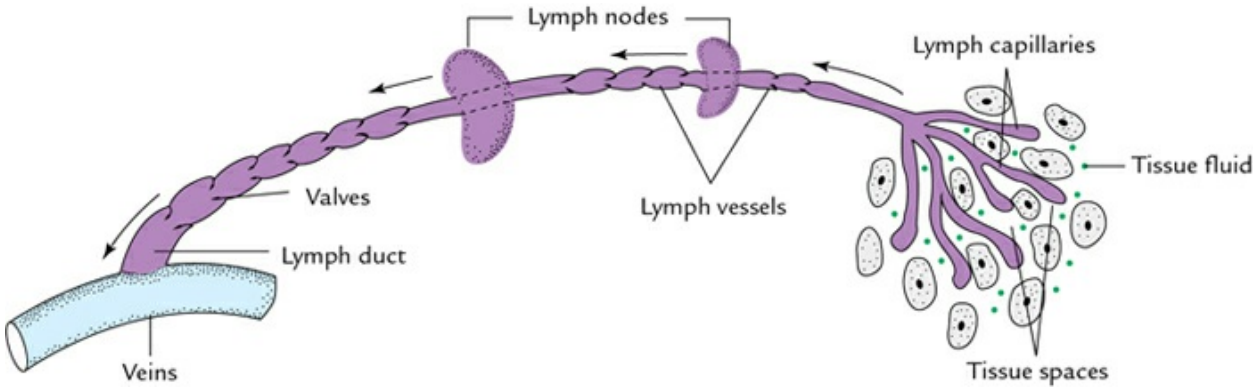


FIG. 11.3 ■ Schematic diagram showing the origin of lymph vessels from lymph capillaries present in the tissue spaces and drain into lymph nodes. The lymph trunk opens into the vein. Note the beaded appearance of lymph vessels due to the presence of valves in their lumen.

In fact, once the vessels are formed, they converge on a lymph node. The lymph passes through this lymph node and leaves it through another lymph vessel which enters another lymph node. The lymph leaves this node through yet another vessel. This process is repeated. The smaller lymph vessels merge to form progressively larger lymph vessels called **lymph ducts** which empty into subclavian veins.

Clinical Correlation

- **Lymphangitis:** Sometimes lymph vessels become inflamed leading to lymphangitis. This often results in visible red streaks in the skin extending from the site of infection to the group of lymph nodes where the lymph vessels drain, e.g. in infection of red streaks on the hand may be seen spreading from the hand to the axilla.
- **Elephantiasis:** If lymph vessels draining the lower limb are blocked by long slender worms of filaria, the accumulation of fluid in the interstitial spaces and lymph vessels may cause permanent swelling and enlargement of the lower limb resembling an elephant's leg producing a clinical condition called '*elephantiasis*'.

There are two principal lymph ducts in the body:

1. Thoracic duct
2. Right lymphatic duct.

Thoracic duct

The **thoracic duct** is the largest lymphatic duct (about 45 cm long) in the body. This begins as the large sac-like dilated lymph channel called **cysterna chyli** lying in front of the bodies of L1 and L2 vertebrae and ends in the angle between the left internal jugular vein and left subclavian vein (Fig. 11.4).

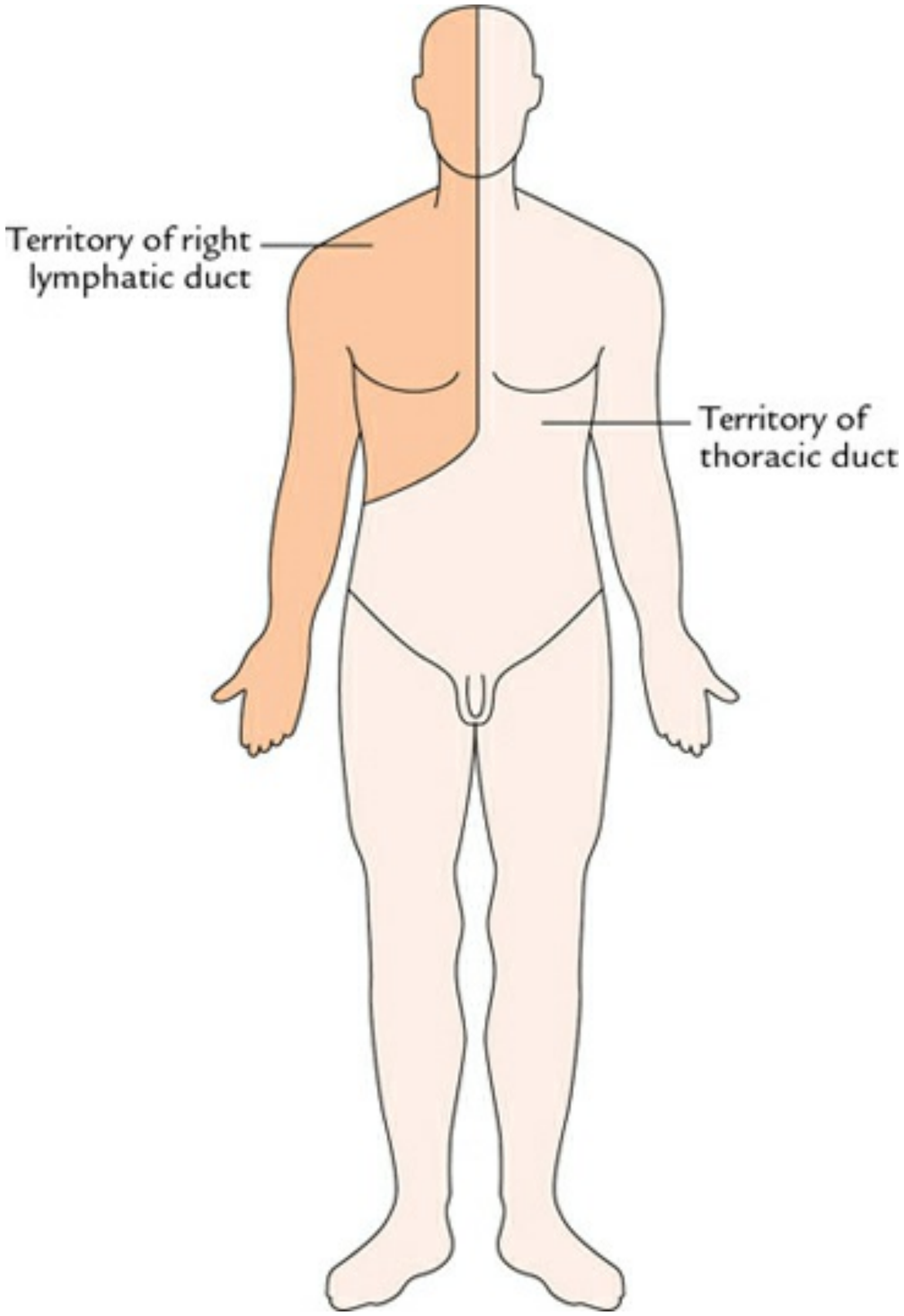


FIG. 11.4 ■ Lymphatic drainage of the body: upper right quadrant of the body drains into the right lymphatic duct. The remaining body drains into the thoracic duct.

It drains lymph from the whole of the body *except* the right upper quadrant (Fig. 11.4) from which the lymph is drained by the right lymphatic duct.

The thoracic duct drains the lymph from:

1. Lower extremities

2. Abdomen
3. Left thoracic region
4. Left upper limb
5. Left side of head and neck.

Right lymphatic duct

The right lymphatic duct is a dilated lymph vessel about 1 cm long. It lies in the root of the neck on the right side and is formed by the union of three vessels: right jugular trunk, right subclavian trunk and right broncho-mediastinal trunk. It ends by opening at the angle between the internal jugular vein and the right subclavian vein.

The right lymphatic duct drains the lymph from:

1. Right upper limb
2. Right thoracic region
3. Right side of head and neck.

Structure of a lymphatic duct: Like the wall of veins, the wall of lymphatic ducts has the same three layers, i.e. tunica adventitia, tunica media and tunica intima.

The lumen of lymphatic ducts contains valves that are more numerous and closely packed than veins. The lumen of the vessel proximal to the valve is expanded into a sinus. The valves are so closely placed that lymph vessel when filled with lymph has a **beaded appearance** (Fig. 11.3).

Superficial and deep lymph vessels

According to the location, the lymph vessels are divided into two types:

1. **Superficial lymph vessels**, which are found in the superficial fascia deep into the skin. They join deep lymph vessels.
2. **Deep lymph vessels**, which are found deep in the deep fascia and accompany the blood vessels.

N.B.

- Lymph vessels are supplied by vasa vasorum and are accompanied by a plexus of fine blood vessels.
- Lymph vessels have a great power of regeneration after their damage.
- The valves in lymph vessels permit the flow of lymph only in one direction, i.e. from the periphery to the centre and prevent the backflow.

Drainage of lymph

The factors responsible for the drainage of lymph through the lymph vessels and lymphatic ducts are as follows:

1. Contraction of smooth muscle in the wall of the lymph vessel.
2. Pulsation of arteries lying near the lymph vessels.
3. Massaging action from contraction of surrounding muscles.
4. Filtration pressure in tissue spaces generated by filtration of fluid from blood capillaries.
5. Respiratory movements.
6. Negative pressure in brachiocephalic veins.
7. Valves within the lumen of the lymph vessels.

N.B.

There is no *pump,* like the heart, involved in the onward movement of lymph but the muscle tissue in the walls of large lymph vessels has an intrinsic ability to contract rhythmically the so-called '*lymphatic pump*'.

Lymphoid organs

The lymphoid organs are made up of lymphatic tissues. The lymphatic tissue is a specialized connective tissue and consists of:

(a) the framework of reticular fibres and reticular cells;
(b) lymphocytes (mainly) and related plasma cells and macrophages.

A circumscribed concentration of lymphatic tissue is called **lymph**

nodules, which are found both in scattered lymphatic tissue and encapsulated lymphoid organs.

The lymphatic nodules may show a lightly stained area in its centre called the **germinal centre**, which contains large euchromatic lymphoblasts and plasmablasts that produce lymphocytes and plasma cells. In the lymph nodule, the germinal centre develops only when the nodule is exposed to the antigen. The germinal centres are absent in embryonic life and in old age. The germinal centre is surrounded by a darkly stained zone of densely packed small lymphocytes.

The lymphoid organs are classified into the following two types:

1. **Primary lymphoid organs**, which are involved in the production of lymphocytes, namely, *bone marrow* and *thymus*.
2. **Secondary lymphoid organs**, which are involved in the activation of lymphocytes and initiation of an immune response, namely, *lymph nodes*, and spleen.

N.B.

- Lymphocytes are capable of identifying foreign antigens at the molecular level and responding to them immunologically.
- Macrophages phagocytose foreign agents such as bacteria, viruses and cancer cells.

Lymph nodes

The lymph nodes are oval or bean-shaped bodies, 0.1–2.5 cm long that lie along the course of lymph vessels. The lymph passes through a number of lymph nodes, usually 8–10 before reaching the large lymphatic ducts. The size of lymph nodes varies from a pinhead to a large bean and is somewhat flattened. The lymph nodes are pink in the living body and brownish in cadaver (embalmed dead bodies).

N.B.

The lymph nodes draining the lymph from the lungs are black due to the

retention of inhaled carbon particles, whereas those draining the small intestine are creamy-white due to the retention of emulsified fat.

The lymph nodes tend to occur in clusters/groups in specific regions of the body (Fig. 11.4). Some of the body's principal groups of lymph nodes are:

1. Cervical lymph nodes in the neck.
2. Axillary nodes in the upper limb.
3. Mediastinal lymph nodes in the thorax.
4. Aortic and mesenteric lymph nodes in the abdomen.
5. Iliac nodes in the pelvis.
6. Popliteal and inguinal nodes in the lower limb.

The superficial lymph nodes are arranged along the veins and deep lymph nodes along the arteries.

The superficial lymph nodes are present in the superficial fascia, deep to the skin, whereas deep lymph nodes are located deep in the deep fascia. The superficial lymph nodes drain into deep lymph nodes.

N.B.

There are about 450 lymph nodes in the body of a young individual; out of which, 60–70 are found in the region of the head and neck, 100 in the thorax, and 250 in the abdomen and pelvis.

Structure of lymph nodes (Fig. 11.5)

The lymph nodes are oval or reniform and slightly flattened. They present a slight depression on one side called the **hilum**. Many afferent lymph vessels enter the gland at the periphery and a single efferent lymphatic vessel leaves the gland through the hilum. The artery enters and the vein leaves the gland at the hilum. Each lymph node consists of a **fibrous capsule** and **gland substance** (parenchyma).

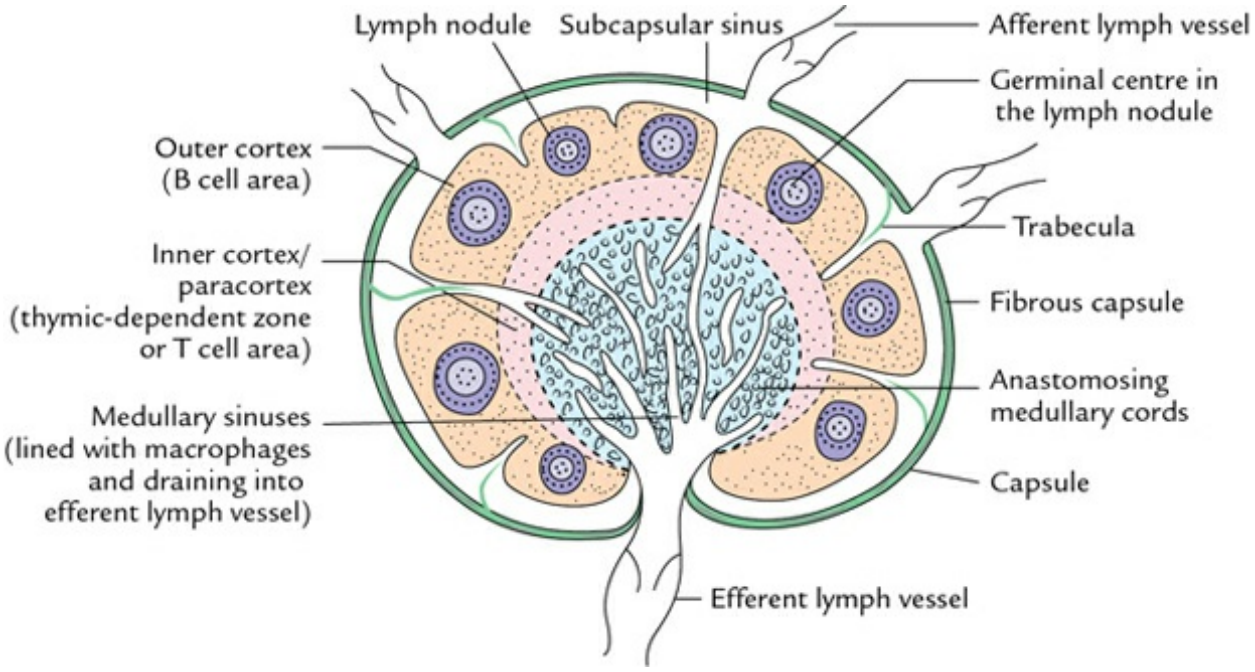


FIG. 11.5 ■ Structure of a lymph node.

Capsule

The fibrous capsule invests the entire node and is separated from the gland substance by a subcapsular space called the **subcapsular sinus**.

A number of trabeculae extended from the capsule at variable distances into the substance of the gland. The trabeculae are accompanied by paratrabecular spaces which are continuous with the subcapsular sinus.

The afferent lymph vessels pierce the capsule and drain into the subcapsular sinus. From the subcapsular sinus, the lymph drains via a series of interconnected channels, the cortical and medullary sinuses, into the hilum of the node from which arises a single efferent lymph vessel.

Gland substance (parenchyma)

The gland substance is divided into two portions:

1. An outer portion called the **cortex**
2. An inner portion called the **medulla**.

Cortex

The outer portion of the cortex, the **superficial cortex**, contains B lymphocytes which form a variable number of densely packed **lymphoid**

follicles/nodules. Many of these nodules show less dense central regions called **germinal centres**. The lymphoid follicles without germinal centres are called **primary lymph nodules** and those with germinal centres are called **secondary lymph nodules**.

The germinal centres are the areas of rapid lymphocyte division and are occupied by lymphoblasts and plasmablasts. The peripheral portion of the nodule consists of small lymphocytes and plasma cells.

The inner portion of the cortex (**paracortex**) contains T lymphocytes (*thymic-dependent zone*). The T lymphocytes do not organize themselves to form lymphoid nodules.

Medulla

The medulla contains a network of anastomosing cords of cells called **medullary cords**. The cells within the medullary cords are **B lymphocytes, plasma cells,** and **macrophages**.

N.B.

Both cortex and medulla in addition to lymphocytes contain:

- *Reticular cells*, which along with reticular fibres form the framework of the lymph node.
- *Plasma cells*, B lymphocytes mature into plasma cells and are mainly located in the medullary cords.
- *Macrophages*, mainly present in the medulla but also common in germinal centres. These cells present the antigens to lymphocytes for an immunological response.
- The *parenchyma* of both cortex and medulla is traversed by blood vessels and lymph sinuses.

Circulation of lymph and blood in lymph nodes (Fig. 11.6)

Circulation of lymph

Afferent lymph vessels bring the lymph to the lymph node, where it flows through *subcapsular*, *cortical* and *medullary sinuses* and finally leaves the gland through efferent lymph vessels. The sinuses are lined with phagocytic

macrophages that remove bacteria and other foreign material from the lymph.

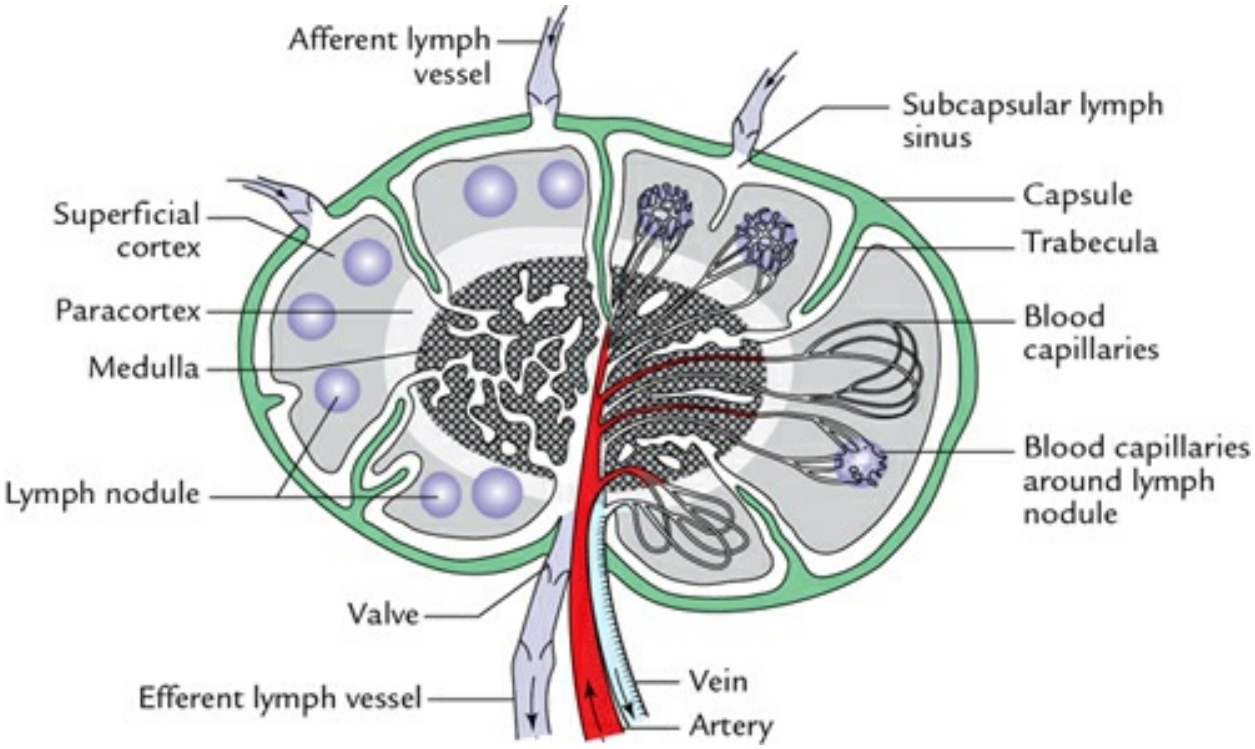


FIG. 11.6 ■ Schematic diagram of a lymph node showing blood and lymph circulation. Note that lymph enters through the convex side of the lymph node and leaves through the hilum, whereas blood enters and leaves the lymph node through the hilum.

N.B.

- Lymph nodes are the only structures that filter the lymph.
- Lymph nodes are the only lymphoid organs that have both afferent and efferent lymph vessels.

Flow of blood (Fig. 11.6)

The blood reaches the lymph node through arteries that enter through the hilum. These arteries branch in the medulla and form capillary plexuses within the cortex. The lymphocytes enter lymph nodes mainly via the arteries. They leave the blood by migrating across the walls of postcapillary

venules.

The arteries enter the lymph nodes through its hilum and give straight branches which traverse the medulla. In the cortex, arteries form dense arcades of arterioles and capillaries in numerous anastomosing loops eventually forming venules and veins. The capillaries are profuse around the lymph nodules. Postcapillary high endothelial venules are abundant in the paracortex and are the important sites of blood-borne lymphocyte extravasation into lymphoid tissue. The veins leave the lymph node through its hilum.

N.B.

Most of the lymphocytes enter the lymph node through blood while only a few enter through lymph of afferent lymph vessels.

Functions of lymph nodes

1. Filter the lymph (i.e. when lymph passes through the lymph node, foreign particles, and injurious substances, including pathogens are removed by phagocytic activities of macrophages of the lymph nodes).
2. Evoke immunological response. (The plasma cells of the lymph node produce antibodies in response to infection.)
3. Produce various types of lymphocytes. (The germinal centres of lymphatic nodules within the node are sites of lymphocyte production.)
4. Provide a portal of entry for lymphocytes into lymphatic channels.

Clinical Correlation

- **Germinal centres are absent in embryonic life and in old age:** In lymphoid nodules, germinal centre develops only after birth when it is exposed to antigens. The germinal centre regresses when infection subsides. The lymphoid nodules atrophy with increasing age and may be absent in old age.

They are circumscribed structures made up of compact lymphoid tissue. Its

lightly stained central portion is called the *germinal centre*. It is made up of lymphoblasts which give rise to lymphocytes. Its darkly stained peripheral portion contains lymphocytes.

- **Spread of cancer:** The lymph vessels are the most convenient routes of spread of the cancer cells, i.e. they are major routes by which carcinoma metastasizes. When cancer cells enter the lymph vessels, they are trapped in the lymph nodes. If cancer cells escape from the lymph nodes, they may pass through lymph vessels to the blood and eventually reach the other parts of the body. Therefore, during cancer surgery, malignant (cancerous) lymph nodes are often removed and their vessels are tied off and cut to prevent the spread of cancer. Therefore, surgeons must know the main routes of lymphatic drainage and the position of lymph nodes especially the superficial ones because they have a well-defined area of lymphatic drainage. **AN 6.3**
- **Lymphadenitis:** Acute lymphadenitis (acute infection of lymph nodes) is often caused by microbes transported in it, through lymph from the area of infection. The lymph nodes become inflamed and enlarged; and then can be palpated by the clinician. The commonly palpated lymph nodes are cervical, axillary and inguinal (Fig. 11.1). Figure 11.7 shows the method of palpating cervical, axillary and epitrochlear nodes.

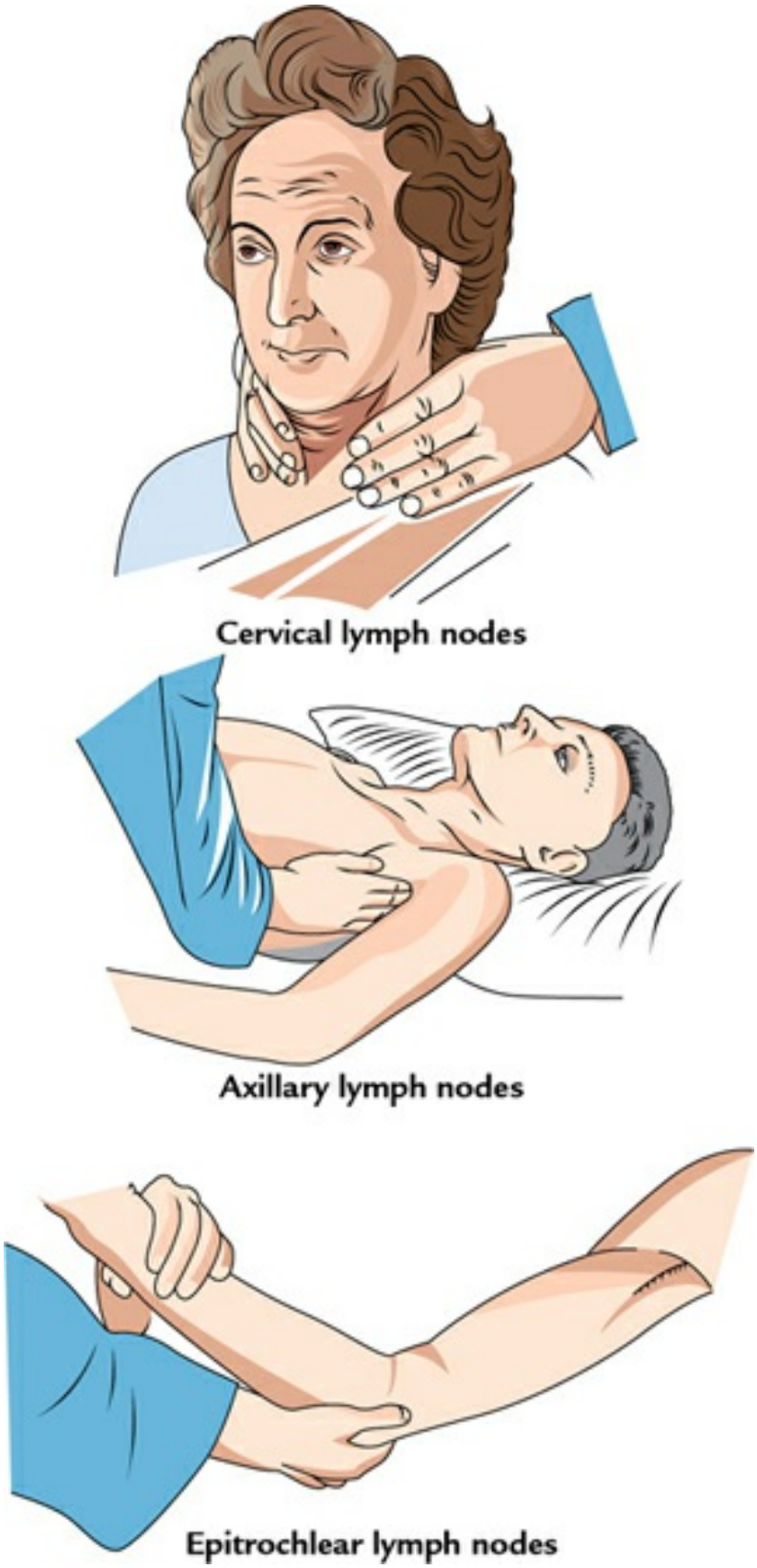


FIG. 11.7 ■ Palpation of lymph nodes.

Spleen

The spleen (Fig. 11.8) is the largest lymphoid organ in the body. It is located deep in the left hypochondrium of the abdominal cavity between the fundus of the stomach and the diaphragm. It is purplish and varies in size in different individuals. Usually, it is the size of a closed fist of that individual.

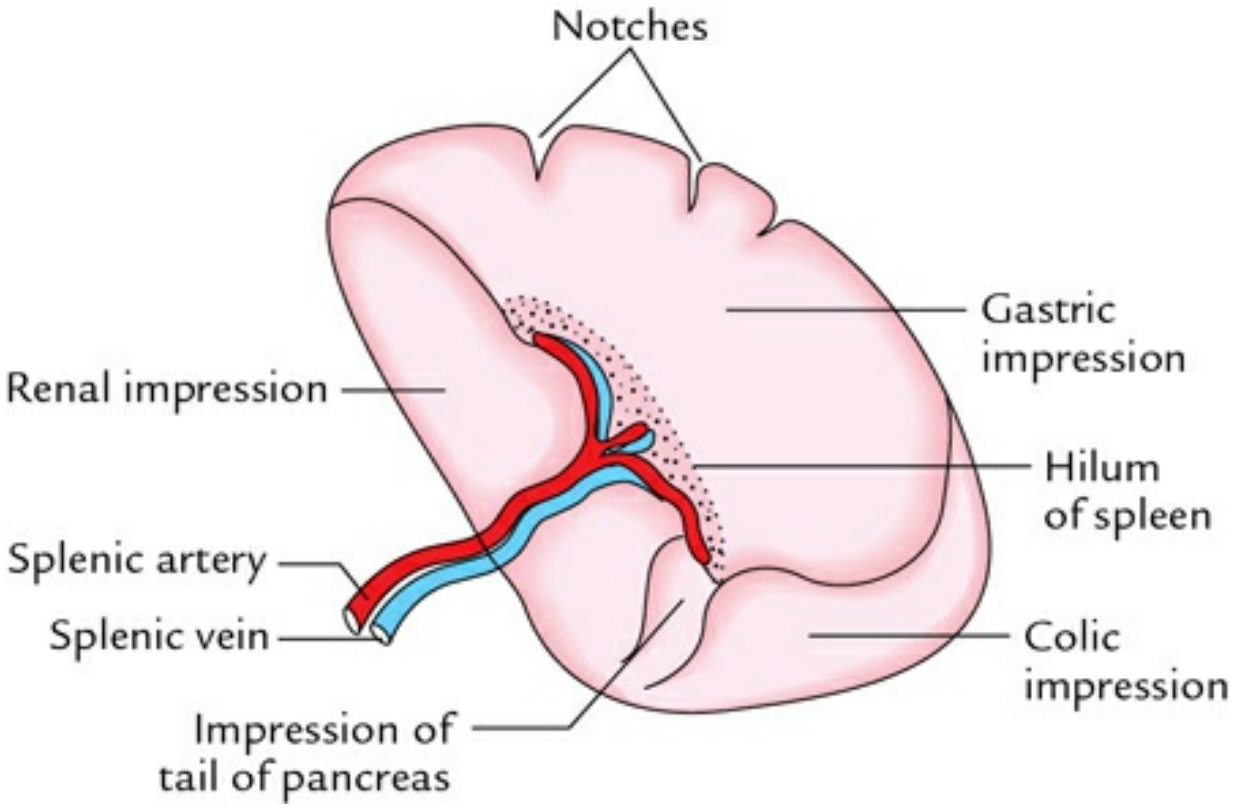


FIG. 11.8 ■ Spleen.

Structure (Fig. 11.9)

It consists of red and white pulp—the spleen thus representing the **haemolymph node** in the human body.

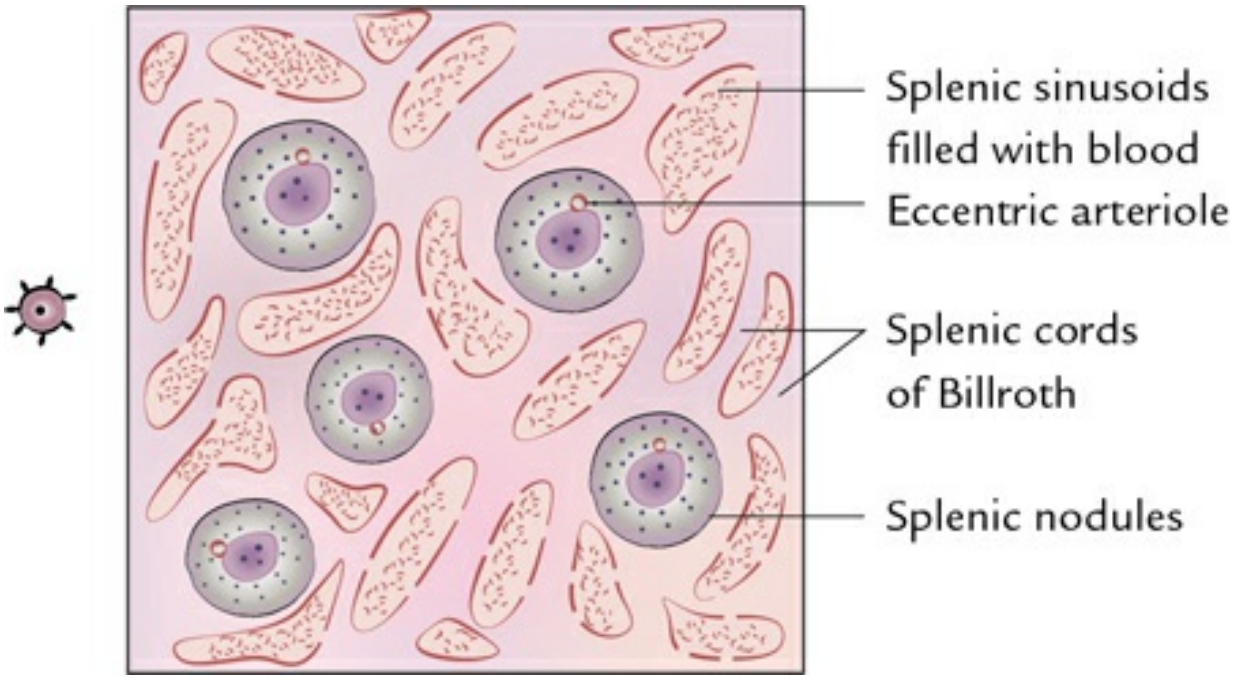


FIG. 11.9 ■ Structure of splenic parenchyma.

The **white pulp** is the **lymphatic tissue sheath** that surrounds the central artery. This periarterial lymphatic tissue sheath possesses nodules with or without centres. These nodules are called **splenic nodules** or **Malpighian corpuscles** (periarterial lymphoid sheath (PALS).

The **red pulp** consists of a network of anastomosing splenic cords (cords of Billroth). **The splenic cords are made up of lymphocytes (both B and T types), macrophages and plasma cells.** The spaces between the cords are occupied by blood sinusoids. The spleen is covered by a connective tissue capsule which sends trabeculae within the substance of the organ where they are repeatedly divided to form the network. The blood-borne antigens are removed from the spleen.

Red pulp consists of splenic sinusoids filled with blood and cords of Billroth made up of lymphocytes, plasma cells and macrophages

White pulp is made up of PALS/lymphatic nodules/splenic nodules/Malpighian carpuscles.

N.B.

Haemal nodes: These are found along the course of blood vessels in relation to thoracic and abdominal viscera. Their sinuses are filled with blood rather than lymph. The haemal nodes represent an intermediate stage between lymph node and spleen.

Functions

1. Filters the blood from antigens and microorganisms (the most important function).
2. Evokes immunological response against the antigens circulating in the blood.
3. Produces B and T lymphocytes.
4. Removes old and abnormal RBCs.
5. Removes bacteria by phagocytosis.
6. Stores blood.
7. Forms blood cells during foetal life.

Clinical Correlation

Splenomegaly: The enlargement of the spleen (splenomegaly) is usually secondary to other conditions, e.g. infections, circulatory disorders, blood diseases, malignant neoplasms:

(a) Spleen may be infected by blood-borne microbes, e.g. malaria or typhoid fever.

(b) Circulatory disorder like portal obstruction due to cirrhosis of the liver leads to congestion of blood in the spleen.

(c) In blood diseases such as chronic myeloid leukaemia, the spleen enlarges to the extra workload associated with removing abnormal blood cells.

(d) Malignant neoplasms, e.g. lymphomas may cause metastatic tumours in the spleen.

N.B.

The most common causes of enlargement of the spleen are portal hypertension, malaria, chronic myeloid leukaemia and typhoid fever.

Thymus

The thymus is an asymmetrical bilobed organ/gland located in the superior mediastinum of the thoracic cavity behind the manubrium of the sternum.

This extends upwards into the root of the neck (Fig. 11.10). The thymus is devoid of lymph capillaries and lymphoid nodules.

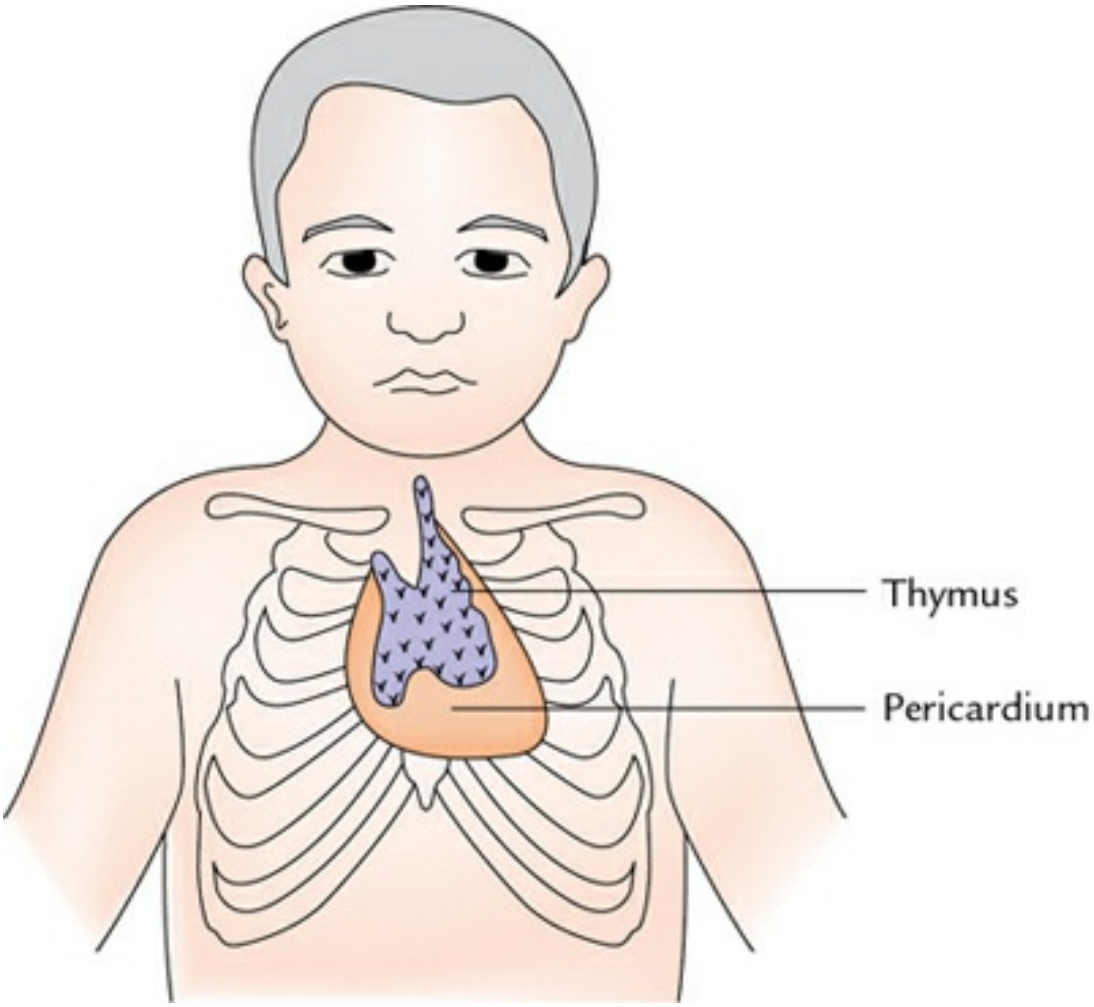


FIG. 11.10 ■ Location of the thymus.

The thymus is the central lymphoid organ and is essential for the development of other lymphoid organs. It is large and well developed in foetus and in early childhood. It attains its peak development at puberty and thereafter it starts involuting and is replaced by fibrofatty tissue. It weighs about 12–15 g at birth, 30–40 g at puberty and 10–15 g at 60 years.

Structure

The thymus consists of a supporting framework made by epithelial reticular cells and parenchymal cells, namely, lymphocytes and macrophages. Thus, the thymus contains the following three main types of cells:

1. Epitheliocytes (thymic epithelial cells)
2. Lymphocytes
3. Macrophages.

The thymus has a dual origin, its epitheliocytes (epithelial reticular cells) arise from the endoderm of the third pharyngeal pouch, whereas its lymphocytes and macrophages arise from the mesoderm. Each lobe of the thymus is divided into incomplete lobules. Each lobule has a darkly stained cortex at the periphery and a lightly stained medulla at the centre. The cortex is densely packed with lymphocytes (thymocytes). The outer part of the cortex contains immature large lymphocytes (lymphoblasts) that divide by mitosis to produce clones of small T lymphocytes, which are pushed into the deep part of the cortex. The epitheliocytes help in the maturation of T lymphocytes through the hormone (**thymosin**) secreted by them. Immunocompetent T-cells leave the thymus and through circulation reach the peripheral lymphoid tissue. The medulla mainly consists of epitheliocytes and a few lymphocytes. The most important feature of the medulla is the presence of **Hassall's corpuscles**. These are made up of concentrically arranged flattened cells which are the degenerating epitheliocytes. The centre of the corpuscle contains homogenous hyaline material produced by degenerating cells of the corpuscle.

N.B.

The reticulum of all the lymphoid organs is made of reticular cells and reticular fibres except the thymus where the reticulum is formed by epitheliocytes.

Functions

The thymus is the site of the production of T lymphocytes. It receives immunologically incompetent stem cells (lymphocytes) from bone marrow. In the thymus, these cells divide and mature into **T lymphocytes**—the specialized group of lymphocytes (thymus-dependent cells). These cells leave the thymus via blood to reach the lymph nodes, spleen and other lymphatic tissues. The T lymphocytes are important for cellular immunological responses (i.e. **cell-mediated immunity**).

The thymus secretes a hormone called **thymosin** which supports the activity of T lymphocytes throughout the body.

The production of T lymphocytes is most prolific in youth, an essential requisite to the development of the protective immune function. For this reason, the thymus weighs about 10–15 g at birth and about 20–30 g at puberty. Therefore, it regresses and is converted into fibrofatty tissue.

Clinical Correlation

Enlargement of thymus gland: It is associated with some autoimmune diseases e.g. thyrotoxicosis, Addison's disease and myasthenia gravis. Autoimmune conditions are those in which the immune system treats normal body cells or secretions as antigens and destroy them.

Epitheliolymphoid system

Mucosa-associated lymphoid tissue (MALT)

A large amount of unencapsulated lymphatic tissue exists in the walls (submucosa) of alimentary, respiratory and urinary tracts. It is collectively termed MALT. The MALT is generally subdivided into the following two types:

1. Gut-associated lymphoid tissue (GALT)
2. Bronchus-associated lymphoid tissue (BALT).

The important collections or aggregations of MALT are as follows:

1. Pharyngeal tonsil
2. Tubal tonsil
3. Palatine tonsil
4. Lingual tonsil
5. Peyer's patches
6. Abdominal tonsil.

Pharyngeal tonsil

It is the aggregation of lymphoid tissue underneath the mucous lining of the

roof and posterior wall of the pharynx. When enlarged due to infection, it is termed an **adenoid** which obstructs nasal respiration and makes breathing through the mouth obligatory.

Tubal tonsil

It is the aggregation of lymphoid tissue around the upper and posterior margin of the opening of the pharyngo-tympanic tube in the nasopharynx underneath the mucous lining.

Palatine tonsil

It is a large aggregation of lymphoid tissue, one on each side, in the lateral wall of the oropharynx in the triangular fossa called the **tonsillar fossa** underneath the mucous lining. They are commonly infected in children causing **tonsillitis**.

Lingual tonsil

The dorsal surface of the posterior one-third of the tongue (pharyngeal part) contains numerous lymphoid follicles underneath the mucosa, which together form the lingual tonsil.

Peyer's patches

These are aggregated lymphoid follicles, varying from 2–10 cm in length, underneath the mucous membrane of the small intestine, being the largest and most numerous in the ilium and placed lengthwise along the antimesenteric border. The Peyer's patches are ulcerated in typhoid fever forming ulcers (typhoid ulcers) having a long axis perpendicular to the long axis of the bowel.

Abdominal tonsil

There is a huge amount of lymphoid tissue underneath the mucous membrane of the appendix in the form of rounded aggregations of lymphoid follicles which form a ring and together constitute the abdominal tonsil.

Reticuloendothelial system

The cells of this system are concerned with phagocytosis. They pick up,

ingest and store foreign substances. Thus, the cells of this system are important for general and local defence mechanisms.

Different types of cells in the reticulo endothelial system are enumerated in Table 11.1.

 **TABLE 11.1**

Different types of cells in the reticuloendothelial system and their sites of location

Cells	Sites of location
Macrophages	Connective tissue, bone marrow, suprarenal gland
Pericytes (Rouget cells)	Capillaries
Monocytes	Blood
Dust cells (alveolar macrophages)	Lungs
Reticular cells	Spleen and lymphoid tissue
Kupffer cells	Liver
Microglia	Central nervous system

Lymphocytes and immunity

Immunity is the defence mechanism of the body, i.e. the ability of the body to resist damage from foreign substances such as microorganisms and harmful toxins (antigens) released by them. The defence mechanism of the body includes **phagocytosis**, which is a non-specific engulfing process and **immune response**, which is a specific reaction to microorganisms and antigens. The cell type involved in the immune response is lymphocyte.

The lymphocytes are smaller than monocytes and have large nuclei. They are of two types:

B-lymphocytes and T-lymphocyes.

The lymphocytes circulate in the blood and are present in large numbers in lymphatic organs and tissues. They develop from pluripotent stem cells in

the red bone marrow and then travel in the blood to lymphoid tissues elsewhere in the body where they are activated, i.e. becoming immunocompetent which means they are able to respond to antigens (foreign material, e.g. bacteria, viruses, etc.)

Although all lymphocytes arise from common stem cells in bone marrow, when they are activated in lymphoid tissue, two distinct types of lymphocytes are produced, namely, T lymphocytes and B lymphocytes. The T lymphocytes are so named because they mature and are processed in the thymus. The B lymphocytes acquire their name from the bursa of Fabricius (cloacal diverticulum) in birds, for it was in chickens that the bursa of Fabricius was first found to be the source of humoral antibodies.

The T lymphocytes are processed in the thymus and provide **cell-mediated immunity**, whereas the B lymphocytes are processed in the bone marrow and provide **antibody-mediated (humoral) immunity**.

Antibody-mediated (humoral) immunity (Fig. 11.11)

The B lymphocytes, unlike T lymphocytes which are free to circulate in the body, are fixed with lymphoid tissue. When B lymphocytes come in contact with an antigen, they enlarge and begin to divide (Fig. 11.11). It produces two functionally distinct types of cells—plasma cells and memory B lymphocytes. The plasma cells produce and release antibodies (i.e. immunoglobulins: IgG, IgA, IgM, IgE and IgD) that bind to the antigen and destroy it. The memory B lymphocytes are long-lived and provide immunity to the body against antigens. **The B-cells, therefore provide 'antibody-mediated (humoral) immunity'**.

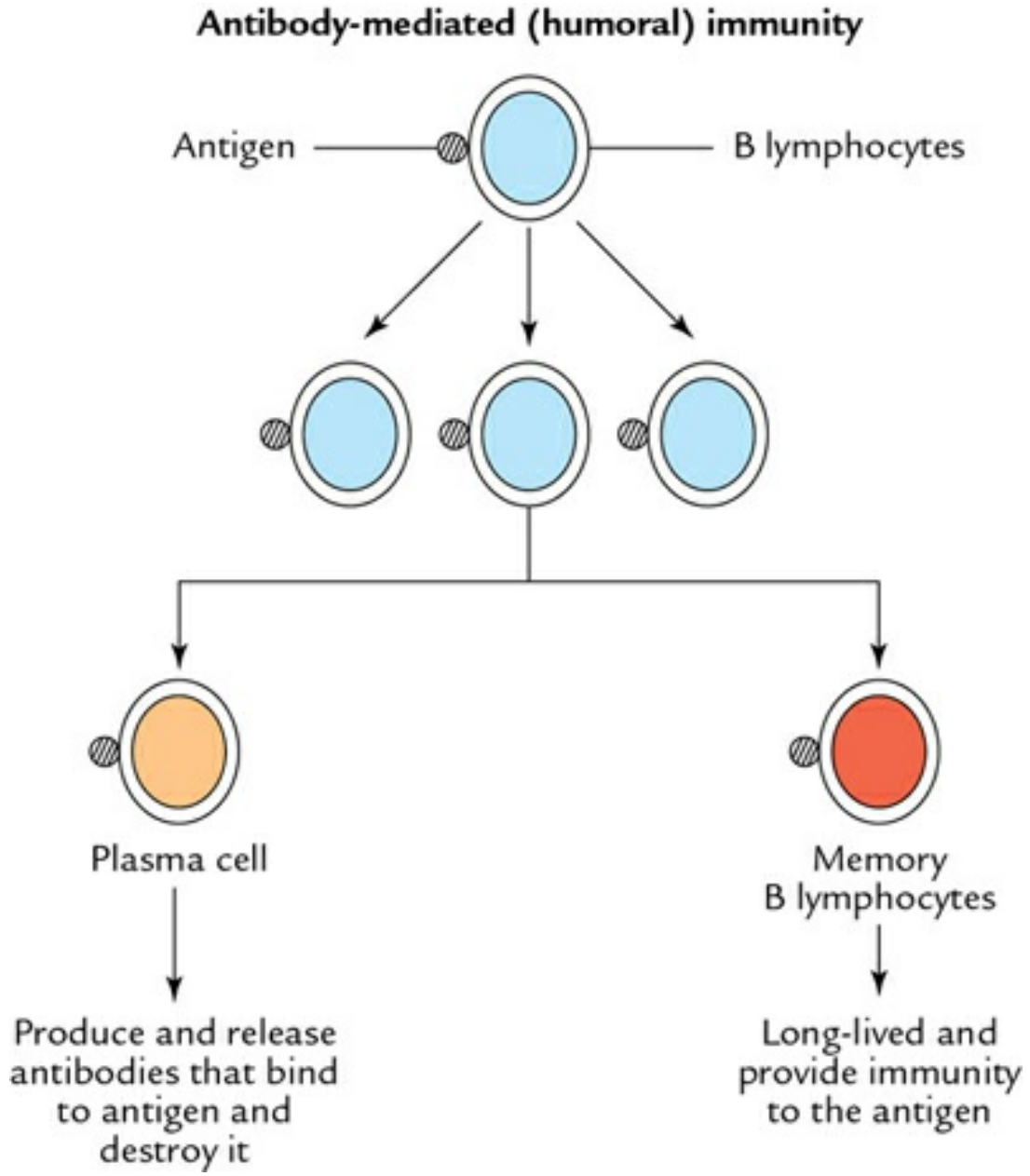


FIG. 11.11 ■ Proliferation of B lymphocytes in antibody-mediated (humoral) immunity.

Cell-mediated immunity (Fig. 11.12)

When antigen comes in contact with T lymphocytes, it stimulates the division and proliferation of the T lymphocytes, leading to the production of three main types of specialized T lymphocytes:

1. Cytotoxic T lymphocytes

2. Helper T lymphocytes
3. Memory T lymphocytes.

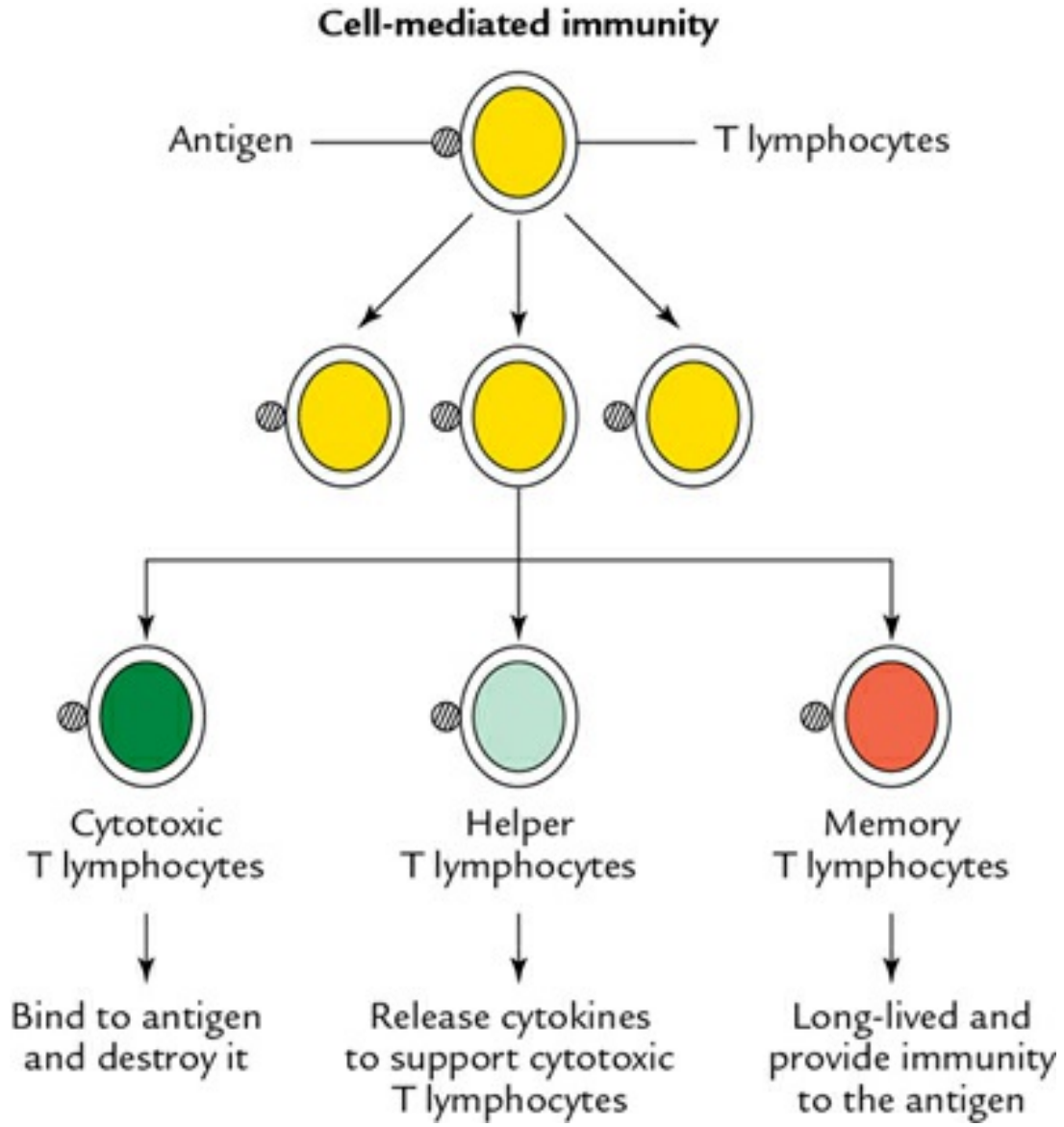


FIG. 11.12 ■ Proliferation of T lymphocytes in cell-mediated immunity.

All these cells tackle the same antigen in different ways (Fig. 11.11), e.g. the cytotoxic T lymphocytes bind to the antigen and destroy it. The helper T lymphocytes release cytokines to support cytotoxic T lymphocytes. The memory T lymphocytes are long-lived and provide immunity to the antigen. The **T-cells, therefore, provide 'cell-mediated immunity'**.

N.B.

One of the primary causes of acquired immunodeficiency syndrome (AIDS)

is the killing of helper T lymphocytes by the human immunodeficiency virus.

Differences between blood vascular and lymphatic systems AN 5.1

The blood vascular system delivers oxygen and nutrients to virtually all the cells, tissues and organs of the body. While the lymphatic system drains 15%–202% of interstitial fluid made up of macromolecules (viz. large protein molecules, fat and fat-soluble substances) which cannot be drained by the venous system. In addition, the lymphatic system provides immunity to the body.

Bone marrow

The bone marrow is soft pulpy vascular tissue. It consists of a delicate network of reticular tissue stroma and clustres of haemopoietic cells. For details see Chapter 6, page 73.

Golden Facts to Remember

• **Total number of lymph nodes in the body**	About 450
• **Body region having highest number of lymph nodes in the body**	Abdomen and pelvis
• **Largest lymphoid organ in the body**	Spleen
• **Only lymphoid organ in the body which has both afferent and efferent lymph vessels**	Lymph node
• **All lymphoid organs in the body possess lymphatic nodules/follicles** ***except***	Thymus
• **In all lymphoid organs of the body, supporting framework is made up of reticular cells and reticular fibres** ***except*** **in**	Thymus where it is made up of epitheliocytes (also called epithelioreticular cells)

• **Only lymphoid organ in the body which is fully developed at birth**	Thymus
• **Largest lymphatic channel in the body**	Thoracic duct
• **Most common route for spread of cancer (metastasis)**	Lymph vessels
• **All lymphocytes arise from common stem cells in bone marrow *except***	During embryonic life when they arise from yolk sac, liver, and spleen
• **Most abundant cell types present in the lymphoid organs**	Lymphocytes
• **Largest lymphatic sac in the body**	Cisterna chyli
• **Most abundant immunoglobulin (antibody) in the body**	IgG

Multiple choice questions

1. **All are true statements, regarding the lymphatic system *except***:
   (a) Return all the tissue fluid to the venous system
   (b) Lymph is filtered by lymph nodes
   (c) Spleen and thymus are lymphoid organs
   (d) Lymph capillaries begin blindly in intercellular spaces
2. **Thoracic duct drains lymph from all of the following regions *except***:
   (a) Right lower limb
   (b) Right side of the head and neck
   (c) Left lower limb
   (d) Left side of the head and neck
3. **All the lymphoid organs have lymphoid nodules *except***:
   (a) Spleen
   (b) Lymph node
   (c) Thymus
   (d) Palatine tonsil
4. **Lymphoid organ having both afferent and efferent lymph vessels is:**
   (a) Spleen
   (b) Thymus

(c) Lymph node
(d) Tonsil

5. **All are true regarding thymus *except that it***:
   (a) Is located in the superior mediastinum
   (b) Secretes a hormone called '*thymosin*'
   (c) Filters blood to remove blood-borne antigens
   (d) Receives immunologically incompetent cells from bone marrow
6. **All of the following factors help in lymphatic drainage *except***:
   (a) Respiratory movements
   (b) Filtration pressure in tissue spaces
   (c) Positive pressure in brachiocephalic veins
   (d) Presence of valves within the lumen of lymph vessels
7. **All of the following sites are devoid of lymph capillaries *except***:
   (a) Epidermis
   (b) Dermis
   (c) Hair
   (d) Nails
8. **Lymph vessels are present in all *except:***
   (a) Brain
   (b) Liver
   (c) Lungs
   (d) Vagina
9. **Which of the following is primary lymphoid tissue?**
   (a) Lymph node
   (b) Spleen
   (c) Thymus
   (d) Palatine tonsil
10. **Epithelial reticulum is a feature of:**
    (a) Spleen
    (b) Lymph node
    (c) Thymus
    (d) All of the above

Answers

1. *a*, 2. *b*, 3. *c*, 4. *c*, 5. *c*, 6. *c*, 7. *b*, 8. *a*, 9. *c*, 10. *c*.

Chapter 12: Nervous system

Specific learning objectives

After studying this chapter, the student should be able to:

- Describe the general plan of the nervous system with components of central, peripheral and autonomic nervous systems. **AN 7.1**
- List the components of nervous tissue and their functions. **AN 7.2**
- Outline the main morphological types of neurons and describe the structure of a typical neuron.
- Describe various types of neuroglia and discuss their functions.
- Describe parts of a neuron and classify them based on number of neurites, size and function. **AN 7.3**
- Describe the various types of synapses. **AN 7.7**
- Classify the nerves and discuss the reflex action.
- Describe the structure of a typical spinal nerve and give a brief account of a ‘dermatome’. **AN 7.4**
- Discuss two divisions of the autonomic nervous system and compare and contrast the effects of sympathetic and parasympathetic stimulation.
- Describe differences between sympathetic and spinal ganglia. **AN 7.8**
- Give the anatomical basis of referred pain.
- Enumerate the neurotransmitters liberated by pre-and postganglionic fibres of the parasympathetic and sympathetic nervous system.

• Correctly solve the Multiple Choice questions given at the end of the chapter.

The nervous system integrates and controls the activities of all other systems of the body; hence, it is also termed the '**master system'** of the body. The functions of the nervous system include:

1. Reception of stimuli from within and outside the body.
2. Integration of sensory information.
3. Initiation and execution of motor responses.
4. Assimilation of experience, an essential requisite to memory, learning and intelligence.

Due to these functions, an individual is able to maintain the internal environment of the body and react to the changes in the external environment.

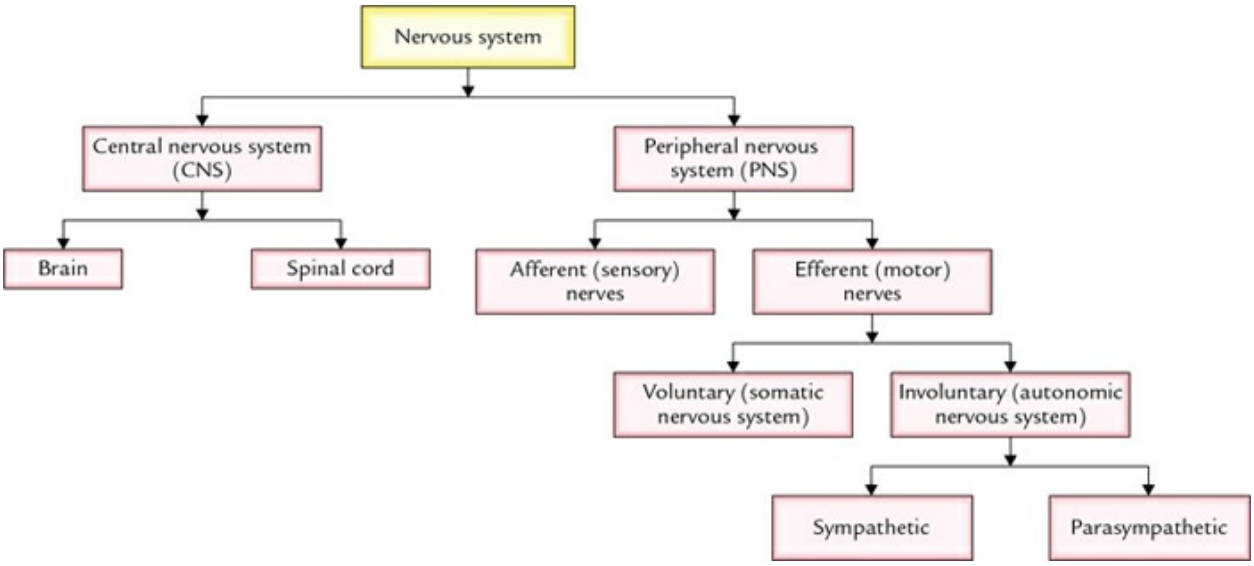
All activities of the nervous system whether simple or complex involve three neural factors or elements: (a) reception, (b) integration and (c) response.

In human beings, the integrative element shows the maximum degree of development and they are the most intelligent animals in the animal kingdom.

General plan and subdivisions of the nervous system AN 7.1

The human nervous system consists of two main parts: the central nervous system and the peripheral nervous system.

The subdivisions of the nervous system are shown in Flowchart 12.1. The details are as under:



FLOWCHART 12.1 ■ Subdivisions of the nervous system.

Anatomical subdivisions (Fig. 12.1)

1. **Central nervous system (CNS):** It includes the brain and spinal cord.
2. **Peripheral nervous system (PNS):** It includes all neural structures outside the CNS, namely
   (a) Peripheral nerves
      - 12 pairs of cranial nerves
      - 31 pairs of spinal nerves

   (b) Ganglia (autonomic and sensory)
   (c) Autonomic nervous system (ANS) (sympathetic and parasympathetic nervous systems).

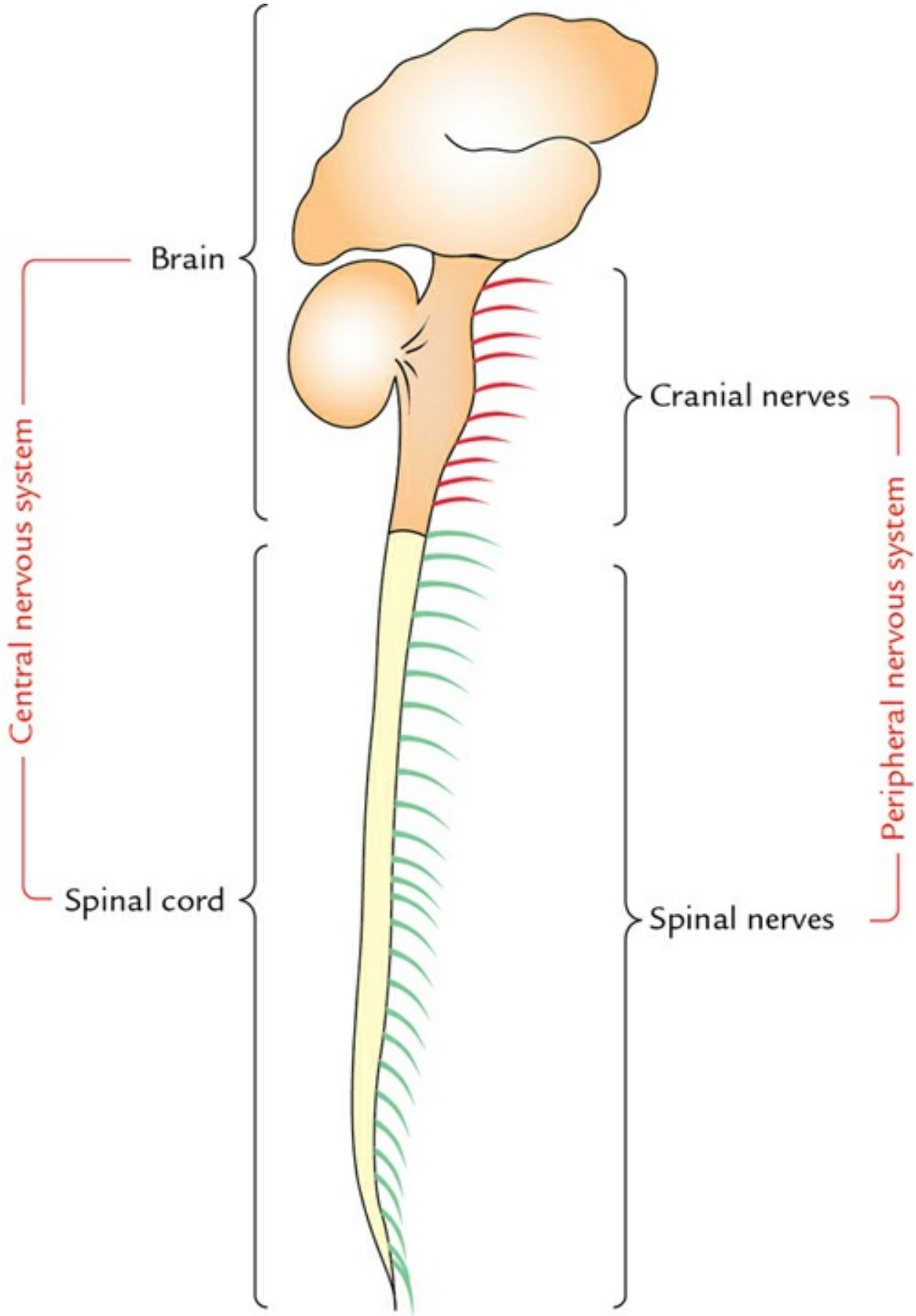


FIG. 12.1 ■ Anatomical subdivision of the nervous system.

Functional subdivisions (Fig. 12.2)

1. **Afferent (sensory) division:** It brings information to the CNS.
2. **Efferent (motor) division:** It gives an appropriate motor command to muscles and glands. The efferent division is further subdivided into components:
   (a) *Somatic nervous system:* It innervates somatic structures such as skeletal muscles and is responsible for voluntary motor activities.
   (b) *ANS:* It innervates visceral structures such as cardiac muscle, smooth muscle and glands. The activities of viscera are mostly involuntary, i.e. not under voluntary control. The ANS is further divided into **sympathetic** and **parasympathetic** nervous systems.

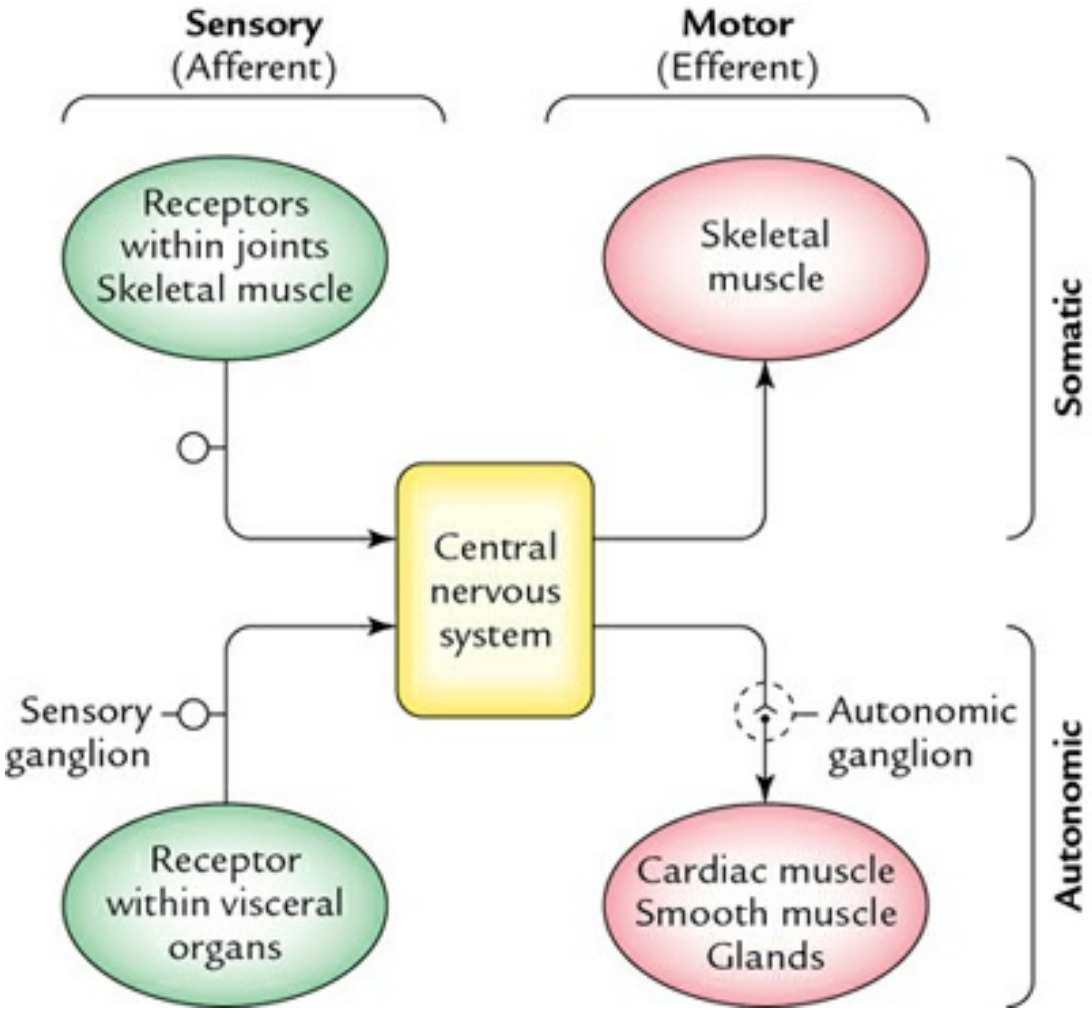


FIG. 12.2 ■ Functional subdivisions of the nervous system.

Structural organization/components of the nervous system AN 7.2

The structural organization of the nervous system is very simple as it consists of only two principal types of cells: (a) **neurons** and (b) **neuroglia**.

The neurons are the structural and functional units of the nervous system, whereas neuroglia provides structural and functional support to the neurons.

The neurons generate and conduct impulses from one place to another in the body. They also receive signals from other neurons carrying information from different tissues and organs of the body.

The **neuroglia** provides structural and functional support to the neurons, i.e. they assist in the propagation of nerve impulse and also provides nutrients to neurons.

Neurons AN 7.3

The neurons are the *structural and functional units* of the nervous system. The number of neurons in the nervous system is estimated to be in the range of 100 billion. The two main properties of neurons are excitability and conductivity. The neurons are specialized for reception, integration, transformation, and transmission of impulses. The neurons are highly differentiated cells and have lost their power of division.

Structure of a neuron

A neuron consists of a cell body (perikaryon or soma) and processes (Fig. 12.3).

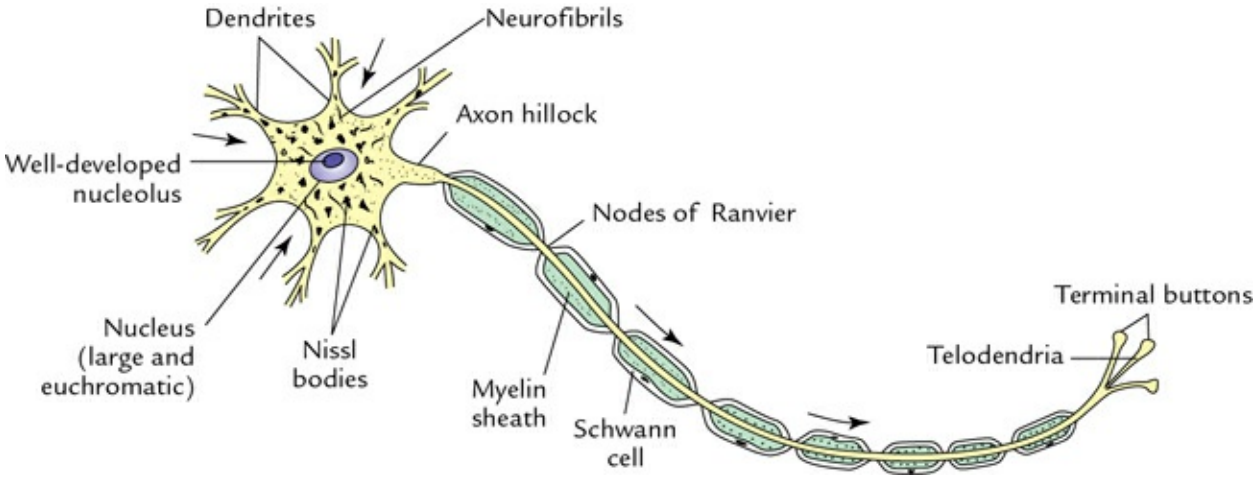


FIG. 12.3 ■ A typical peripheral neuron.

Cell body

The cell body consists of a mass of cytoplasm surrounded by a plasma membrane. It contains a large vesicular nucleus with a prominent nucleolus.

The two main characteristic features of the cytoplasm of the neuron are:

1. Presence of a basophilic **Nissl substance** (Nissl bodies)
2. Neurofibrils.

The *Nissl substance* is composed of large aggregations of rough endoplasmic reticulum, which contain ribonucleic acid concerned with protein synthesis, namely neurotransmitters. The *neurofibrils* are filamentous strands of proteins.

N.B.

There are no centrioles and centrosomes in the nerve cell body, which indicates that the highly specialized nerve cell has lost its power of division. Consequently, once the nerve cell is destroyed it is replaced by neuroglia.

Process

The processes are of two types:

1. Numerous short processes called **dendrites** (*dendron* = tree).
2. A single long process called the **axon**.

The dendrites bring impulses towards the cell body, hence they often branch profusely to increase the reception area of the neuron.

The axon is a single long process. It does not branch except at its termination to form **telodendria** which possess terminal **boutons** (*presynaptic knobs*).

Classification of neurons AN7.3

According to polarity (Fig. 12.4)

1. **Pseudo-unipolar neurons:** They appear to have only one process which soon divides into a central branch that functions as an axon and a peripheral branch that serves as a dendrite. Most sensory neurons of the nervous system are pseudo-unipolar type.

N.B.

Pseudo-unipolar neurons are so called because originally, two processes emerge at the same pole. But during the course of development, two processes fuse to form a single process that bifurcates at a little distance from the cell body.

Sites of location:
(a) Posterior (dorsal) root ganglia of spinal nerves
(b) Sensory ganglia of cranial nerves

2. **Bipolar neurons:** They have two processes one on each pole, one process acts as the dendrite and the other process acts as an axon.
Sites of location:
(a) Retina of the eye
(b) Olfactory epithelium
(c) Vestibulocochlear ganglia
3. **Multipolar neurons:** They have several dendrites and only one axon extends from the cell body. They are the most common type of neurons in the nervous system.
Sites of location:
(a) Motor neurons forming tracts of the brain and spinal cord.
(b) Motor neurons of anterior horn cells forming peripheral nerves.

(c) Motor neurons of autonomic ganglia.

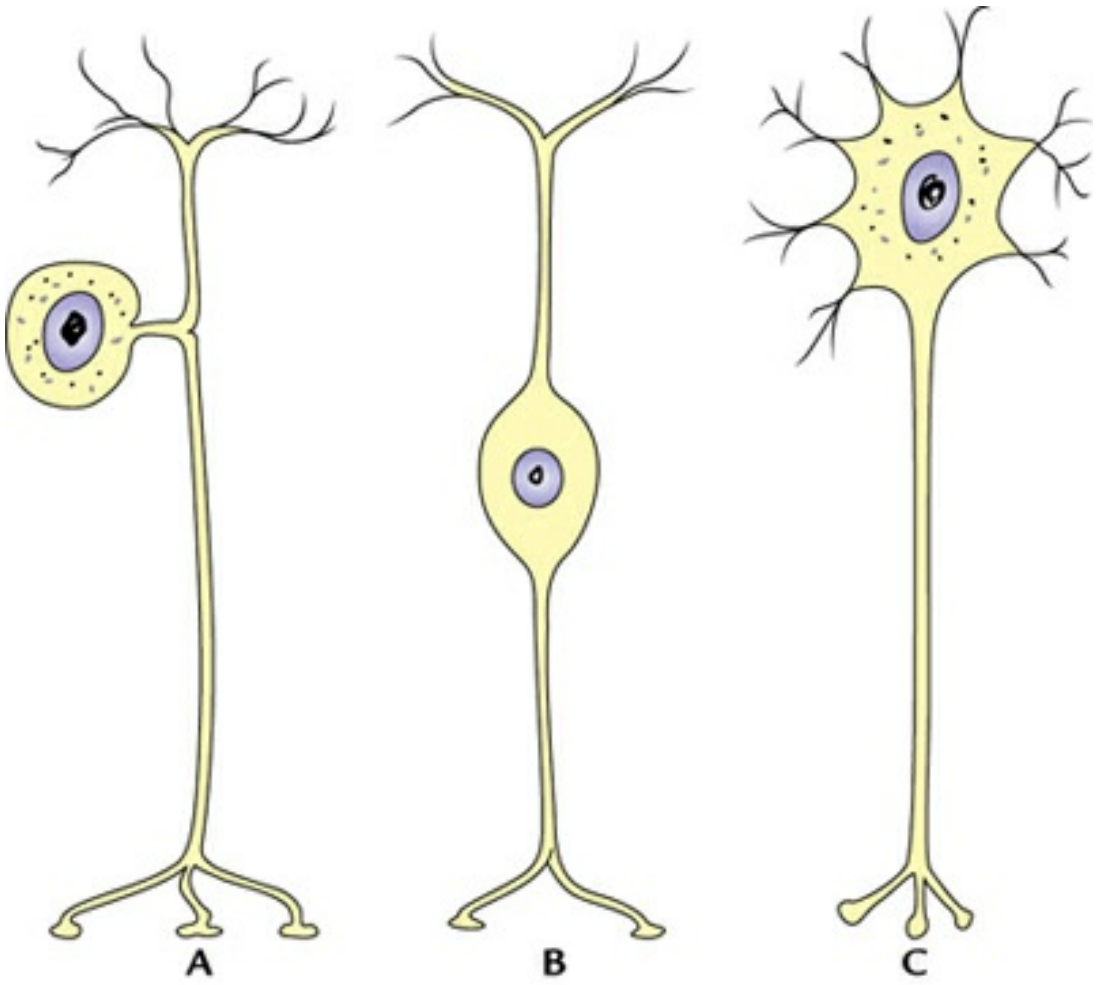


FIG. 12.4 ■ Three main types of neurons, based on their morphology (i.e., polarity): **(A)**, pseudo-unipolar; **(B)** bipolar and **(C)** multipolar.

According to relative length of axons and dendrites

1. **Golgi type I neurons:** These neurons have long axons which may be up to 1 m long, e.g. *pyramidal cells* of the cerebral cortex, *anterior horn cells* of the spinal cord and *Purkinje cells* of the cerebellum.
2. **Golgi type II neurons (microneurons):** The axons of these neurons are short and morphologically similar to dendrites, giving these neurons a star-shaped appearance.

According to shape of the cell body

1. **Pyramidal cells:** The cell body is cone/pyramidal-shaped and dendrites

arise from the angles of the cone, e.g. pyramidal cells of the motor cortex of the cerebral hemisphere.
2. **Fusiform cells:** The cell body is spindle-shaped and processes emerge at both ends, e.g. fusiform cells of the motor cortex of the cerebral hemisphere.
3. **Pyriform cells**: The cell body is flask-shaped. A thick dendrite arises from the upper end and divides repeatedly, whereas the axon arises from the base, e.g. Purkinje cells of the cerebellum.

Other types

1. **Stellate cells:** Dendrites extend in all directions from the cell body, e.g. stellate cells of the cerebellar cortex and sympathetic ganglia.
2. **Glomerular cells:** Dendrites at their tip are highly coiled, granule cells of the cerebellar cortex.
3. **Amacrine cells:** They lack an obvious axon and a single process permits conduction in either direction, e.g. amacrine cells of the retina of the eye.

Ganglia

These are collections of cell bodies of neurons outside the CNS. They can be classified into two types:

1. **Cerebrospinal ganglia:** They are connected with sensory afferent nerve fibres of the cranial and spinal nerves, hence they are called **sensory ganglia**.
2. **Autonomic ganglia:** They are connected with autonomic outflow and consist of cell bodies of multipolar motor neurons, hence they are called **motor ganglia**. They are relay stations of preganglionic sympathetic and parasympathetic fibres.

The sympathetic ganglia lie away from the viscera they supply, whereas parasympathetic ganglia lie near the viscera they supply.

The differences between sympathetic and spinal ganglia are given in Table 12.1.


TABLE 12.1

Differences between sympathetic and spinal ganglia

Sympathetic ganglia	Spinal ganglia
• Located close to and on either side of the vertebral column in long chains	• Located on the posterior root of spinal nerves as nodules and lie along the side of the vertebral column
• Contain neuronal cell bodies which receive preganglionic fibres from spinal cord and give postganglionic fibres to the effector organ	• Contain cell bodies of sensory neurons
• Deliver information to the body about stress and impending danger for **fight or flight response**	• Carry signals from sensory organs towards the CNS (appropriate integration centre)

Neuroglia

They provide structural and functional support to the axons. The neuroglia plays no important role in the propagation of impulses or processing of perceived information (Fig. 12.5).

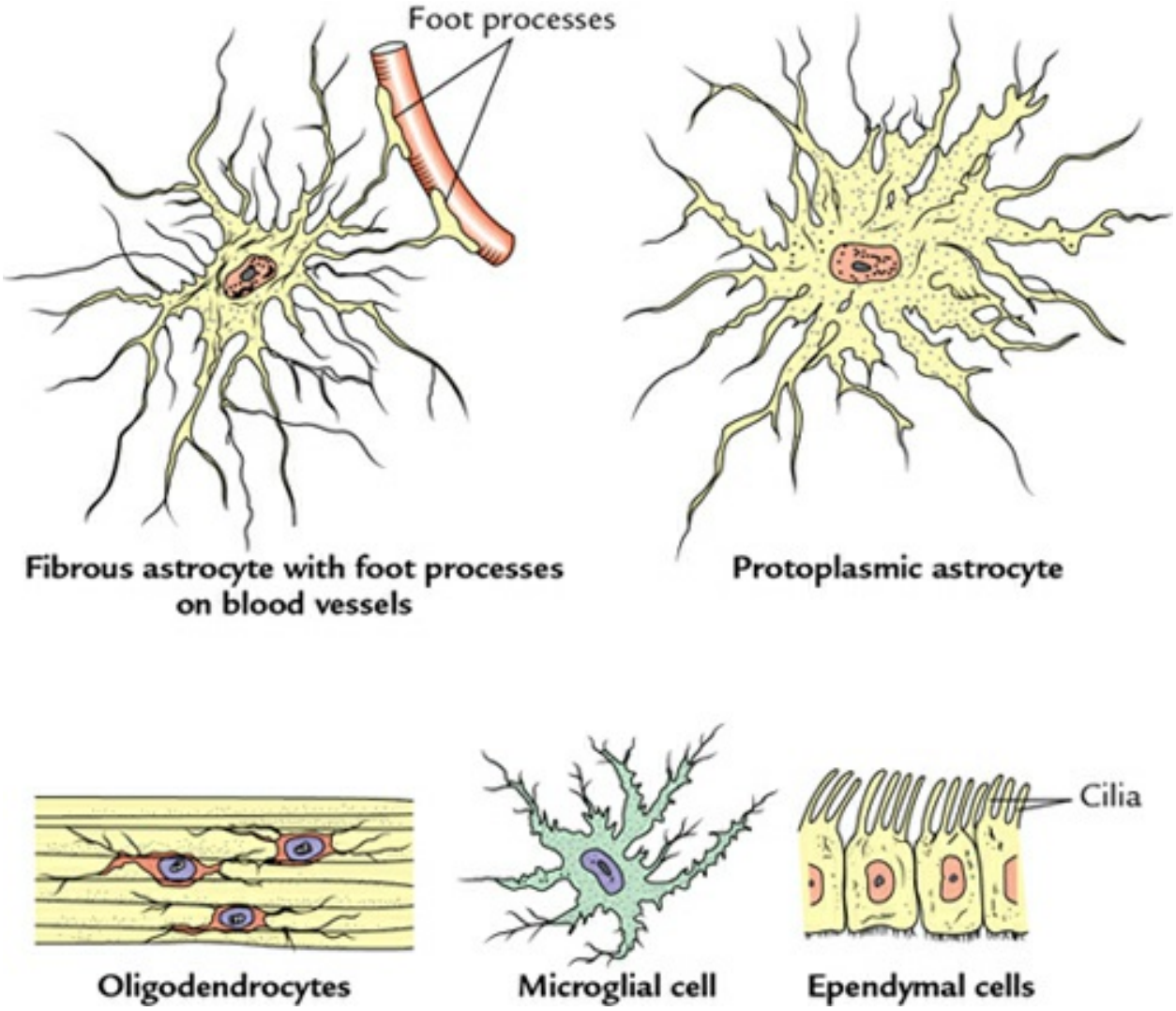


FIG. 12.5 ■ Different types of neuroglia.

The neuroglia is far more numerous (about 5–10 times more) than neurons and accounts for more than half of the brain's weight.

Structure of neuroglia

Neuroglia is highly branched cells and occupies the spaces between the neurons to provide a microenvironment suitable for neuronal activity (Remember that nervous tissue has no intercellular matrix.)

Classification of neuroglia

According to their location, origin and function

Neuroglia in CNS

1. **Astrocytes:** These are the largest and most numerous. The astrocytes are star-shaped with many dendrite-like processes whose ends possess small swellings called **foot processes**. The foot processes form a sleeve around the capillaries. The sleeve along with an endothelial wall of the capillary forms the **blood-brain barrier**. The astrocytes are of two types: (a) protoplasmic found in grey matter and (b) fibrous found in white matter.
2. **Oligodendrocytes:** These are smaller than astrocytes and as the name implies, have fewer processes. Oligodendrocytes form the myelin sheath around the fibres of the CNS.
3. **Ependymal cells:** These cells line the ventricles of the brain and the central canal of the spinal cord.
4. **Microglia:** These are the smallest glial cells. These are phagocytic cells derived from mesoderm.

Clinical Correlation

Gliosis: The microglia migrate to areas damaged by infection, trauma or stroke and perform phagocytosis. The damaged neurons are replaced by the proliferation of astrocytes, a process called '*gliosis*'.

Glioblastoma multiforme: It is the most fatal brain tumour with a life expectancy of 2–3 months only. It arises from astrocytes.

Neuroglia in PNS

1. **Satellite (capsular) cells:** These cells surround the cell bodies of autonomic and sensory ganglia to which they provide support and nutrition.
2. **Schwann cells or neurolemmocytes:** These cells form the myelin sheath around the nerve fibres of the PNS.

According to their structure

1. **Macroglia:** They include astrocytes, oligodendrocytes and ependymal cells.

2. **Microglia: (**already described.)

N.B.

- Schwann cells form neurolemma (Schwann sheath) around all nerve fibres of PNS whether they are myelinated or non-myelinated. The Schwann cells play an important role in the regeneration of the peripheral nerve fibre.
- **All the neuroglia develop from the neural crest except microglia** which develops from mesoderm (bone marrow).

Functions of neuroglia

The functions performed by neuroglial cells are as follows:

1. Provide structural and functional support to neurons.
2. Help to form the blood-brain barrier.
3. Phagocytose foreign substances.
4. Produce cerebrospinal fluid (CSF).
5. Form myelin sheaths around axons.

Terms commonly used for describing nervous system

These are:

- **Nerve fibre:** Axon
- **Nerve:** Bundle of nerve fibres outside the CNS
- **Tract:** Bundle of nerve fibres inside the CNS
- **Ganglion:** Collection of nerve cell bodies outside the CNS
- **Nucleus:** Collection of nerve cell bodies inside the CNS
- **Nerve plexus:** Network of intercalated nerves
- **Grey matter:** Mainly consists of nerve cell bodies and dendrites
- **White matter:** Mainly consists of nerve fibres

Nerve fibres

The axon of a nerve cell is called **nerve fibre**. The bundles of nerve fibres within the CNS are called tracts, whereas the bundles of nerve fibres in the PNS are called **peripheral nerves** or simply **nerves**.

The following two types of nerve fibres are found in the nervous system:

1. Myelinated nerve fibres
2. Non-myelinated nerve fibres

Myelination of nerve fibres

The fibres of the CNS are myelinated by oligodendrocytes while those of PNS by Schwann cells.

Myelination of peripheral nerve fibre

The myelination of a peripheral nerve fibre occurs in the following way:

- The Schwann cells are arranged in a sequence along the nerve fibre which invaginates them in forming **mesaxons**.
- Then, each Schwann cell rotates many times around the nerve fibre; as a result, the mesaxon becomes wrapped repeatedly around the axon and cytoplasm is extruded in the Schwann cell body (Fig. 12.6).
- Thus **myelin sheath** *consists of many layers of the plasma membrane of Schwann cell*, which is made up of white lipid protein and provides a whitish appearance to the fibre. The outer surface of the myelin sheath is encased in a glycoprotein forming a **neurilemmal sheath**.
- Each Schwann cell myelinates only 1 mm of the axon, thus leaving gaps in the myelin sheath where the axon is exposed to the exterior. These gaps are called the **nodes of Ranvier**.

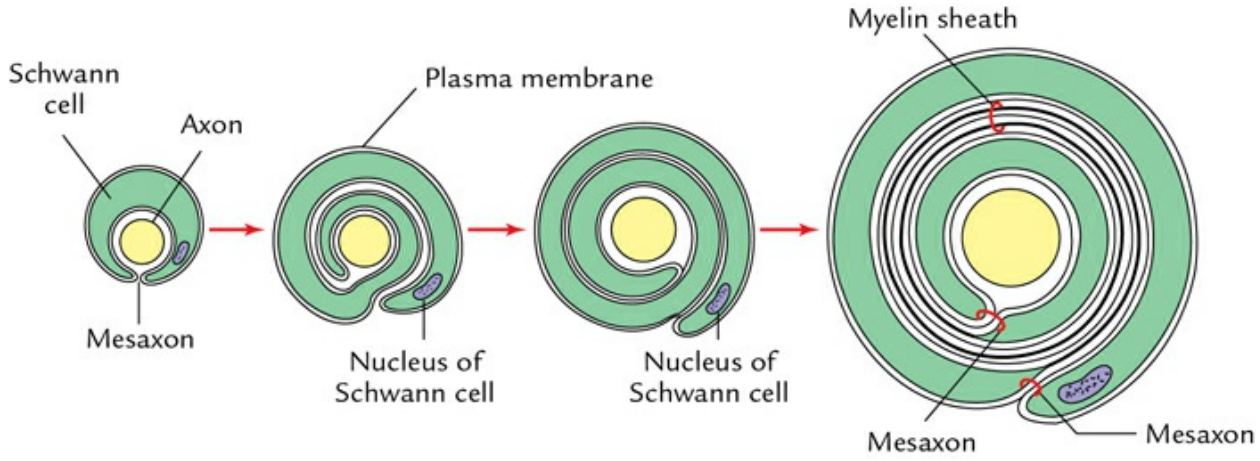


FIG. 12.6 ■ Stages in the formation of the myelin sheath around peripheral nerve fibre.

Myelination of CNS fibres

The CNS fibres are myelinated by oligodendrocytes. Unlike the Schwann cells which form a myelin sheath around only one axon, each oligodendrocyte has extensions that form a myelin sheath around several axons.

The examples of myelinated fibres are:

1. Nerve fibres of the somatic nervous system more than 1 μm in diameter.
2. All preganglionic fibres of ANS.

The **non-myelinated fibres** are also surrounded by the Schwann cells. Several axons (15 or more) become longitudinally invaginated into the cytoplasm of the Schwann cell and are sealed by a plasma membrane (Fig. 12.7).

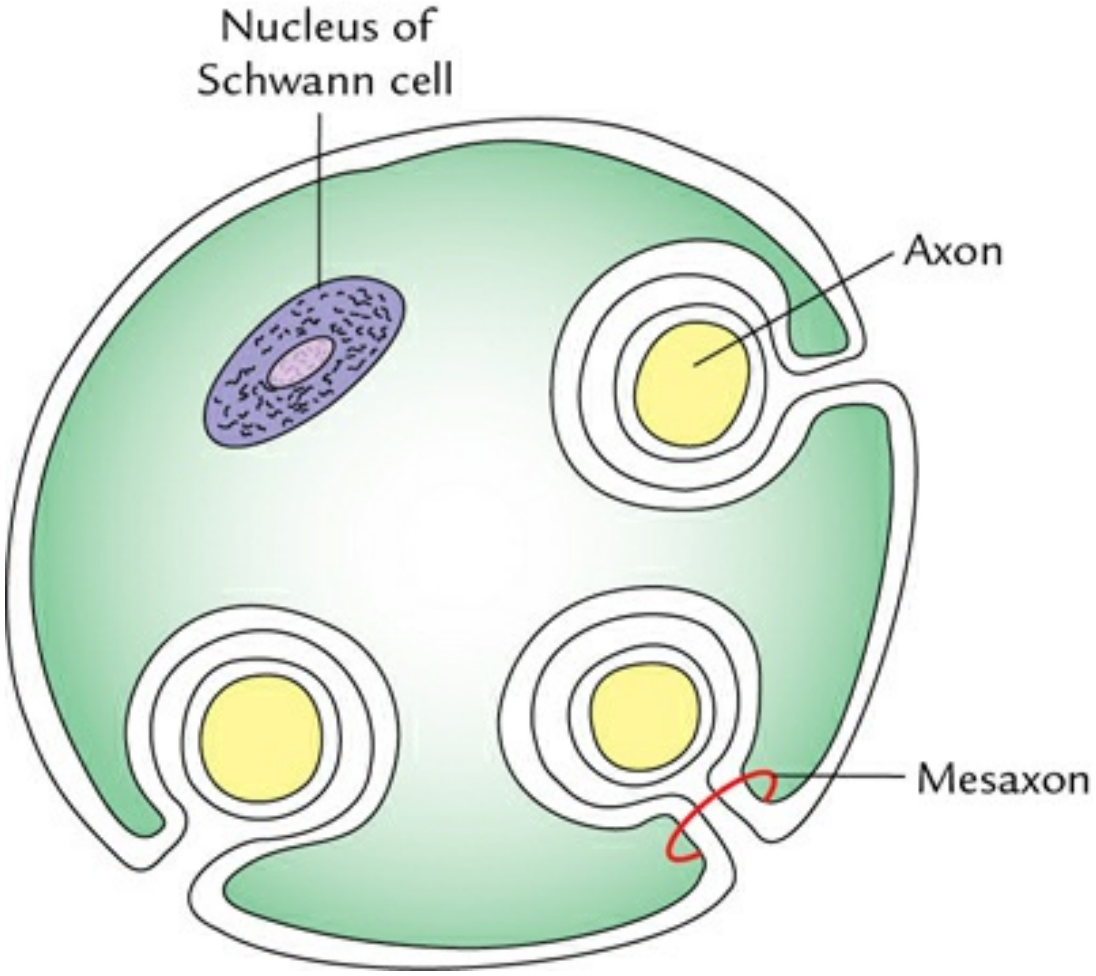


FIG. 12.7 ■ Relationship of several non-myelinated axons to a Schwann cell.

Non-myelinated nerve fibres

The examples of non-myelinated nerve fibres are:

1. Nerve fibres of the somatic nervous system less than 1 μm in diameter.
2. All postganglionic fibres of ANS.

Conduction of action potential along an axon

When the nerve is stimulated, the plasma membrane becomes depolarized and an **action potential** (tiny electrical charge) is generated. This action potential then spreads along the plasma membrane (Fig. 12.8).

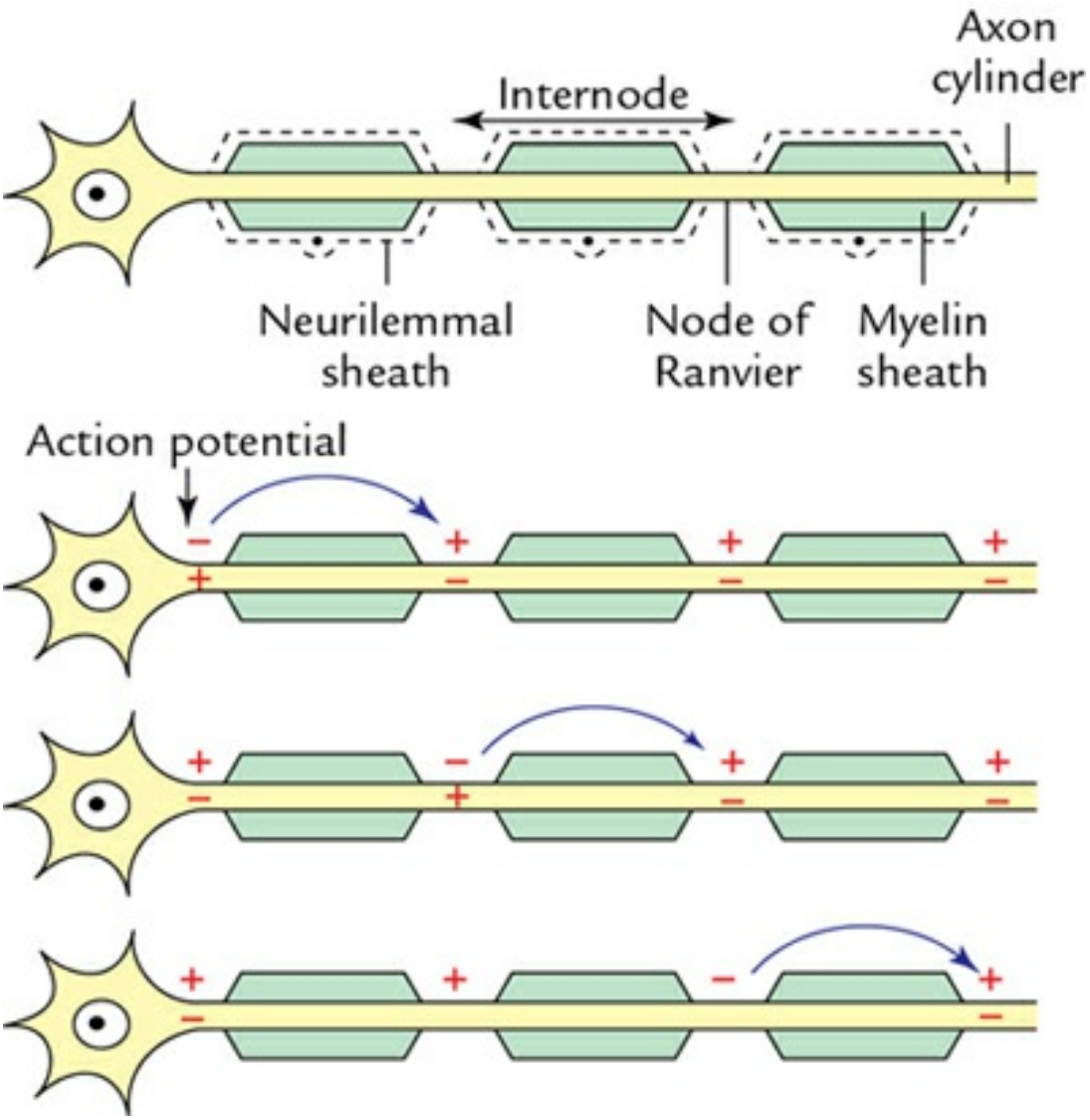


FIG. 12.8 ■ Conduction of action potential along an axon.

The speed of conduction of action potential is faster along the myelinated nerve fibres as it jumps from one node to the other and is called **saltatory conduction** (*saltase* = to leap/jump). The speed of conduction is slower in non-myelinated fibres, as advancement of the action potential is consistent and at a moderate pace. Thus the conduction of action potential in myelinated fibres is like a **grasshopper jumping,** whereas in non-myelinated fibres it is like a **grasshopper walking**.

Transmission of impulses

In the nervous system, the information passes from one place to the other in

the form of an **action potential or nerve impulse**. The nerve impulse is akin to a tiny electrical charge generated due to exchange of sodium (Na^+) and potassium (K^+) ions across the plasma membrane following a stimulus.

The nerve impulse travels progressively along a nerve fibre and then passes on to another neuron across the *synapse*.

Synapse AN 7.7

The junction at which the nerve impulse passes from one neuron to another is called **synapse**. The synapse is the contact between two neurons by contiguity and not by continuity.

Types of synapses

Anatomically, depending upon the parts of two neurons coming in contact and the direction of transmission of a nerve impulse, synapses are classified into the following types:

1. Axodendritic (commonest)
2. Axosomatic
3. Dendrosomatic
4. Dendroaxonic
5. Dendrodendritic
6. Axoaxonic.

Structure of a synapse

It consists of a synaptic knob of the presynaptic neuron and a plasma membrane of the postsynaptic neuron. The presynaptic knob contains synaptic vesicles filled with neurotransmitters (Fig. 12.9A).

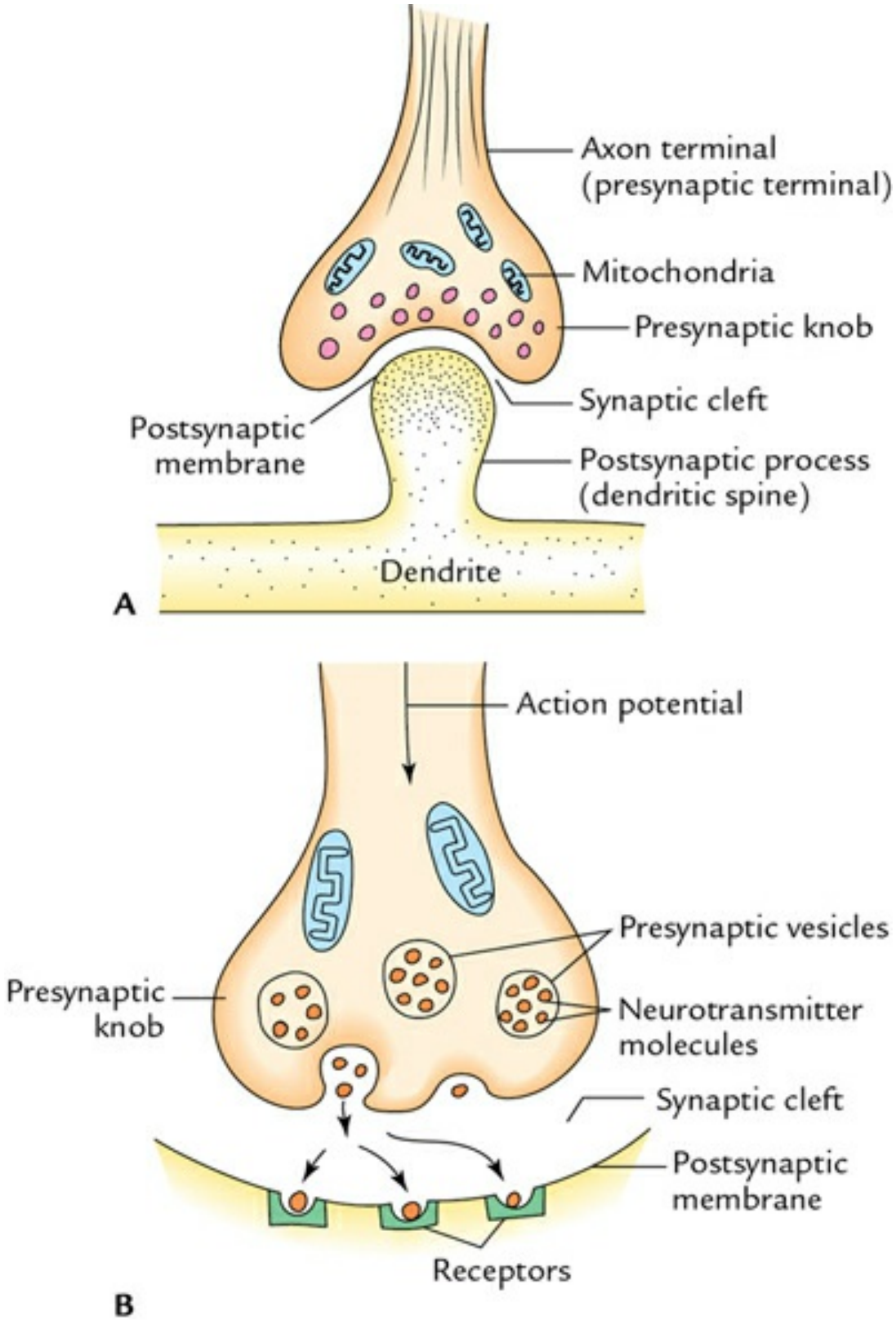


FIG. 12.9 ■ Transmission of nerve impulse: **(A)** structure of synapse (axodendritic); **(B)** mechanism of transmission of a nerve impulse at synapse.

The plasma membranes of two neurons opposed to each other at the synapse are called **presynaptic and postsynaptic membranes**. A small gap

between these two membranes (20–30 nm) is called **synaptic cleft**.

Mechanism of transmission of impulse across the synapse

As the nerve impulse arrives at the presynaptic knob, the neurotransmitter is released into the synaptic cleft. Here, it binds with the receptors located on the postsynaptic membrane. This causes depolarization of the postsynaptic membrane, leading to generation of nerve impulses in the postsynaptic membrane. In this way, nerve impulses pass from one neuron to another (Fig. 12.9B).

Neurotransmitter

Neurotransmitter is a chemical substance involved in the transmission of nerve impulses across the synapse. There are several neurotransmitters but the most common of them is **acetylcholine**. The acetylcholine once liberated in the synaptic cleft binds with the receptors of the postsynaptic membrane to depolarize it. The remaining acetylcholine in the synaptic cleft is broken down into **acetate** and **choline** by an enzyme called **acetylcholine esterase**.

N.B.

The nerve impulse causing depolarization of the postsynaptic membrane is called *excitatory nerve impulse*, whereas nerve impulse causing hyperpolarization of the postsynaptic membrane is called *inhibitory nerve impulse* (Fig. 12.10).

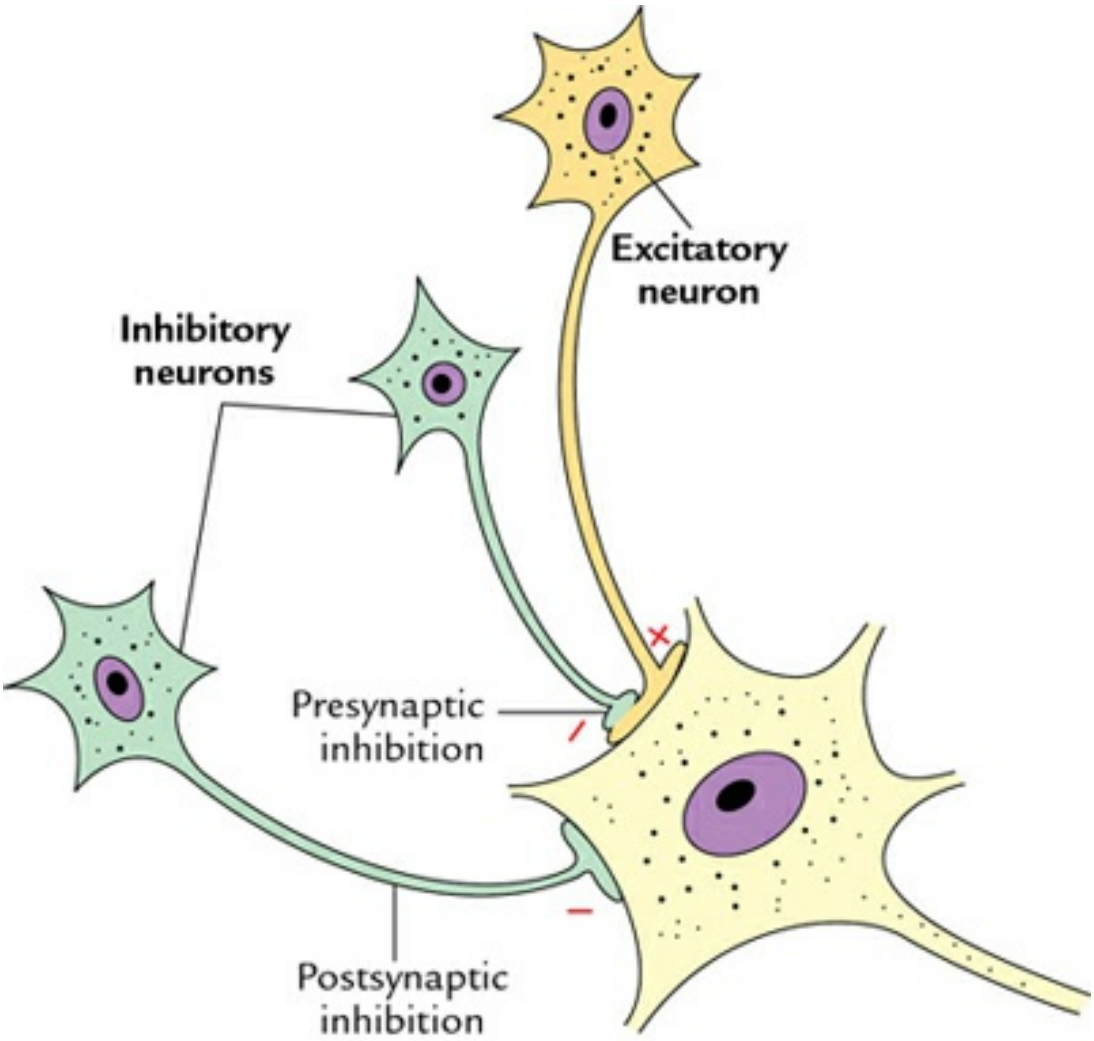


FIG. 12.10 ■ Excitatory and inhibitory synapses in a motor neuron.

Clinical Correlation

The synaptic transmission may be affected by various drugs, e.g. *caffeine* is a stimulant that increases the rate of transmission across the synapse. That is why office workers are very fond of taking tea and coffee.

Nerves

The term **'nerve'** refers to the peripheral nerve. The peripheral nerve consists of bundles of nerve fibres.

Structure of a nerve/peripheral nerve

Each nerve consists of bundles or fasciculi of nerve fibres and connective tissue.

Each nerve fibre is enclosed in a delicate connective tissue sheath called **endoneurium**.

Each group of nerve fibres (fasciculus) is surrounded by a connective tissue sheath called **perineurium.**

The entire nerve is surrounded by a dense connective tissue sheath called **epineurium** which contains blood vessels (Fig. 12.11).

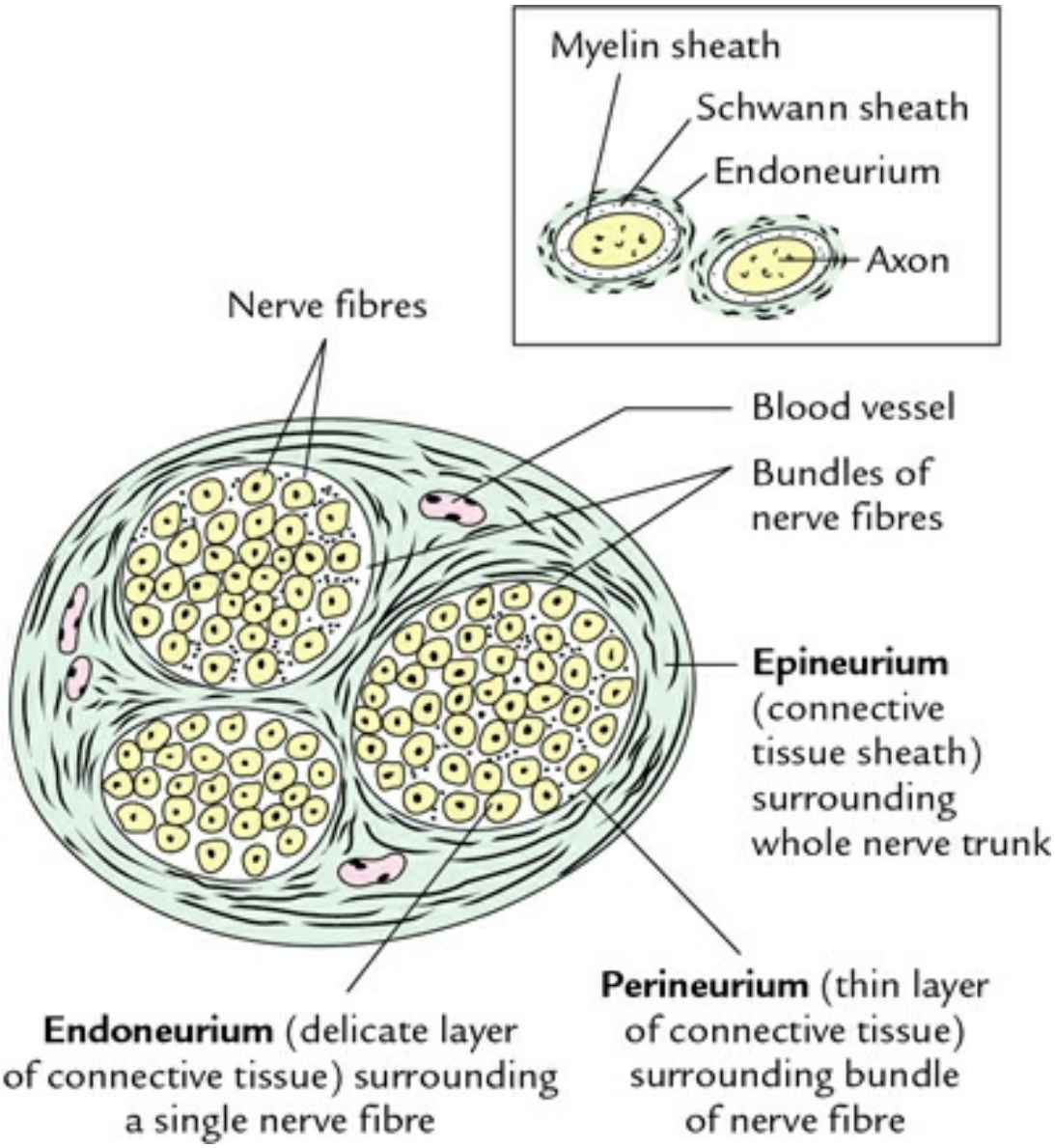


FIG. 12.11 ■ Structure of a peripheral nerve. Figure in the inset shows covering of an axon/nerve fibre in detail.

N.B.

The three connective tissue sheaths provide considerable mechanical strength to the peripheral nerve and form half of the bulk of the nerve.

Classification of nerves AN7.5

The nerves are classified into the following three types:

1. Motor nerves
2. Sensory nerves
3. Mixed nerves.

The **sensory nerves** transmit impulses from receptors in the periphery to the CNS.

The **motor nerves** transmit motor impulses from CNS to the effector organ, *namely*, skeletal muscle. The loss of motor nerve supply leads to degeneration of skeletal muscle fibres.

The **mixed nerve** consists of both the motor and sensory fibres.

Reflex action

A reflex action is an automatic response to a stimulus without conscious thought. It is protective in nature. The structures involved to carry out this reflex are:

1. Sensory receptor
2. Afferent (sensory) neuron
3. Association (connector) neuron
4. Efferent (motor) neuron
5. Effector organ.

The classic example of reflex action is a **withdrawal reflex** such as when a pin is pricked in the hand, the receptor is stimulated. The nerve impulse produced by a painful stimulus reaches the spinal cord through a sensory (afferent) neuron. The impulse is passed to the motor neuron via an association neuron (interneuron) which, in turn, stimulates the flexor muscles of the hand (effector organ) and as a result, the hand moves (i.e. withdrawn) away from the pin (Fig. 12.12).

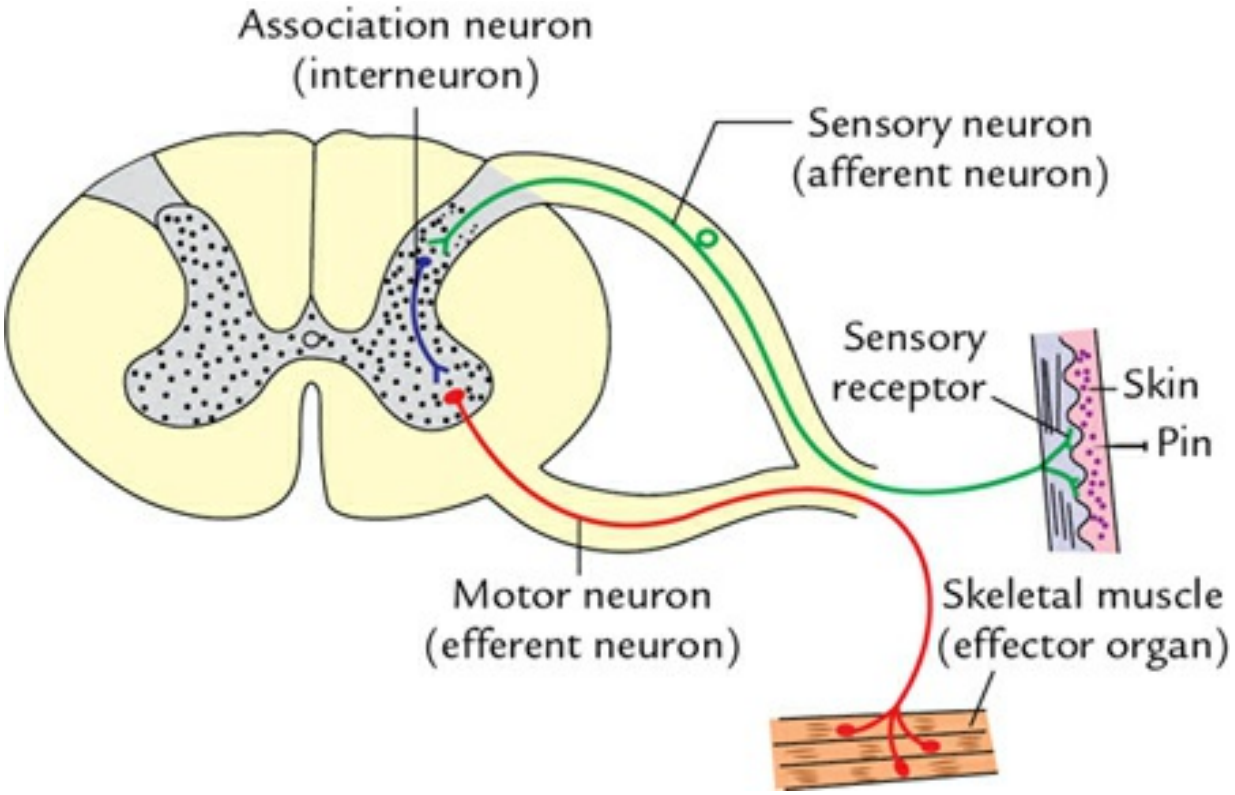


FIG. 12.12 ■ Reflex arc (withdrawal reflex). The components of reflexes are labelled in the order in which action potential passes through them. The five components are sensory receptor, afferent neuron, association neuron, efferent neuron and an effector organ.

N.B.

Various other reflexes such as ocular, cardiac, cough and intestinal operate in a similar fashion.

Degeneration and regeneration of nerves after injury

The injuries to peripheral nerves are quite common. They may occur due to compression, traction, trauma, intramuscular injection, cuts, etc.

There are three types of nerve injuries as follows:

1. **Neurotmesis:** Interruption of axon and its myelin sheath.
2. **Axonotmesis:** Interruption of the axon with preservation of myelin sheath.
3. **Neuropraxia:** Both axon and myelin sheath are preserved.

Recovery can occur in cases of neuropraxia and axonotmesis but some degree of function loss is inevitable with neurotmesis. When a nerve (axon) is

cut, a series of degenerative and regenerative changes follows.

Degeneration

When the nerve fibre is cut, the distal segment of the axon, which is severed from the cell body, degenerates. This is called **Wallerian degeneration**. The process is named after Augustus V. Waller, who first described (in 1850) the histological effects of nerve degeneration (Fig. 12.13).

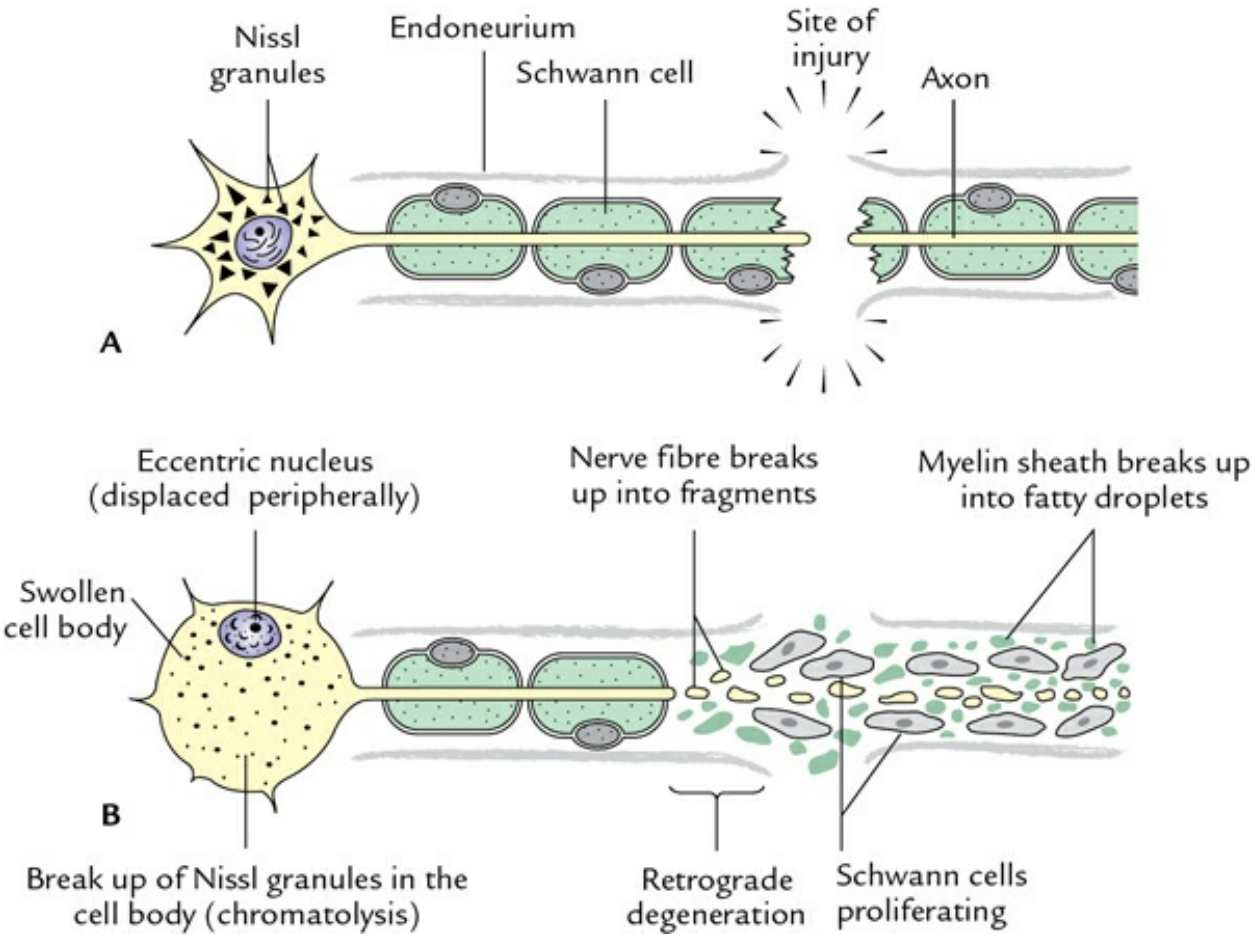


FIG. 12.13 ■ Degeneration of nerve fibre (Wallerian degeneration). **(A)** Complete transection of axon at the site of injury; **(B)** Degeneration of distal segment of axon and chromatolysis in nerve cell body (retrograde degeneration).

There is complete fragmentation of nerve fibre including its myelin sheath; however, myelin-producing sheath cells (Schwann cells) survive.

In addition to degeneration of the distal segment of the axon, degenerative changes are seen in the cell body:

1. Cell body swells and nucleus becomes eccentric.
2. Nissl bodies degenerate and form granules that are dispersed throughout the cell body. This process is called **chromatolysis**.

The changes that occur in the cell body following an injury to its axon are called **'retrograde degeneration'**.

Regeneration

The *Schwann cells* and *macrophages* distal to site of injury play an important role in regeneration. The *macrophages* migrate to the site of the lesion and phagocytose the debris. The neurolemmocytes (Schwann cells) proliferate and form a cord of cells called **band fibre** within the endoneurium.

The part of the axon that is connected to the cell body begins to grow forming sprouts with bulbous tips and enters the cord of neurolemmocytes (Fig. 12.14).

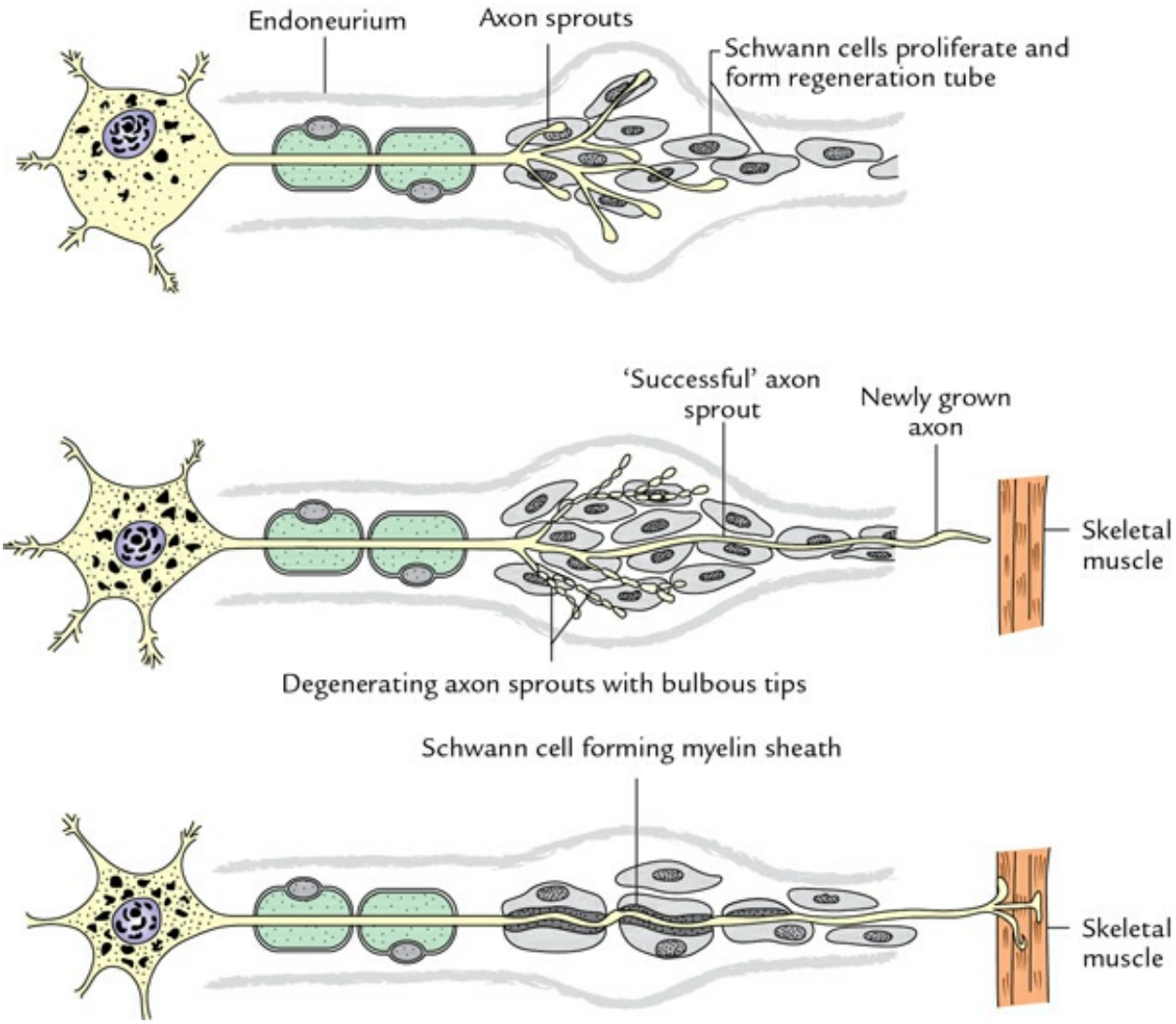


FIG. 12.14 ■ Regeneration of a divided nerve.

The neurolemmocytes of the cord secrete a chemical substance, the **nerve growth factor** that attracts the growing axon tip and guides it to its proper destination.

Factors necessary for the satisfactory regeneration are:

1. Endoneurium and neurolemmal sheath should be present intact.
2. Distance between the cut ends should not be more than a few millimetres.
3. Presence of nerve growth factor.
4. Infection should be absent at the site of the lesion.

N.B.

The peripheral nerves, if damaged, may regenerate, but nerve fibres within

the CNS cannot regenerate after damage due to the absence of neurolemmal sheath and endoneurium.

Clinical Correlation

Nerve repair: The severed major nerves may be surgically reconnected and the function of the nerve re-established if the surgery is performed before the tissue death i.e. within the first 72 h after injury. The axon grows at a rate of 1–2 mm per day. The regeneration may take 3–6 months.

Types of peripheral nerves

The peripheral nerves lie outside the brain and spinal cord. They are of the following two types:

1. Cranial nerves
2. Spinal nerves.

Cranial nerves

There are 12 pairs of cranial nerves that arise from brain within the cranial cavity and come out of it through foramina in the skull. The cranial nerves are designated by Roman numerals in order of their attachment to the brain in the craniocaudal direction. The 12 pairs of nerves are as follows:

I **Olfactory:** concerned with the sense of smell (olfaction).
II **Optic:** concerned with a sense of sight (vision).
III **Oculomotor:** supplies most of the extraocular muscles.
IV **Trochlear:** supplies one extraocular muscle.
V **Trigeminal:** provides sensory innervation to head and face, and motor supply to muscles of mastication.
VI **Abducent:** supplies an extraocular muscle.
VII **Facial:** supplies muscle of facial expression, and lacrimal, submandibular and sublingual salivary glands.
VIII **Vestibulocochlear:** concerned with the sense of hearing and balance.
IX **Glossopharyngeal:** provides sensory innervation to the tongue and pharynx, and motor supply to a pharyngeal muscle.
X **Vagus:** provides motor supply to gut, heart and respiratory tract, and

sensory innervation to tongue, thoracic and abdominal viscera.

XI **Accessory:** provides motor innervation to muscles of palate, pharynx, larynx and neck.

XII **Hypoglossal:** provides motor supply to muscles of the tongue.

N.B.

A pair of small nerves called *nervi terminalis* is recently discovered. It is attached to the brain ahead of all other cranial nerves and is designated as *'O' pair*. It is thought to be concerned with smell-mediated sex behaviour.

Spinal nerves

There are 31 pairs of spinal nerves that arise from the spinal cord within the vertebral canal and come out of it through intervertebral foramina. The 31 pairs of nerves are as follows:

1. Eight pairs of **cervical nerves** (C1 to C8)
2. Twelve pairs of **thoracic nerves** (T1 to T12)
3. Five pairs of **lumbar nerves** (L1 to L5)
4. Five pairs of **sacral nerves** (S1 to S5)
5. One pair of **coccygeal nerves** (C1).

Typical spinal nerve AN 7.4

A typical spinal nerve* arises from the spinal cord by two roots: (a) anterior and (b) posterior. The **anterior root** is motor and arises from anterior horn cells. The **posterior root** is sensory and possesses a knot-like swelling called *posterior (dorsal) root ganglion* consisting of nerve cell bodies of sensory nerve fibres (Fig. 12.15).

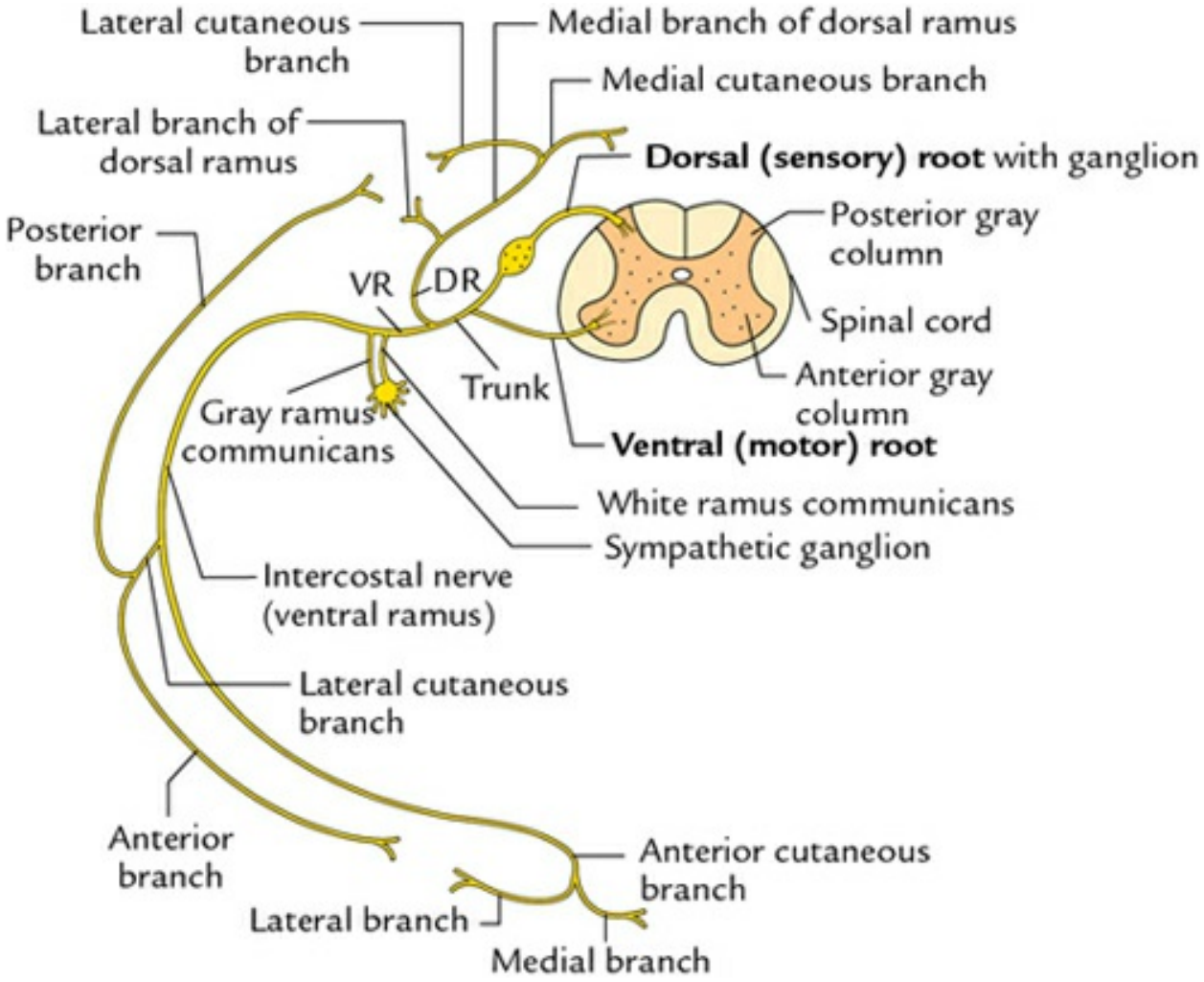


FIG. 12.15 ■ A typical spinal nerve. DR, dorsal ramus; VR, ventral ramus.

The two roots come out of the vertebral canal through the intervertebral foramen and then join each other to form a **nerve trunk**, which divides into a small **posterior ramus** and a large **anterior ramus**, both containing motor and sensory fibres.

The posterior ramus curves backward around the vertebral column to supply the muscles of the back and the skin covering these muscles. The anterior ramus runs anterolaterally around the body wall to supply the muscles and skin of the anterolateral wall of the body.

The students should not confuse the rami (branches) into which the nerve divides with the roots by which it is formed.

The **small dorsal ramus** divides into the lateral and medial branches which supply the muscles and one of them sends a branch called the posterior cutaneous branch which divides into lateral and medial branches.

The **large ventral ramus** runs along the lower border of the corresponding

rib and supplies intercostal muscles. Further, it gives rise to lateral and anterior cutaneous branches in the midaxillary line and just lateral to the sternum, respectively. The lateral cutaneous branch further divides into posterior and anterior branches, whereas the anterior cutaneous branch divides into lateral and medial branches.

Distribution of sympathetic fibres through spinal nerves

Soon after its formation, the ventral ramus receives a slender bundle of myelinated fibres, the **gray rami communicantes,** from the corresponding sympathetic ganglion of the sympathetic trunk. The nerve fibres of each grey ramus arise from the cells in the sympathetic ganglion. These are postganglionic sympathetic fibres. The fibres which enter the ventral ramus are distributed through all its branches. They also enter every branch of each dorsal ramus by coursing back into the corresponding ventral ramus to enter the dorsal ramus (Fig. 12.16).

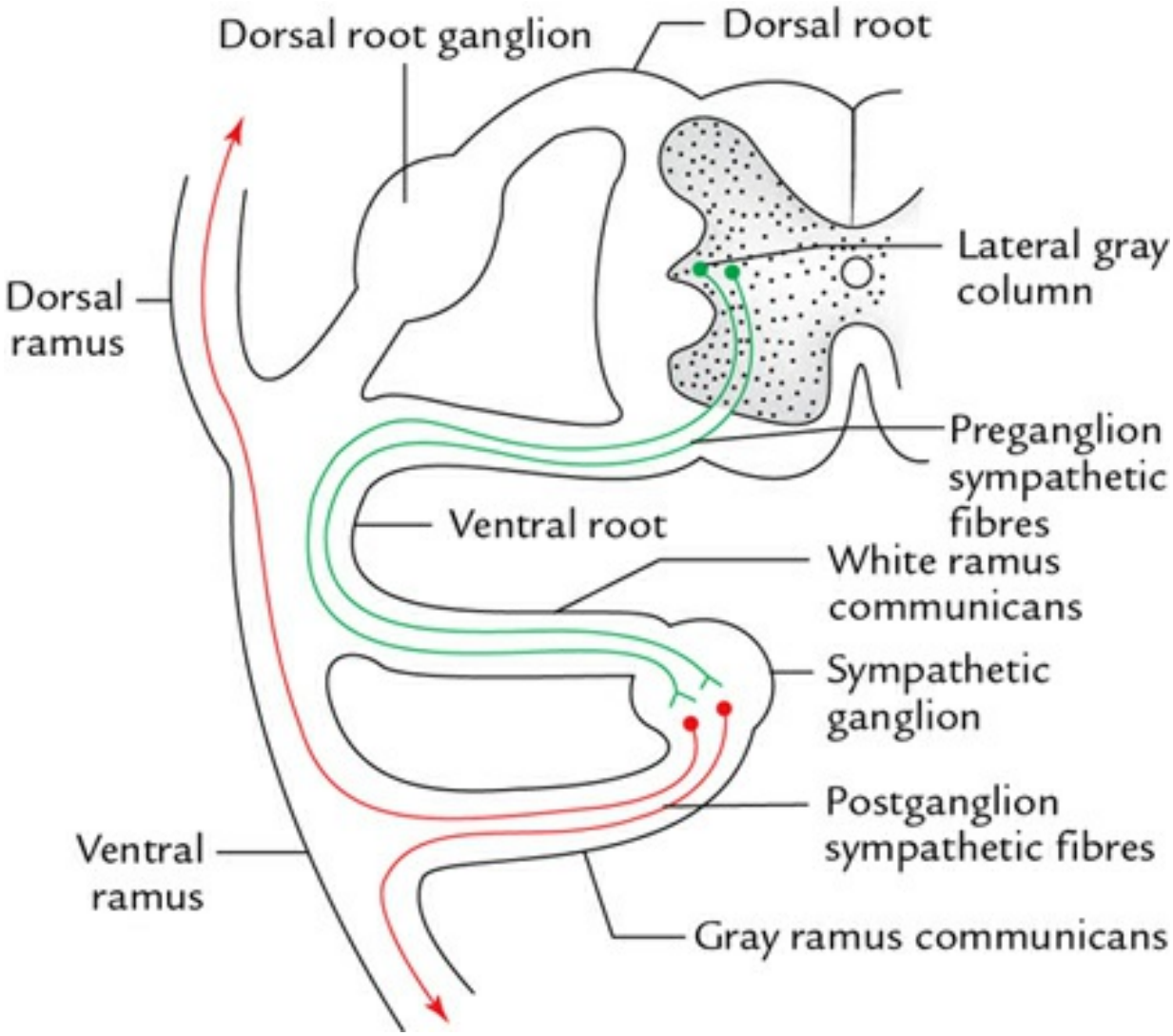


FIG. 12.16 ■ Distribution of sympathetic fibres through spinal nerves. Note that white ramus consists of preganglionic fibres, whereas gray ramus communicans consists of postganglionic fibres.

These sympathetic fibres supply the smooth muscle of blood vessels and muscles associated with hair (arrectores pilorum) and sweat glands.

The ventral rami of each thoracic and upper two lumbar spinal nerves are also connected with the corresponding sympathetic ganglion by another slender bundle of myelinated nerve fibres called **white ramus communicantes**. The fibres of this bundle are preganglionic sympathetic fibres which arise from the lateral grey horn of the spinal cord and relay in the sympathetic ganglion.

The differences between the white and gray rami communicantes are given in Table 12.2.

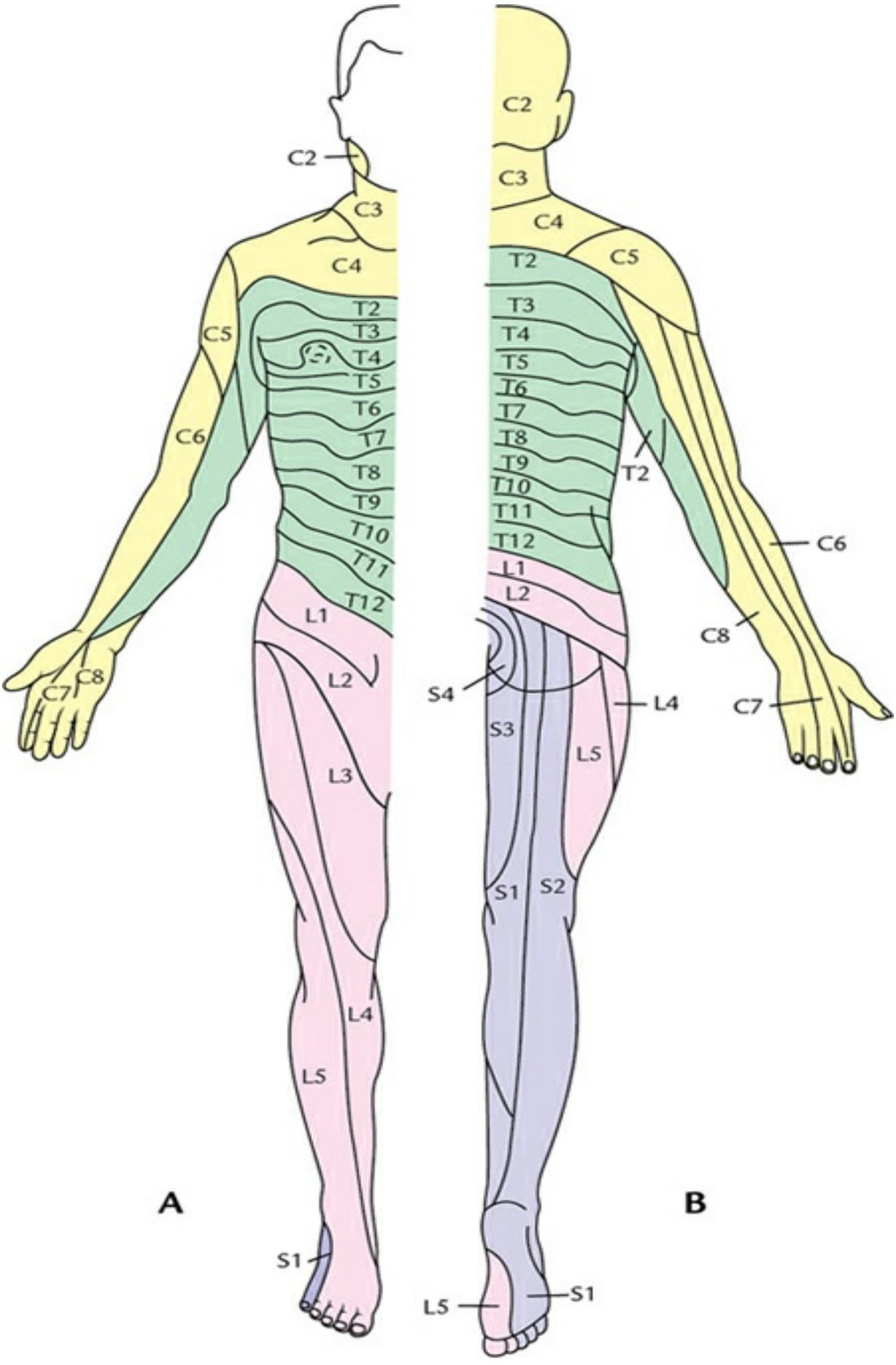
TABLE 12.2

Differences between the white and gray rami communicantes

	White Ramus Communicantes	Gray Ramus Communicantes
Type of fibres	Myelinated	Non-myelinated
Source of origin	Lateral horn cells of the spinal cord	Cells of sympathetic ganglion
Destination	Relay in the sympathetic ganglion (preganglionic fibres)	Distributed to blood vessels, hair and sweat glands through branches of anterior and posterior rami of spinal nerves

Dermatome

The cutaneous area supplied by one spinal nerve, through both its rami is called a **dermatome**. Figure 12.17 depicts the dermatomal map of the body for the sensory cutaneous distribution of the spinal nerves.


C2
C3
C4
C5
C6
C7
C8
T2
T3
T4
T5
T6
T7
T8
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T11
T12
L1
L2
L3
L4
L5
S1
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T8
T9
T10
T11
T12
L1
L2
S4
S3
S1
S2
L4
L5
L5
S1
B

FIG. 12.17 ■ Dermatomal map (i.e. pattern of peripheral distribution of spinal nerves): **(A)** anterior view and **(B)** posterior view.

N.B.

- With the exception of the first cervical nerve (C1), all the spinal nerves are associated with the specific dermatome.
- Typically, a dermatome extends around from anterior to the posterior median line. The upper half of each zone is supplemented by the nerve above and the lower half by the nerve below (Fig. 12.18).
- No area of skin is supplied by a single spinal nerve because adjacent dermatomes overlap.

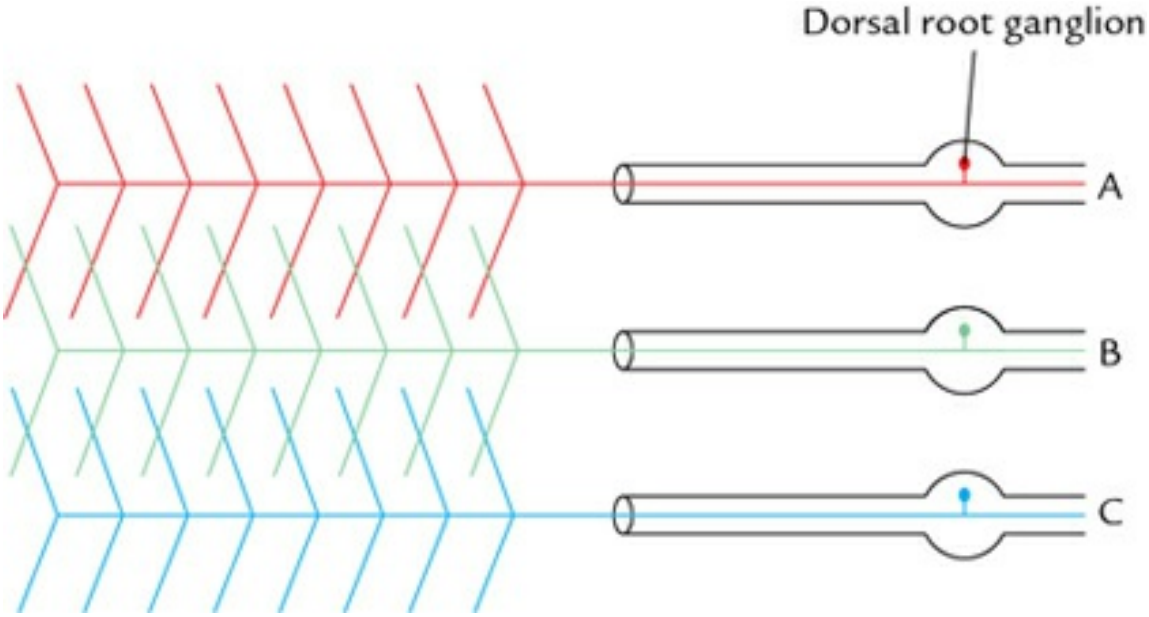

FIG. 12.18 ■ Cutaneous distribution of a series of three spinal nerves (A–C); note the overlappings.

Clinical Correlation

Dermatomal map: The knowledge of dermatomal map is important in clinical correlation of nerve damage because the loss of sensation in a dermatomal pattern provides valuable information about the location of damage in spinal segments. **AN 4.1**

Due to overlapping of contiguous dermatomes, anaesthesia (loss of sensations) will not occur unless more than two spinal nerves are involved in a lesion. If an injury involves only one spinal nerve, the sensations are decreased or altered but not completely lost.

In the trunk, the arrangement of dermatomes is simple as each dermatome extends around the body wall from posterior median line to the anterior median line. In the limbs, arrangement of dermatomes is complicated, firstly because the spinal nerves supply the limbs to form plexuses before innervating the skin, and secondly because the limbs rotate during embryonic life.

Plexus formation by spinal nerves

In general, except for thoracic nerves (T2–T12), anterior primary rami of all the spinal nerves join and then split again to form a network of nerves called **nerve plexuses**. There are three major nerve plexuses:

1. **Cervical plexus:** It is formed by the anterior primary rami of C1, C2, C3 and C4 spinal nerves, and innervates the head and neck.
2. **Brachial plexus:** It is formed by the anterior primary rami of C5, C6, C7, C8 and T1 and innervates the upper limb.
3. **Lumbosacral plexus:** It is formed by L1, L2, L3, L4, L5 and S1, S2, S3 and innervates the lower limb.

Autonomic nervous system

The ANS controls involuntary activities of the body such as the activities of smooth muscle, cardiac muscle and glands.

Like somatic nervous system, the autonomic system also consists of two components: (a) afferent and (b) efferent.

The **afferent component** is identical to that of the somatic nervous system but **efferent component** differs from the somatic nervous system. The basic difference between the efferent component of the somatic nervous system and the efferent component of ANS is that: the somatic efferent fibres directly pass from CNS to the somatic effector organs, *namely*, skeletal muscle, whereas the autonomic efferent fibres do not directly pass from CNS

to the visceral effector organs, but first, they relay in the autonomic ganglia outside the CNS and then fibres arising from ganglion cells supply the effector organs. Thus, the somatic efferent (motor) pathway consists of only first-order neurons arising from CNS while the autonomic efferent (motor) pathway consists of first-order neurons arising from CNS and second-order neurons arising from autonomic ganglia. The first- and second-order neurons are autonomic efferent pathways and are called **preganglionic** and **postganglionic neurons,** respectively.

The nerve impulses passing through autonomic motor pathways cause stimulation or inhibition of glandular secretion and contraction or relaxation of smooth/cardiac muscles.

Subdivisions of ANS

The efferent (outflow) component of ANS is divided into two divisions:

1. Sympathetic nervous system
2. Parasympathetic nervous system.

Sympathetic nervous system

The preganglionic sympathetic fibres arise from the spinal cord only, i.e. from the lateral grey column of the spinal cord from T1 to L2 segments; hence sympathetic outflow is termed thoracolumbar outflow (Fig. 12.19).

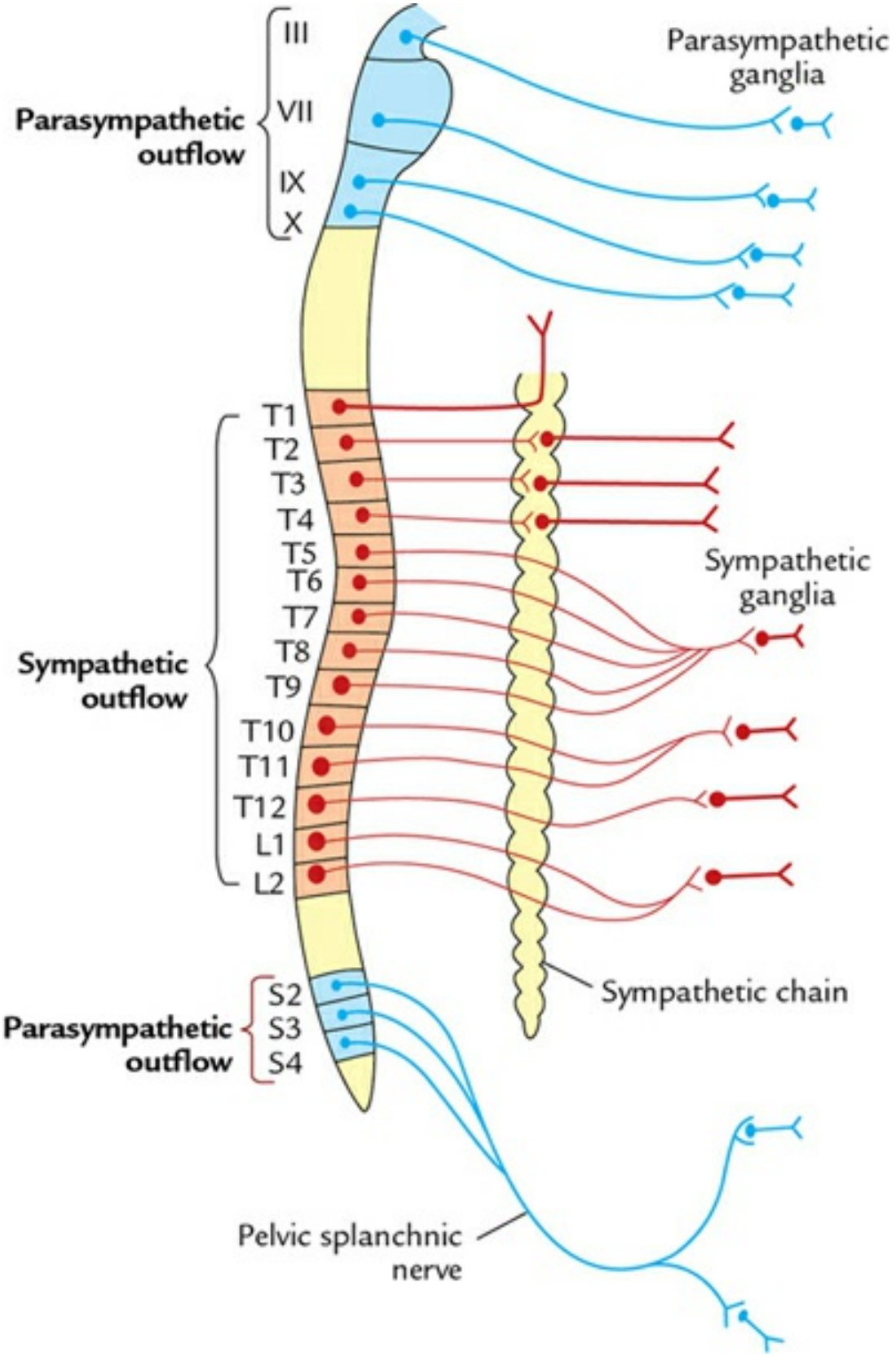

FIG. 12.19 ■ Schematic diagram showing the efferent component of the autonomic nervous system. The parasympathetic (craniosacral) outflow is shown in blue, and the sympathetic (thoracolumbar) outflow is shown in red.

Parasympathetic nervous system

The preganglionic fibres arise from the brain as well as from spinal cord.

In the brain, they arise from visceral efferent nuclei and leave the cranium through 3rd, 7th, 9th and 10th cranial nerves —**cranial outflow**.

In the spinal cord, they arise from the lateral grey column of 2nd, 3rd and 4th sacral segments —**sacral outflow**.

Therefore, in general, the parasympathetic outflow is termed as **'craniosacral outflow'** (Fig. 12.19).

All the parts of the body whether somatic or visceral receive sympathetic supply but parasympathetic supply has no somatic distribution, which supplies only viscera. Even some viscera such as suprarenal glands and gonads have no parasympathetic supply.

Functions of Sympathetic and Parasympathetic Nervous System

In general, sympathetic stimulation mobilizes the body's energy to fight or flight during fright/sudden fear (Fig. 12.20A), whereas parasympathetic stimulation slows down the body processes to **conserve and restore energy**, e.g. sleep (Fig. 12.20B).

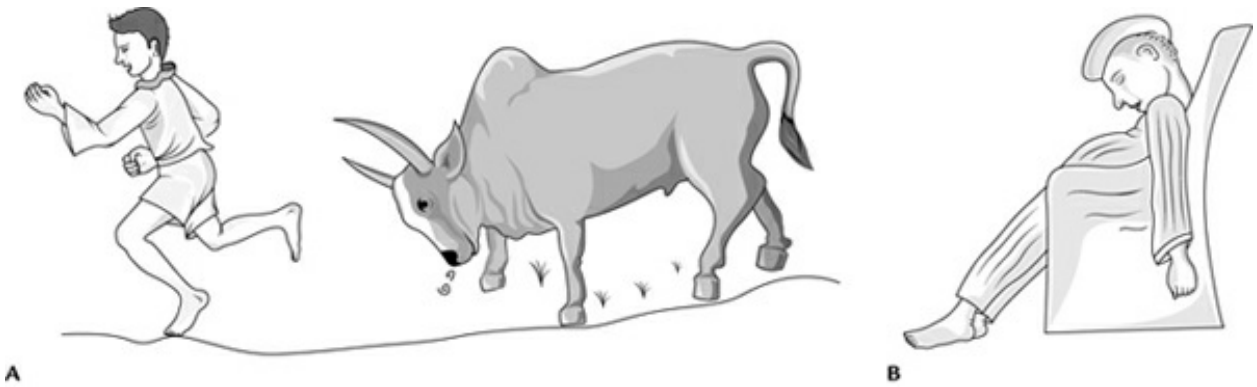

FIG. 12.20 ■ Pictorial depiction of effects of sympathetic **(A)** and parasympathetic **(B)** activities.

The effects of sympathetic and parasympathetic stimulation on some organs are enumerated in Table 12.3.

TABLE 12.3

Organs and effects of sympathetic and parasympathetic stimulation

Organs	Sympathetic effect	Parasympathetic effect
Pupil of the eye	Dilatation	Constriction
Lacrimal gland	Vasomotor	Secretomotor
Salivary glands	Constriction of blood vessels, produces viscous saliva	Produces watery saliva
Bronchial gland	Inhibition of secretion	Increases secretion
Bronchioles	Dilatation	Constriction
Muscles of gastrointestinal tract	Inhibition of gastric motility but constricts sphincters	Increases peristalsis but relaxes (opens) the sphincters
Glands of gastrointestinal tract	Inhibition of secretions	Increases the secretion
Muscle of bladder	Relaxation of the muscle of the bladder wall but the constriction of the sphincter	Contraction of the muscle of the bladder wall but relaxation of the sphincter
Blood vessels	Vasoconstriction[a] (vasomotor)	No effect
Sweat glands	Sudomotor (sweating)	No effect
Muscles of hair follicles (arrector pili)	Pilomotor/contraction (erection of hair)	No effect
Penis	Causes ejaculation	Causes erection
Heart	Increases heart rate	Decreases heart rate

[a]Sympathetic stimulation causes vasoconstriction of blood vessels all over the body, except those in skeletal muscles.

From the interpretation of the effects presented in Table 12.3, it is clear that the effects of these two systems are:

1. *Antagonistic,* e.g. effects on heart, pupil, GIT and respiratory tract.
2. *Complementary,* e.g. effects on salivary glands.
3. *Cooperative,* e.g. effects on urinary and reproductive systems.

Clinical Correlation

Effects of sympathetic and parasympathetic over-activity: The sympathetic

system is stimulated at the time of stress and strain.

- **The sympathetic overactivity causes:**
  (a) Rise in blood pressure
  (b) Increased heart rate (tachycardia)
  (c) Increased respiratory rate
  (d) Sweating
  (e) Dilatation of pupil
  (f) Dryness of mouth
  (g) Loss of appetite
  (h) Constipation
- **The parasympathetic overactivity causes:**
  (a) Constriction of the pupil
  (b) Decrease in heart rate (bradycardia)
  (c) Increase in the motility of the gut (to help evacuation)

N.B.

The sympathetic system is stimulated at the time of stress and strain. These days most people suffer from high blood pressure and constipation because they live in an era of stress and strain.

Neurotransmitters of the ANS

The autonomic nerve fibres release two types of neurotransmitters: (a) acetylcholine and (b) norepinephrine (noradrenaline) (Fig. 12.21).

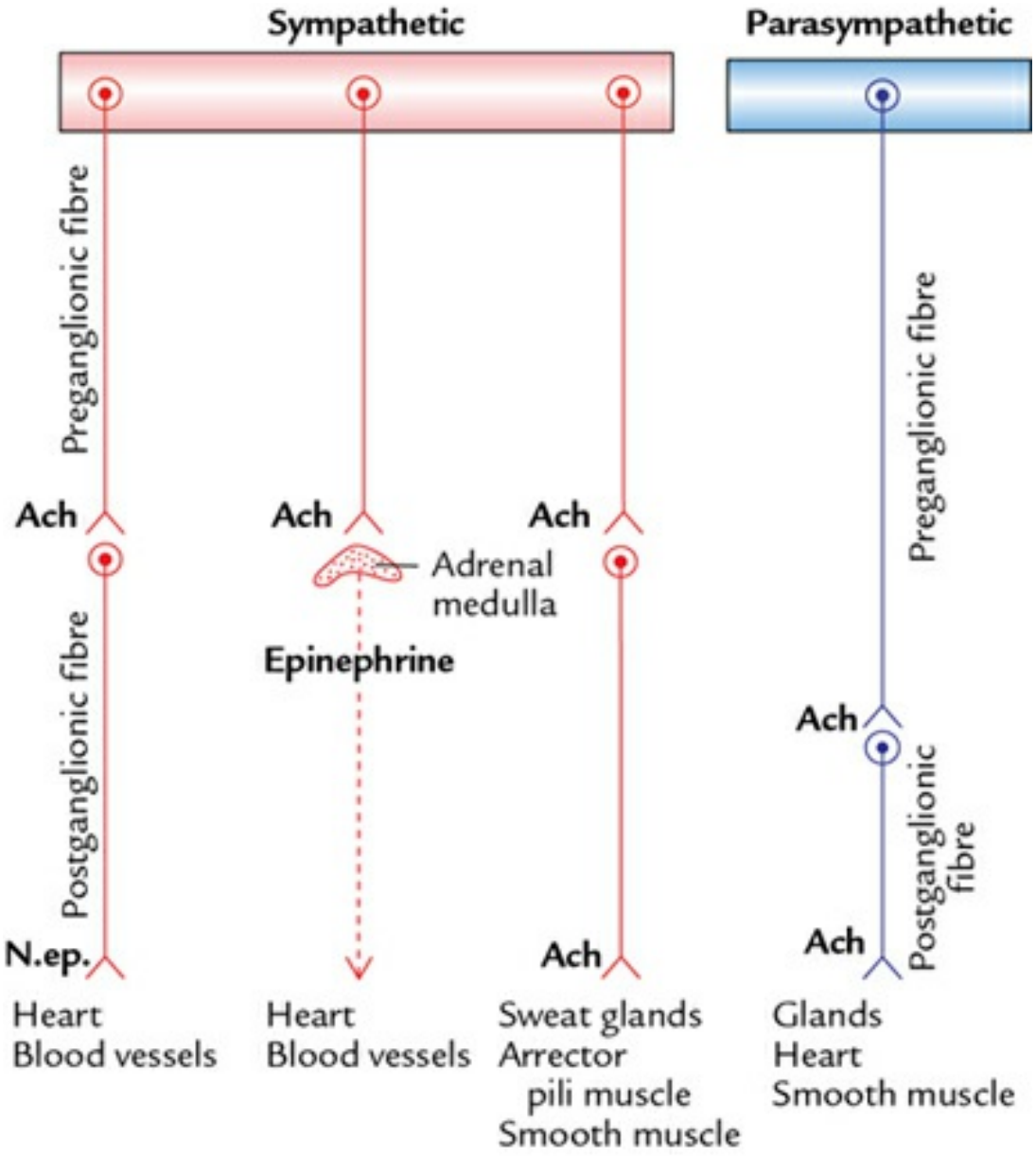

FIG. 12.21 ■ Neurotransmitters released by sympathetic and parasympathetic nerve fibres.

All the preganglionic parasympathetic and sympathetic fibres release acetylcholine (Ach).

All the postganglionic parasympathetic fibres release acetylcholine (Ach).

All the postganglionic sympathetic fibres release norepinephrine *except* those supplying sweat glands and *arrector pili* muscles which release acetylcholine (Ach).

N.B.

The fibres which release acetylcholine are termed *cholinergic fibres* and

those which release norepinephrine (noradrenaline) are termed *adrenergic fibres*.

Clinical Correlation

The drug atropine, derived from the deadly nightshade plant (*Atropa belladona*), inhibits the parasympathetic stimulation of the constrictor pupillae muscle of the iris leading to dilatation of the pupil of the eye. Therefore, extracts of this plant were used by women during Middle Ages to dilate their pupils in order to enhance their beauty (***belladonna*** = **beautiful woman**).

Nowadays in clinical practice, atropine is used to dilate the pupil during eye examination.

Afferent component of ANS

As described earlier, the afferent fibres of ANS are identical to the afferent fibres of the somatic nervous system. The cell bodies of the afferent fibres (first-order sensory neurons) of ANS are located in the dorsal root ganglia of spinal nerves and the sensory ganglia of cranial nerves.

The impulses carried by afferent fibres of ANS are associated with:

(a) visceral reflexes usually at an unconscious level,
(b) sensations of hunger, thirst, nausea, sex desire, distension of bladder and bowl and
(c) visceral pain.

Visceral pain is commonly encountered in day-to-day clinical practice. The sensations of visceral pain are conveyed by sympathetic afferent fibres.

The visceral pain is caused by either of the following:

(a) stretching of solid viscera,
(b) distension of hollow viscera,
(c) spasm of smooth muscles of viscera or
(d) ischaemia of viscera.

Three types of pain may be encountered:

1. **True visceral pain:** It is dull and poorly localized over the viscera.
2. **Sharp pain:** It occurs due to inflammation and is felt on the body surface close to the viscera.
3. **Referred pain:** It is localized acute pain felt on the body surface away from the affected viscera. The referred pain is of great clinical significance.

Referred pain

The pain arising from a diseased viscera does not occur in the viscera itself but is referred to as an area of skin, which is supplied by the same segment/segments of the spinal cord that supply/supplies that diseased viscera.

The segmental innervation of diseased viscera and areas of skin where the pain is referred to are listed in Table 12.4. The important sites of referred pain are shown in Figure 12.22.

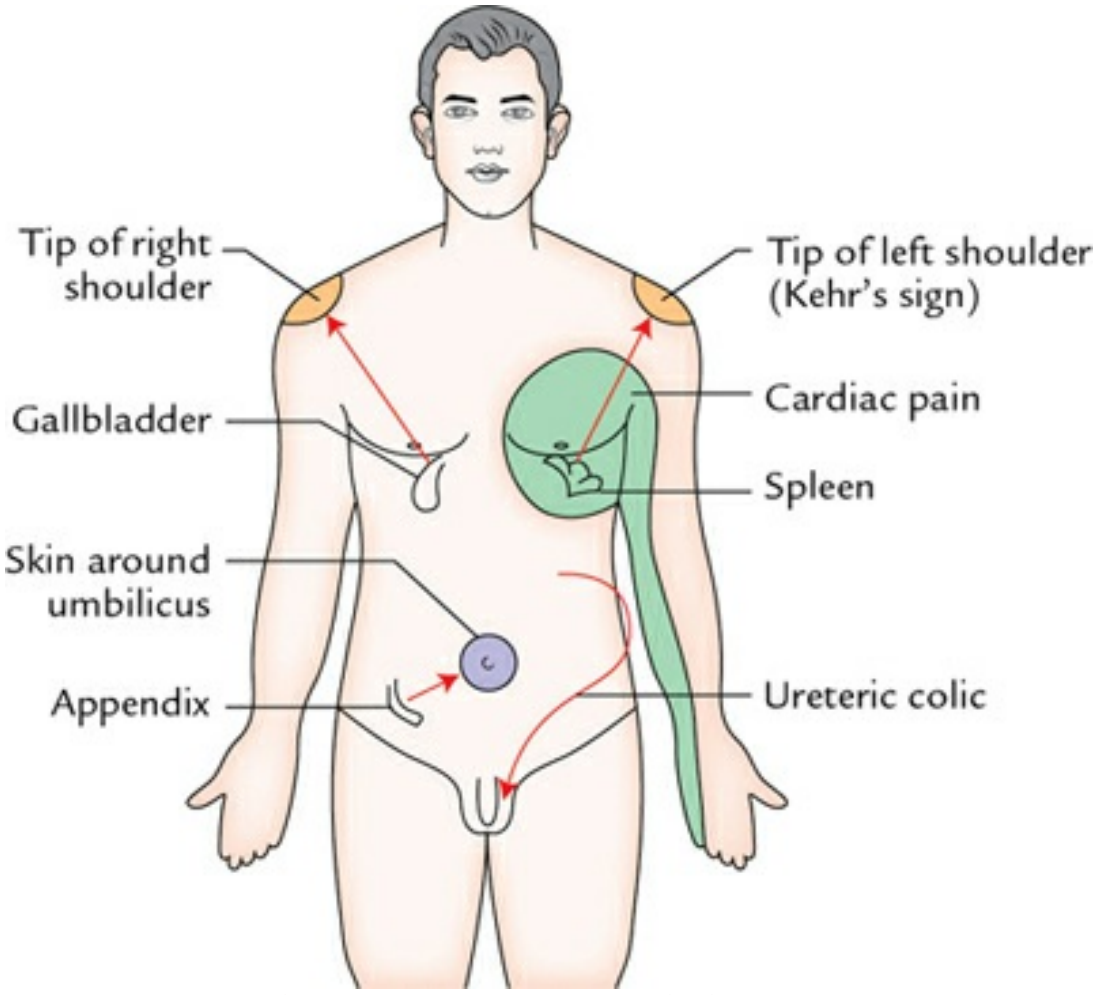

FIG. 12.22 ■ Important sites of referred pain.

TABLE 12.4

Segmental innervation of diseased viscera and areas of skin where the pain is referred

Diseased viscera	Site of referred pain	Segmental innervation
Appendix	Skin around umbilicus	T10
Gallbladder (causing irritation of right dome of diaphragm)	Skin over the tip of right shoulder	C3, C4, C5 (phrenic and supraclavicular nerves)
Spleen (causing irritation of left dome of diaphragm)	Skin over the tip of left shoulder (**Kehr's sign**)	C3, C4, C5 (phrenic and supraclavicular

		nerves)
Heart	Skin over precordium, medial side of arm and forearm	T1, T2, T3, T4
Ureter	Skin in loin, groin, scrotum, labium majus	T11, T12, L1, L2

Golden Facts to Remember

• Number of neurons in the body	About 100 billion
• Number of neuroglia in the body	About 1000 billion
• Most important property of the neuron	Excitability and conductivity
• Most excitable part of the axon	Axon-hillock
• Longest neurons in the body	Sensory neurons of the first sacral spinal nerve (S1)
• Largest neuroglia	Astrocytes
• Smallest neuroglia	Microglia
• All neuroglia develop from neural crest except	Microglia which develops from mesoderm
• Commonest variety of synapse	Axodendritic
• Most common type of neurons in the body	Multipolar
• Largest sensory receptor	Pacinian corpuscles
• Cell bodies of all primary (first-order) sensory neurons are located outside the CNS except	Cell bodies of primary sensory neurons forming the mesencephalic nucleus of the trigeminal nerve which is located within the CNS
• Cell bodies of all the motor neurons are	Postganglionic motor neurons of ANS which are located in the

located within CNS *except* those of	peripheral ganglia
• All the viscera are supplied by postganglionic autonomic fibres *except*	Adrenal medulla which is supplied by preganglionic autonomic fibres
• Largest cranial nerve	Trigeminal (5th cranial) nerve
• Longest cranial nerve	Vagus (10th cranial) nerve
• Smallest cranial nerve	Trochlear (4th cranial) nerve
• All cranial nerves emerge from ventral aspect of the brain *except*	Trochlear nerve which emerges from dorsal aspect of the brain
• All spinal nerves are associated with a specific dermatome *except*	First cervical spinal nerve (C1) as it has no cutaneous distribution

Multiple choice questions

1. **Bipolar neurons are found at all of the following sites *except*:**
   (a) Retina
   (b) Olfactory epithelium
   (c) Cerebrospinal ganglia
   (d) Vestibulocochlear ganglia
2. **All the neuroglia are derived from the neural crest *except:***
   (a) Astrocytes
   (b) Microglia
   (c) Oligodendrocytes
   (d) Neurolemmocytes
3. **Neuroglial cells that form the myelin sheath around the peripheral nerve fibres are:**
   (a) Oligodendrocytes
   (b) Neurolemmocytes
   (c) Astrocytes
   (d) Microglia
4. **Which of the following neurons are pseudo-unipolar?**

(a) Neurons of the retina
(b) Motor neurons forming tracts in CNS
(c) Neurons of autonomic ganglia
(d) Neurons of cerebrospinal ganglia

5. **A collection of nerve fibres outside the CNS is called a:**
(a) Tract
(b) Nerve
(c) Ganglion
(d) Nucleus

6. **The commonest type of synapse is:**
(a) Axosomatic
(b) Dendrosomatic
(c) Axoaxonic
(d) Axodendritic

7. **The commonest neurotransmitter is:**
(a) Noradrenaline
(b) Acetylcholine
(c) Serotonin
(d) Dopamine

8. **Select the *incorrect* statement:**
(a) All preganglionic sympathetic fibres secrete acetylcholine
(b) All preganglionic parasympathetic fibres secrete norepinephrine
(c) All preganglionic para sympathetic fibres secrete acetylcholine
(d) All postganglionic parasympathetic fibres secrete acetylcholine.

9. **Nissl granules are absent in all *except***
(a) Dendrites
(b) Axon hillock
(c) Axon terminal
(d) Cell body/perikaryon

10. **Glial cell which acts as a phagocyte is**
(a) Astrocyte
(b) Oligodendrocyte
(c) Microglia
(d) Schwann cell

11. **The outer covering of the peripheral nerve is called:**
(a) Epineurium
(b) Perineurium
(c) Endoneurium

(d) Neurilemma

Answers

1. ***c***, 2. *b*, 3. *b*, 4. *d*, 5. *b*, 6. *d*, 7. *b*, 8. *b*, 9. *d*, 10. *c*, 11. *a*.

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*Thoracic spinal nerves from T3 to T11 are considered typical spinal nerves.

Chapter 13: Endocrine system

Specific learning objectives

After studying this chapter, the student should be able to:

- Define the endocrine system and enumerate the important endocrine glands in the body.
- Describe location, parts, structure and functions of the pituitary gland.
- Discuss the position of the thyroid gland and clinical features of thyroid swellings.
- Describe the microscopic structure of the thyroid gland and outline the action of the thyroid hormones.
- Elucidate the position and gross structure of parathyroid glands and outline the functions of the parathyroid hormone.
- Demonstrate location and structure of suprarenal glands and discuss the action of hormones secreted by the adrenal cortex.
- State the position of the pineal gland and outline its functions.
- List the hormones secreted by the endocrine pancreas and describe the actions of insulin and glucagon.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

The endocrine system is one of the two major control systems of the body (other being the nervous system). It secretes various **hormones** which play an

important role in maintaining the homeostasis of the body.

The disorders of the endocrine system lead to important clinical conditions such as *goitre, Graves' disease, diabetes mellitus, diabetes insipidus, Cushing's syndrome, growth disorders* and varieties of reproductive malfunctions.

Functions of Endocrine System

- Metabolism
- Growth and development
- Emotions and mood
- Sleep
- Blood pressure
- Fertility and sexual functions.

Components of the endocrine system

The endocrine system consists of:

1. **Endocrine glands**, which exist as separate distinct organs, namely pituitary, thyroid and parathyroid glands.
2. **Scattered masses of endocrine cells within the exocrine glands,** namely islet of Langerhans within the pancreas, interstitial cells of the testis, corpus luteum of the ovary, etc.
3. **Diffuse neuroendocrine cells**, namely neuroendocrine cells distributed in the lining epithelium of the stomach, duodenum, etc.

Endocrine glands

The endocrine glands are ductless glands that pour their secretion—the hormones directly into the bloodstream. Through blood they reach the target tissues.

The cells of the endocrine glands abut directly against the vascular channels. Most of such groups of gland cells are arranged in cords or plates. These cords are separated by sinusoids or blood capillaries (see Figure 4.15 chapter 4).

Hormones

The secretion of endocrine glands is known as **hormone** or **chemical messenger** which causes activation or inhibition of even a distantly situated target tissues and/or organs.

The hormones/chemical messengers are classified into the following four main types:

1. **Proteins** such as thyroid-stimulating hormone (TSH), growth hormone (GH), parathormone, etc.
2. **Peptides** (small proteins) such as vasopressin, thyroid-releasing hormone, etc.
3. **Amino acid derivatives** such as thyroxine, adrenaline and noradrenaline.
4. **Steroids** such as testosterone, progesterone, etc.

A clinician needs information on several aspects to understand the role of endocrine glands and their secretions in different tissues and organs of the body. This information pertains to:

1. Anatomy and location of each gland
2. Hormone/hormones secreted by each gland
3. Factors regulating the secretion of each hormone
4. Factors causing hypersecretion and hyposecretion of each hormone.

The important endocrine glands of the body (Fig. 13.1) are as follows:

1. **Pituitary gland or hypophysis cerebri**
2. **Thyroid gland**
3. **Parathyroid glands**
4. **Suprarenal (adrenal) glands**
5. **Pineal gland**
6. **Thymus gland.**

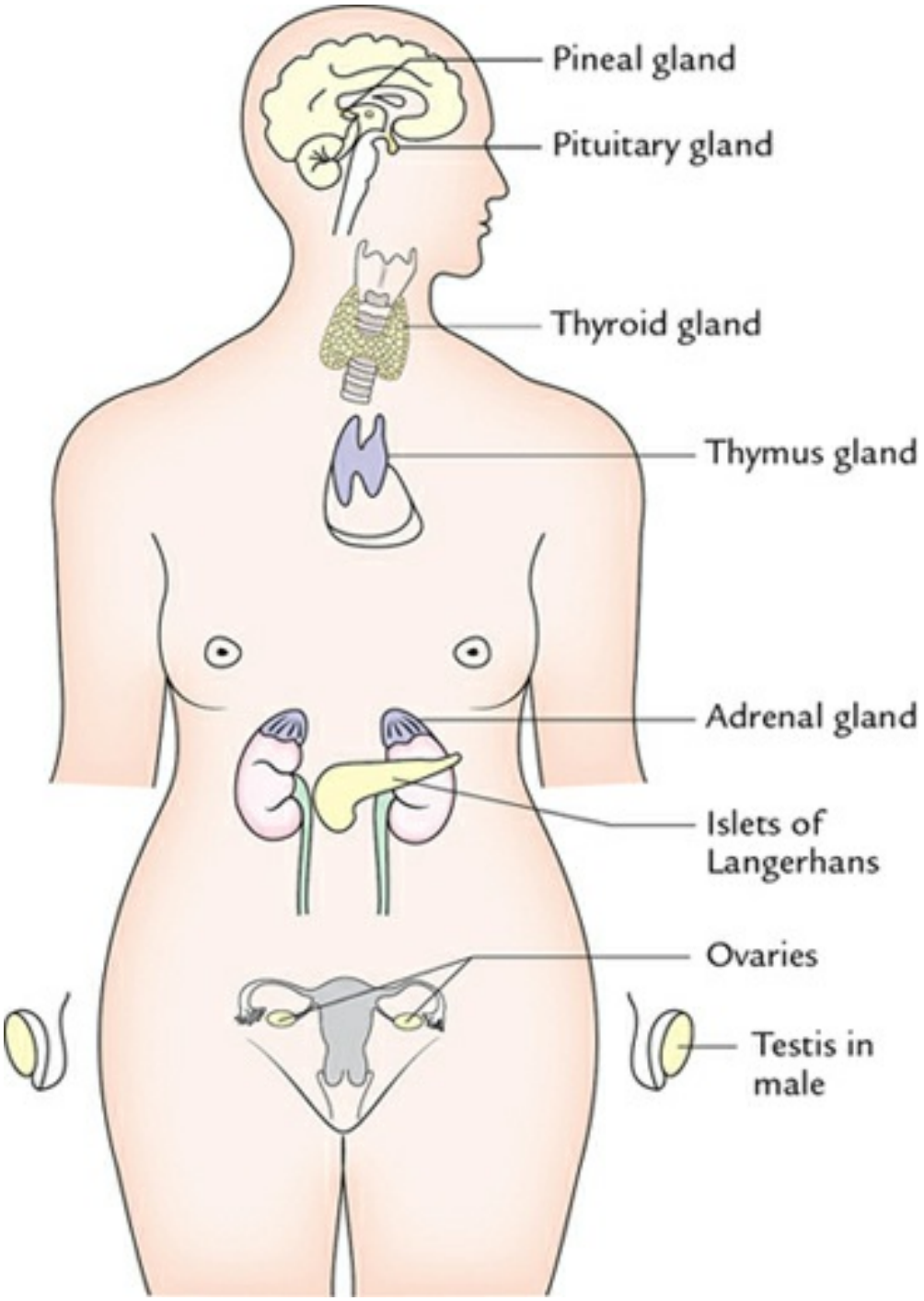


FIG. 13.1 ■ Location of main endocrine glands.

Pituitary gland (hypophysis cerebri)

The pituitary gland is a tiny gland, about the size of a pea, the most complex endocrine gland. It weighs about 0.5 g and its normal dimensions are 10 mm × 13 mm × 6 mm. It is located in the bony fossa of the skull (pituitary fossa or hypophyseal fossa or sella turcica), below the hypothalamus and connected

to it by a stalk of tissue called the **infundibulum**. The optic chiasma is related to the roof of the hypophyseal fossa (Fig. 13.2A).

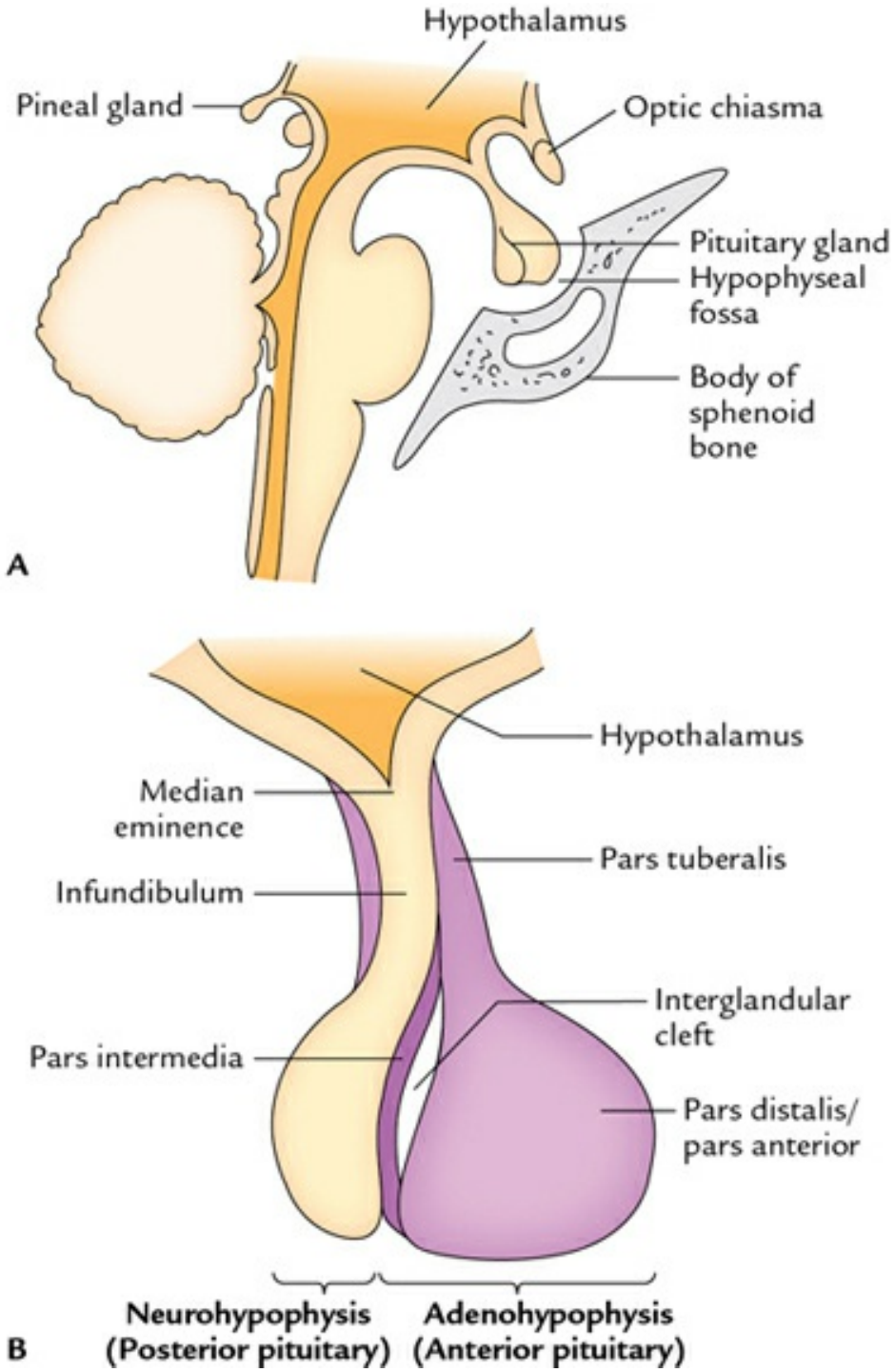


FIG. 13.2 ■ Pituitary gland: **A.** location of the gland and **B.** subdivisions of the gland.

It is often referred to as the '**master gland**' because it controls all other hormone-secreting glands in the body.

Parts of pituitary gland

The pituitary gland consists of two distinct parts (Fig. 13.2B):

1. Adenohypophysis (anterior pituitary)
2. Neurohypophysis (posterior pituitary).

These two parts develop from two entirely different sources. Hence, they have different structures and functions. The adenohypophysis develops from the ectodermal lining of the roof of the primitive oral cavity and neurohypophysis from the hypothalamus (Fig. 13.3).

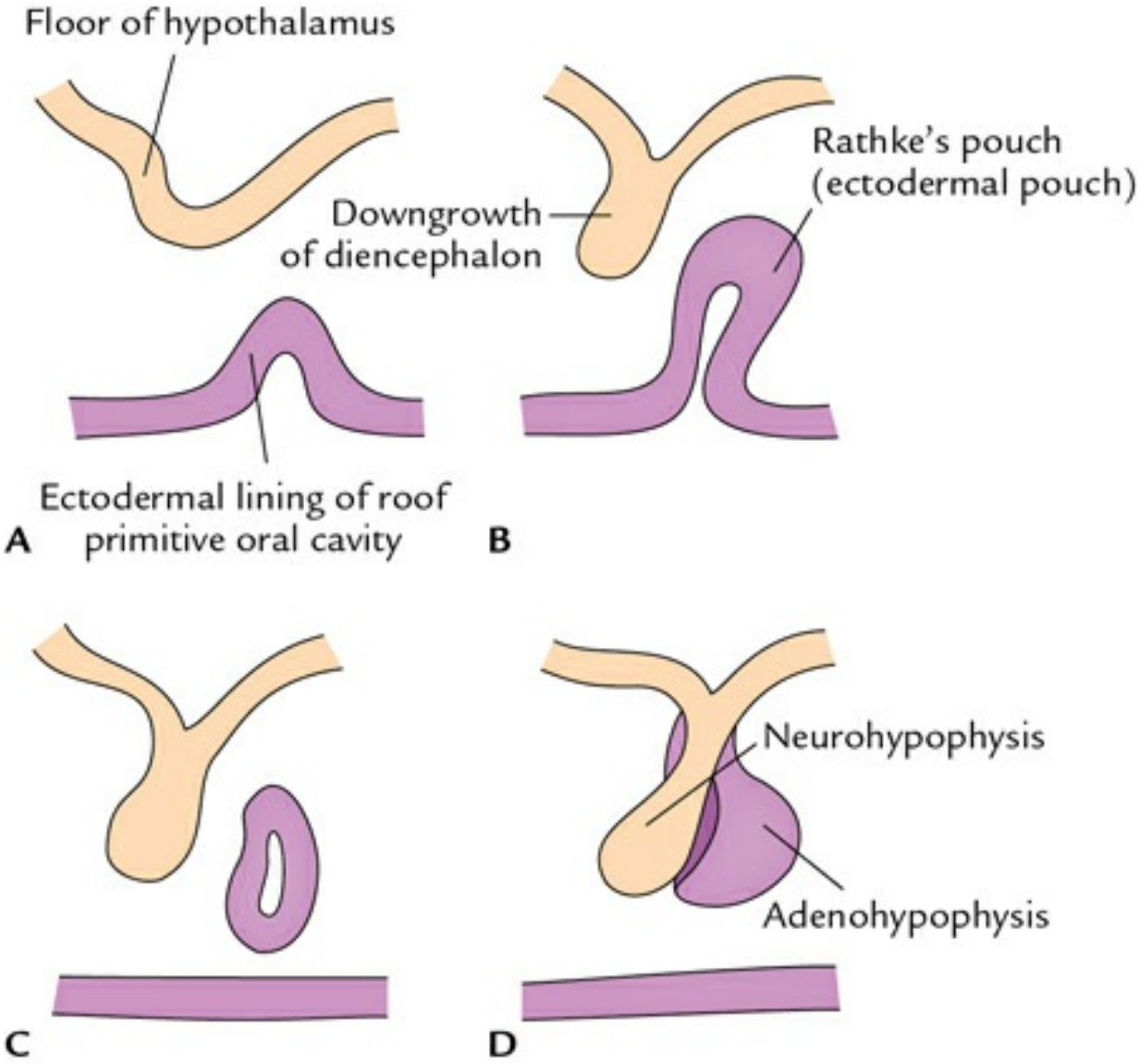


FIG. 13.3 ■ Development of adenohypophysis and neurohypophysis (steps **A** to **D**).

Adenohypophysis (anterior pituitary)

It is divisible into three zones:

1. Pars anterior (pars distalis)
2. Pars intermedia
3. Pars tuberalis.

Pars anterior (pars distalis)

It forms the major part of adenohypophysis and consists of anastomosing cords of cells that are surrounded by sinusoids, the arrangement most suited for direct discharge of hormones into the bloodstream. The cells forming the cords are of the following two types:

1. Chromophobes
2. Chromophils.

Chromophobes are smaller in size and have little affinity for histological stains, hence the name chromophobe. These cells have little cytoplasm which usually does not have any granules. The chromophobes are considered exhausted cells (or inactive phase of chromophils).

Chromophils are stainable, larger than chromophobes, and possess secretory granules. The chromophils are of two types: **acidophils** and **basophils**.

(a) **Acidophils**: According to the function, the acidophils are classified into the following three types:
   (i) ***Somatotrophs***: They regulate body growth by secreting GH which promotes the growth of bone and cartilage.
   (ii) ***Corticotrophs***: They act on suprarenal glands by secreting adrenocorticotrophic hormone (ACTH) which secrete cortisol, a steroid hormone.
   (iii) ***Mammotrophs***: They act on mammary glands by secreting prolactin hormone which is responsible for milk production.

(b) **Basophils**: According to their function, the basophils are classified into two types:

(i) ***Thyrotrophs***: They act on the thyroid gland by secreting TSH to secrete thyroid hormones.

(ii) ***Gonadotrophs***: They act on gonads by secreting:

- *follicle-stimulating hormone* (FSH), which controls growth of ovarian follicles and menstrual cycle.
- *luteinizing hormone* (LH) in females responsible for sexual development.
- *interstitial cell-stimulating hormone* (ICSH) in males which is responsible for the production of progesterone.

Pars intermedia

It is a narrow zone consisting of small cells. The pars intermedia is separated from the pars anterior by the inter glandular cleft. The cells of pars intermedia secrete melanocyte-stimulating hormone (MSH).

N.B.

In amphibians, MSH controls the dispersal of melanin granules in melanocytes, which are responsible for altering the colour of their skin.

Pars tuberalis

It is an upward tubular extension of the pars anterior surrounding a part of the infundibulum. The cells within it are basophilic and contain some granules. The function of pars tuberalis is uncertain.

Clinical Correlation

- **Effects of hypersecretion of the anterior pituitary:** The hypersecretion of GH of the anterior pituitary leads to gigantism and acromegaly. The most common cause of hypersecretion of GH is the pituitary tumour. The excessive secretion of GH leads to:
  - excessive growth of bones
  - enlargement of internal organs
  - growth of excess connective tissue.

  Gigantism occurs when there is excessive secretion of GH while epiphyseal cartilages of long bones are still growing.

  As a result, there is exaggerated and prolonged growth in long

bones resulting in *gigantism*. The affected individuals are abnormally tall, some of them may be 8–9 feet tall or so.

Acromegaly occurs when there is excessive secretion of GH after the ossification is complete. The affected individual presents the following clinical features:

- Prominent jaw and heavy bony ridges above the eyes
- Increased diameter of fingers, toes, hands and feet
- Bulbous or broad nose
- Enlarged tongue
- No increase in height.

- **Effects of hyposecretion of anterior pituitary:** The hyposecretion of GH of the anterior pituitary in infants and children leads to *dwarfism*.

Pituitary dwarfism: The affected individual is of small stature but well proportioned and its mental development is not affected.

Neurohypophysis (posterior pituitary)

Developmentally, it is a ventral outgrowth of the floor of the diencephalon but it does not contain neurons. The neurohypophysis consists of a narrow **infundibulum** (neural stalk) and a swollen **pars nervosa** (infundibular process).

The pars nervosa consists of cells called **pituicytes** and non-myelinated nerve fibres which originate from the cell bodies of the neurons located in the hypothalamus. The nerve fibres constitute the **hypothalamo-hypophyseal tract** which passes to the pars nervosa and terminates with swollen endings close to the blood capillaries.

The *pars nervosa* itself does not secrete any hormone, rather it simply serves as a depot for the storage of the hormones (antidiuretic hormone (ADH) and oxytocin) secreted in the hypothalamus.

The **oxytocin** stimulates the contraction of the uterine musculature during the later part of the pregnancy and also has a contractile action on the myoepithelial cells of the alveoli and ducts of the mammary gland, ejecting the milk.

The **ADH,** also known as vasopressin, increases the permeability of the distal convoluted and collecting tubules of the kidney for the reabsorption of

water, thus inhibiting diuresis.

N.B.

Besides secreting ADH and oxytocin, the neurosecretory cells of the hypothalamus also secrete some hormone-releasing factors, which reach the pars anterior to cause the release of LH, FSH, TSH, etc.

Clinical Correlation

Oxytocin injections

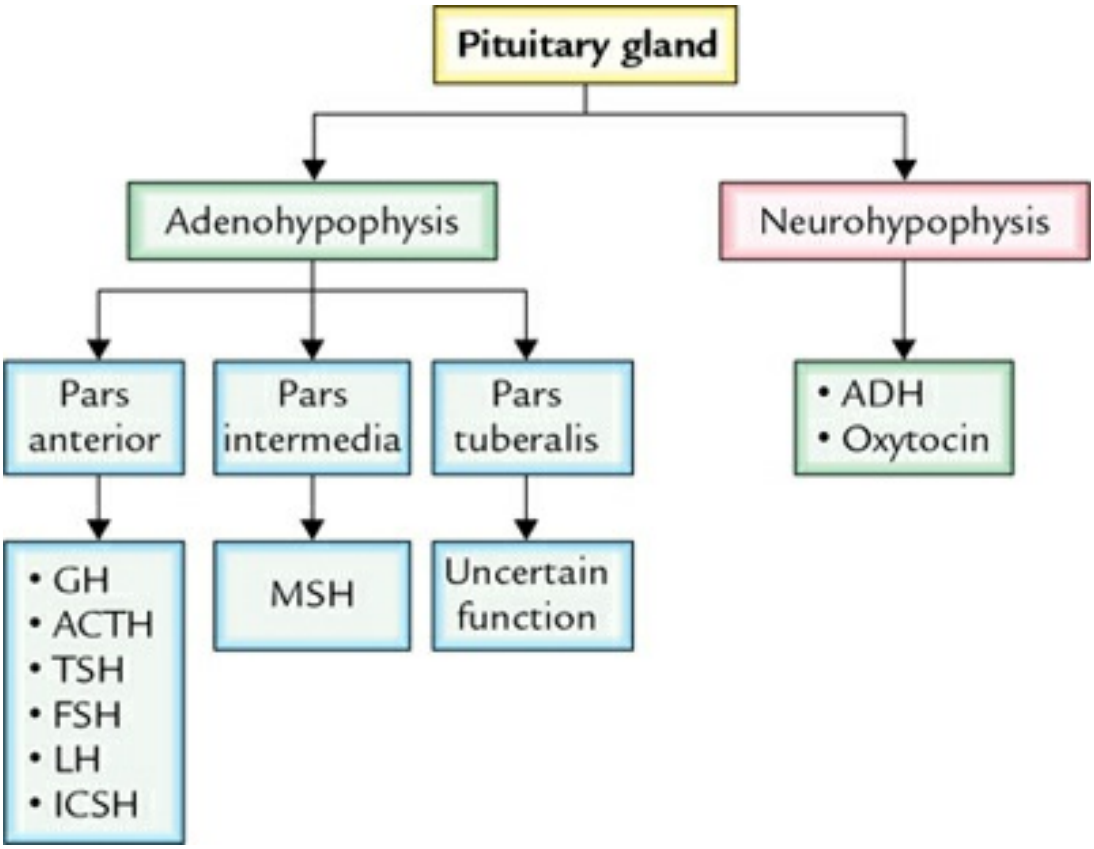
(a) The injections of oxytocin are given to women during labour if they are having difficulty in parturition. The increased amount of oxytocin assist uterine contractions and generally speed up delivery.

(b) The injections of oxytocin are given after the parturition, which causes the uterus to regress in size and the blood vessels to constrict, thus minimizing the chance of *postpartum bleeding*.

The most important function of ADH is to conserve water within the body. A failure of ADH secretion produces a clinical condition called diabetes insipidus which clinically presents as:

1. Passage of a large amount of urine (5–10 L/day)
2. Excessive thirst.

The parts of the pituitary gland and their secretion are summarized in Flowchart 13.1.



FLOWCHART 13.1 ■ Parts and secretions of the pituitary gland Abbreviations: GH = Growth hormone, ACTH = Adrenocortico-trophic hormone, FSH = Follicle-stimulating hormone, LH = Luteinizing hormone, MSH = Melanocyte-stimulating hormone, ADH = Antidiuretic hormone, TSH = Thyroid-stimulating hormone, ICSH = Interstitial cell-stimulating hormone.

Blood supply

The pituitary gland is supplied by superior and inferior hypophyseal arteries from the internal carotid artery.

The arterial supply of the pars anterior exhibits **hypothalamo-hypophyseal-portal circulation**.

The superior hypophyseal arteries first break up into capillaries at the median eminence of the hypothalamus to take up the hypothalamic-releasing hormones. Afterwards, these capillaries reunite to form vessels which again break up into capillaries in the pars anterior and discharge the releasing hormones into the sinusoids of the pars anterior.

Thyroid gland

The thyroid gland is the largest endocrine gland of the body and weighs about 20 g. It lies in front of the lower part of the neck. It is a roughly 'H-shaped' gland consisting of two lateral lobes connected by an isthmus (Fig. 13.4). The lobes are conical in shape and are placed on either side of the upper part of the trachea and lower part of the larynx. The isthmus extends across the anterior aspect of the trachea opposite the 3rd and 4th tracheal rings.

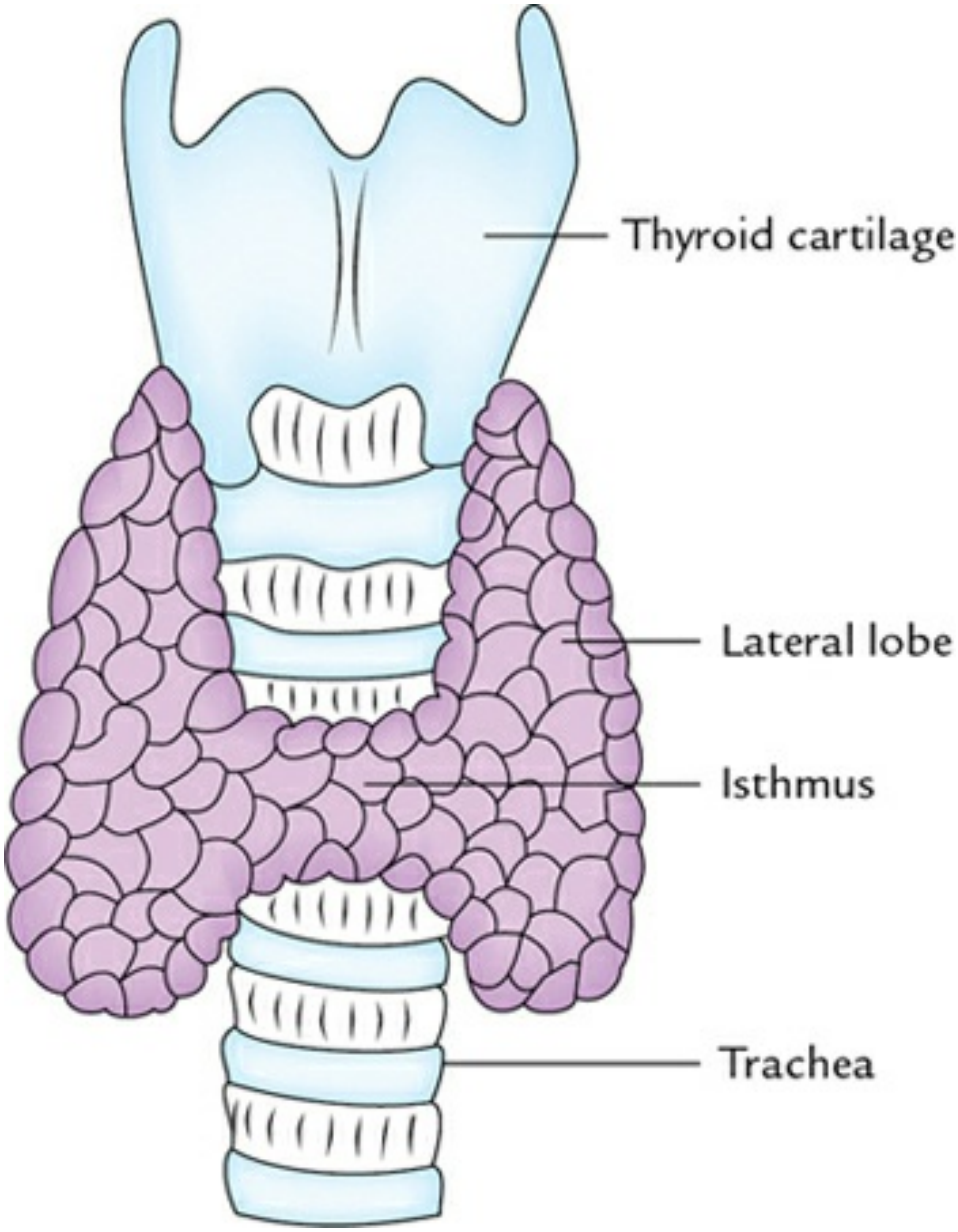


FIG. 13.4 ■ Gross structure and location of the thyroid gland.

The thyroid gland is invested by true and false capsules. The medial

surface of the lateral lobe is related to two tubes: respiratory and alimentary tracts, two nerves: recurrent laryngeal and external laryngeal nerves. The posterior surface of the lateral lobe is related to the carotid sheath containing the common carotid artery, internal jugular vein and vagus nerve.

Structure

The unit structure of the thyroid gland is called the **follicle** which consists of a layer of cuboidal epithelial cells enclosing a cavity filled with colloid substance.

The **parafollicular cells** are found in a delicate network of connective tissue between the follicles and amongst the cells that comprise the wall of follicles, deep to the basement membrane of the follicles (Fig. 13.5).

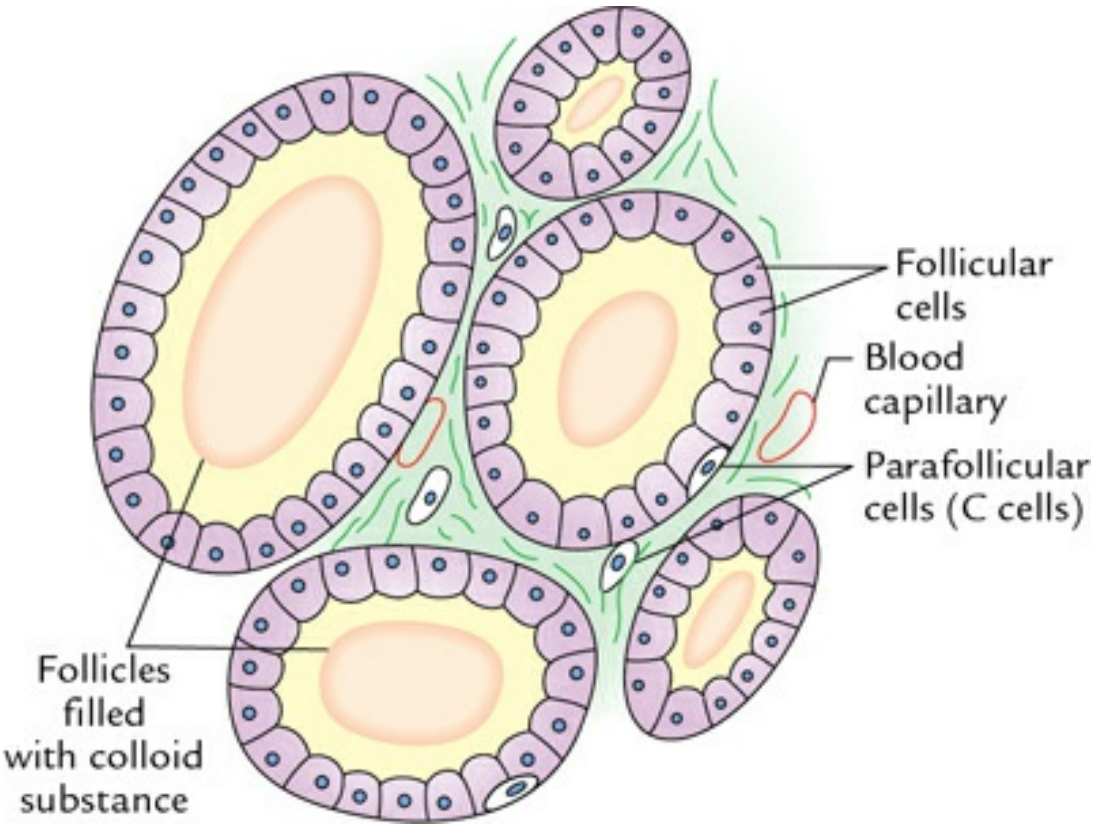


FIG. 13.5 ■ Microscopic structure of the thyroid gland.

The cells of the thyroid gland develop from two different sources:

1. Follicular cells develop from the endodermal cells of the thyroglossal duct.
2. Parafollicular cells develop from the neural crest.

Hormones secreted by thyroid gland

The thyroid gland secretes three hormones:

1. **T3** (tri-iodothyronine or thyroxine) secreted by cuboidal cells of thyroid follicles.
2. **T4** (tetra-iodothyronine or thyroxine) secreted by cuboidal cells of thyroid follicles.
3. **Calcitonin** (thyrocalcitonin) secreted by parafollicular cells.

T4 is called thyroxine. ***Thyroxine*** *forms the bulk of hormones secreted by the thyroid*. The T4 is essential for the psychosomatic growth of the body. They also maintain the BMR (basal metabolic rate) of the body. In peripheral tissues, T4 is converted into more active T3. The normal growth and maturation of the organs are dependent on the thyroid hormone.

Calcitonin plays an important role in calcium homeostasis. It lowers the blood calcium level when the calcium level is elevated. Its action is opposite to that of parathyroid hormone (PTH). The secretion of the thyroid hormone is regulated by TSH. The decreased blood levels of T3 and T4 are lead (by negative feedback) to increased secretion of TSH.

The dietary iodine is essential for the synthesis of thyroid hormones, T3 and T4.

Clinical Correlation

- **Goitre:** An enlargement of the thyroid gland is called *goitre*. Enlargement of the thyroid gland without signs of hyperthyroidism is called *simple goitre*. It usually develops when there is an iodine deficiency in the diet.

  The iodine deficiency leads to reduced secretion of T3 and T4. The low levels of T3 and T4 stimulate the secretion of TSH from the pituitary

gland. The increased secretion of TSH causes hyperplasia of the thyroid gland.

- **Hypothyroidism:** The hyposecretion of the thyroid hormone (*hypothyroidism*) decreases the rate of metabolism. Clinically it presents as low body temperature, weight gain, reduced blood pressure and apathy, a condition called *myxoedema*. *Hypothyroidism* in adult is often associted with *goitre* which leads pressure 3 symptoms often called **"3D" symptoms,** viz. *dyspnoea* due to pressure on trachea, *dysphagia* due to pressure on oesophagus, and *dysphonea* due to pressure on recurrent laryngeal nerve.

  Congenital hypothyroidism or if hyposecretion occurs during early development leads to cretinism. Here in addition to decreased rate of metabolism, there occurs abnormal development of the nervous system leading to mental retardation and/or short stature, a condition called *cretin*. The cretinism is caused by maternal iodine deficiency during pregnancy.
- **Hyperthyroidism:** The hypersecretion of the thyroid hormone (*hyperthyroidism*) increases the rate of metabolism.

  Clinically, it presents as high body temperature, weight loss, high blood pressure, exophthalmos (protrusion of the eyeballs) and an enlarged thyroid gland. This syndrome is also known as *thyrotoxicosis* or *Graves' disease*.

Blood supply

The thyroid gland is profusely supplied by the blood. The arteries supplying the thyroid gland are:

1. **Superior thyroid artery**, a branch of the external carotid artery.
2. **Inferior thyroid artery**, a branch of the thyrocervical trunk of the subclavian artery.

Venous drainage: The venous blood from the thyroid gland is drained by the following veins:

1. **Superior and middle thyroid veins** into the internal jugular vein.
2. **Inferior thyroid veins** into the brachiocephalic vein.

Parathyroid glands

There are four parathyroid glands. These are small, oval, yellowish-brown bodies measuring about 2 mm × 3 mm × 5 mm, roughly equal to the size of a split pea. The two (superior and inferior) parathyroid glands are found embedded on the posterior surface of each lateral lobe of the thyroid gland (Fig. 13.6).

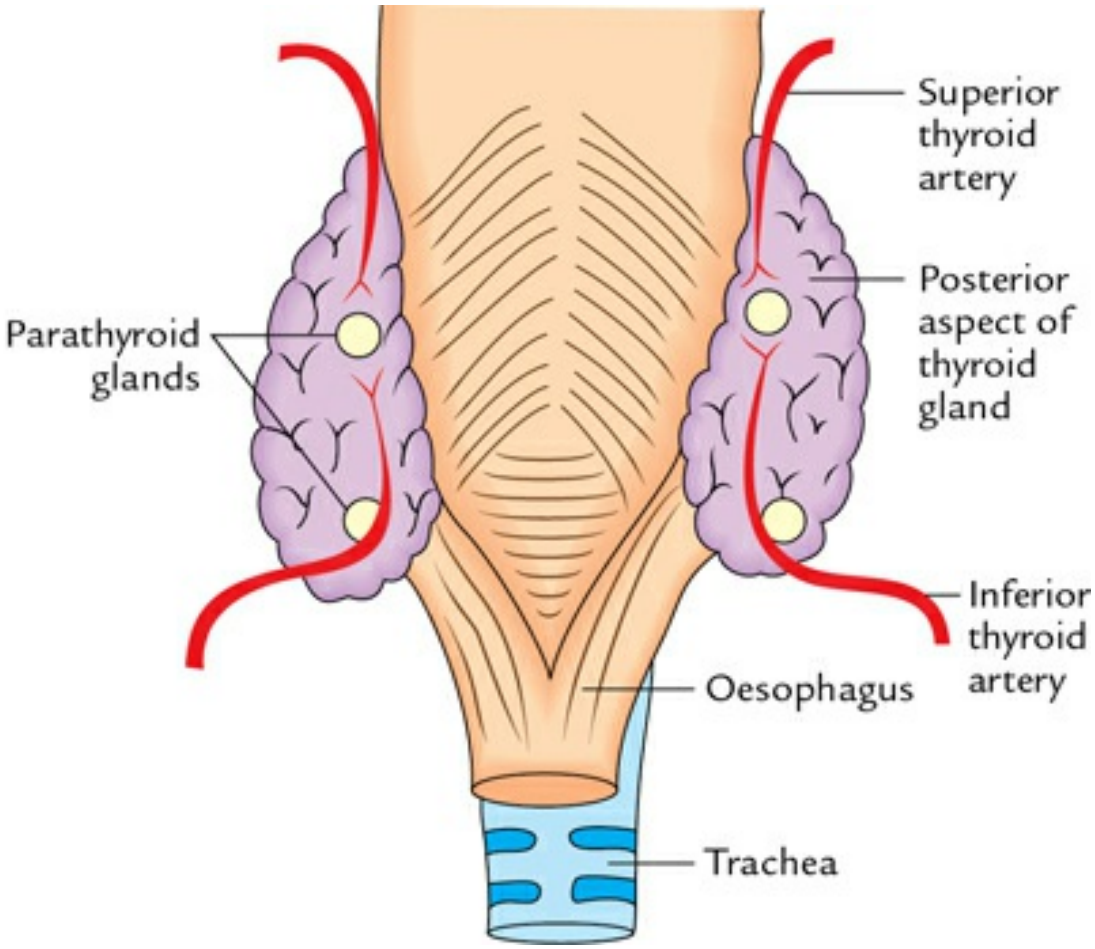


FIG. 13.6 ■ Position of parathyroid glands.

Structure

The cells of the parathyroid glands are densely packed in masses or cords

rather than in follicles.

Hormones secreted by parathyroid glands

The parathyroid glands secrete PTH. The PTH (also called **parathormone**) is important in maintaining blood calcium levels. It mobilizes calcium from bones and raises blood calcium levels. In addition, it inhibits the osteoblastic activity and promotes the osteoclastic activity of a bone. Further, it converts vitamin D into an active form, 1,25-dihydroxycholecalciferol, in the kidney and thus increases the absorption of calcium into the kidney.

An increasing calcium level in the blood, however, depresses the parathyroid activity. These balanced effects maintain blood calcium at a nearly constant level.

Parathormone from parathyroid gland and calcitonin from thyroid gland act in a complementary manner to maintain blood calcium levels within a normal range. This is needed for the following functions:

1. Muscle contraction
2. Blood clotting
3. Nerve impulse transmission.

Blood supply

The parathyroid glands are supplied by the inferior thyroid artery.

Clinical Correlation

- **Hypoparathyroidism:** It most commonly occurs due to *the atrophy or inadvertent surgical removal of the parathyroid glands*. It leads to a fall in blood calcium level (*hypocalcaemia*) which causes hyperexcitability and painful skeletal muscle spasms, causing characteristic inward bending of hands, forearms and feet. This produces a clinical condition called

tetany.

- **Hyperparathyroidism:** It most commonly occurs due to parathyroid adenoma. It leads to osteoporosis and consequent ***pathological fractures, formation of renal calculi, muscle weakness*** and ***calcification of the soft tissue***.

Suprarenal glands (adrenal glands)

There are two suprarenal glands, the right and the left. Each suprarenal gland is situated on the upper pole of each kidney. The right suprarenal gland is *shaped like a hat* and the left is *semilunar in shape* (Fig. 13.7). Like kidneys, they are retroperitoneal and are surrounded by abundant adipose tissue. They are about 4 cm long and 3 cm thick.

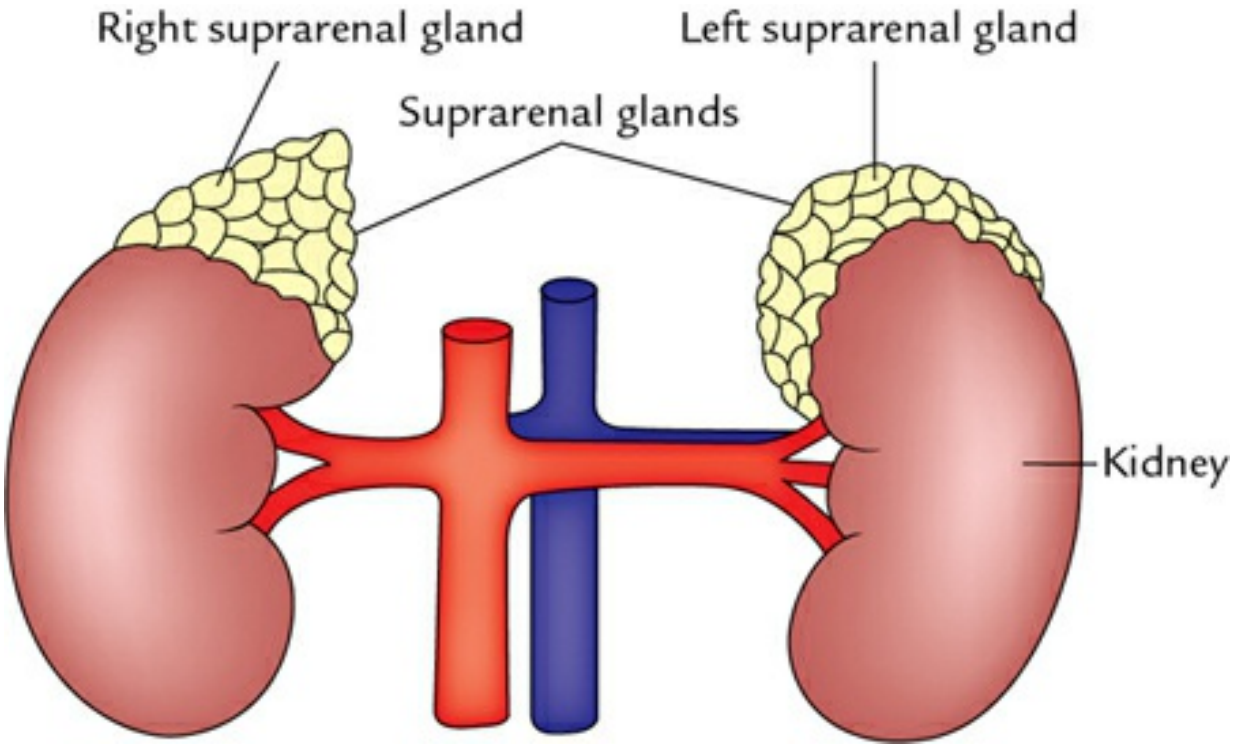


FIG. 13.7 ■ Position of suprarenal glands.

Structure and secretion of hormones

Each suprarenal gland is a composite organ consisting of two distinct parts

(Fig. 13.8) which are developmentally, structurally and functionally different. These parts are:

(a) an outer part called the **adrenal cortex** and
(b) an inner part called the **adrenal medulla**.

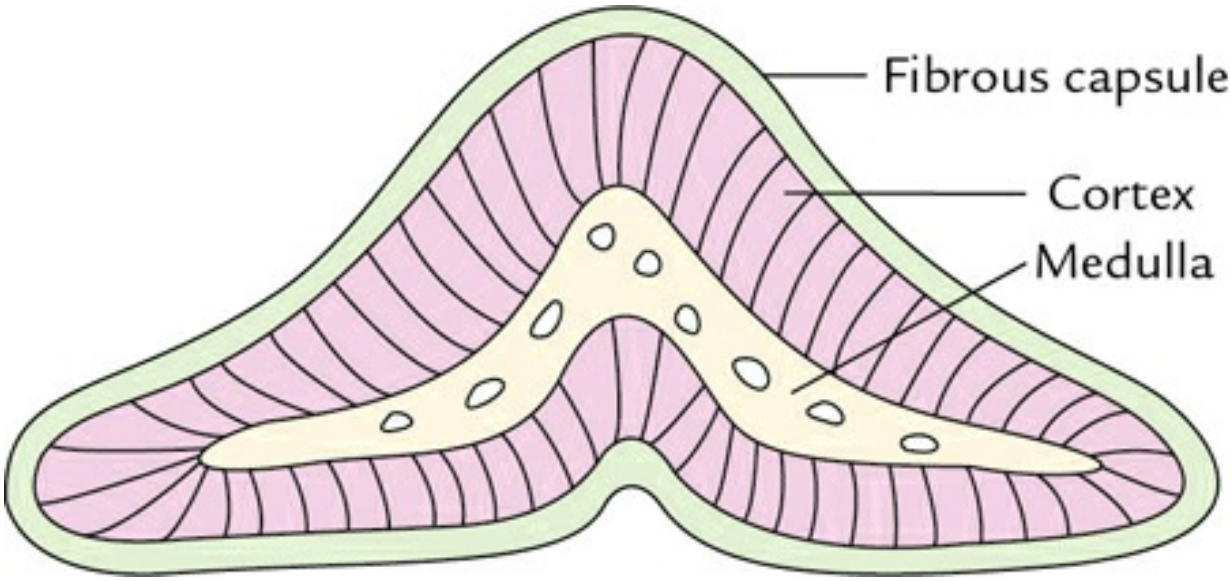


FIG. 13.8 ■ A cross-section through the suprarenal/adrenal gland shows the adrenal cortex and adrenal medulla.

The adrenal cortex develops from the mesoderm, whereas the adrenal medulla develops from the neural crest.

Adrenal cortex

The adrenal cortex is the outer larger part of the adrenal gland.

It is divided into three distinct zones:

1. An outer zone, called **zona glomerulosa**.
2. A middle zone, called **zona fasciculata**.
3. An inner zone, called **zona reticulata**.

Each zone secretes its own hormones as follows:

1. **Zona glomerulosa** secretes mineralocorticoids, e.g. aldosterone. The **aldosterone** increases sodium ion reabsorption and potassium and hydrogen ion secretion to control blood pressure.

2. **Zona fasciculata** secretes glucocorticoids, e.g. cortisol/cortisone. C**ortisol,** a glucocorticoid increases protein and fat breakdown, increases glucose production, and inhibits the immune response. It is thus responsible for the '*fight or flight response*'.
3. **Zona reticulata** secretes adrenal androgens, e.g. sex hormones. The **adrenal androgens** (sex steroids) are of minor importance in males; however, in females, they lead to the development of secondary sexual characteristics such as the development of axillary and pubic hair.

All the hormones (mineralocorticoids, glucocorticoids and sex hormones) secreted by the adrenal cortex are steroids.

Adrenal medulla

The adrenal medulla is inner soft part of the adrenal gland. It consists of cells that are arranged in anastomosing groups and are closely associated with sinusoids. The cells of the adrenal medulla are called **chromaffin cells** because secretory granules within their cytoplasm specifically stain brown when treated with potassium dichromate solution. The chromaffin cells secrete **catecholamines** which are of two types, **epinephrine** and **norepinephrine**. The release of catecholamines from the medulla is controlled by sympathetic nerves.

Medullary secretions result from emotional reactions, sexual excitement or stress. In general, hormones of adrenal medulla prepare the body for strong muscular activity and gear up the body for a fight or flight response.

Blood supply

Arterial supply

Each suprarenal gland is supplied by three arteries:

1. **Superior suprarenal artery**, a branch of an inferior phrenic artery
2. **Middle suprarenal artery**, a branch of the abdominal aorta
3. **Inferior suprarenal artery**, a branch of the renal artery.

Venous drainage

The venous blood from each suprarenal gland is drained by one vein: the right suprarenal vein drains into the inferior vena cava and the left suprarenal vein drains into the left renal vein.

Clinical Correlation

- **Cushing's syndrome:** It is a clinical condition that results due to hypersecretion of the adrenal cortex, i.e. hypersecretion of cortisol, androgens and aldosterone. The characteristic signs and symptoms of Cushing's syndrome are:
  (a) Accumulation of adipose tissue in the face (moon face), neck and the trunk of the body
  (b) Increased blood glucose level
  (c) Muscle wasting
  (d) Atrophy of lymphoid tissue and decreased immune response.
- **Adrenogenital syndrome:** It occurs due to hypersecretion of adrenal androgens and is usually associated with Cushing's syndrome. It is characterized by the early development of secondary sexual characters in male children and the masculinization of female children.
- **Pheochromocytoma:** It is a benign tumour that arises from chromaffin cells of the adrenal medulla. It causes hypersecretion of epinephrine and norepinephrine.
- **Neuroblastoma**: It is a malignant tumour arising from cells of the adrenal medulla. It occurs in infants and children below 15 years of age. Tumours that develop early tend to be highly malignant.

Pineal gland (epiphysis cerebri)

The pineal gland is a small cone-shaped outgrowth from the roof of the diencephalon. It is present below the splenium of the corpus callosum and is attached to the roof of the third ventricle by a stalk. The pineal gland is reddish-brown and typically measures around 7 mm × 6 mm × 3 mm in size. It is regarded as a photosensitive neuroendocrine gland.

Structure

The pineal gland consists of epithelioid cells called **pinealocytes** and neuroglial cells, and may contain calcareous granules called '**brain sand**'. It is richly supplied with capillaries and sympathetic fibres.

Hormones secreted by pineal gland

The pineal gland secretes two hormones: **melatonin** and **serotonin**. The pineal secretion is influenced by light, i.e. secretion is more in darkness than in light.

The **melatonin** decreases gonadotrophin-releasing hormone (GnRH) secretion from the hypothalamus and thus inhibits the development of the reproductive organs. It probably holds the onset of puberty until the appropriate time. S**erotonin** is an effective vasodilator.

The **pineal concretions** composed of calcium, magnesium, phosphates and carbonates begin to appear by middle age. They are not indicative of degenerative changes as was thought earlier. The secretory status of the gland is not affected by the appearance of the pineal concretions.

Functions of pineal gland

The functions of pineal gland are contradictory and not yet fully known. However, following functions are being attributed to the pineal gland:

1. Receives information about state of light and dark cycles from environment, i.e. it *maintains diurnal and circadian rhythms* of an individual.
2. Inhibits the growth and development of the sex organs before puberty, i.e. pineal gland *controls the onset of early puberty*
3. Modifies the activities of the adenohypophysis, neurohypophysis, endocrine pancreas, parathyroid, adrenal glands, and gonads (hence it is also called the master gland of the body).

Clinical Correlation

Calcification of pineal gland: In middle age, calcareous deposits accumulate in the pineal gland. The calcification of the pineal gland is often detectable in skull radiographs when it can provide a useful indicator of a space-occupying lesion as there is significant displacement of the gland from the midline in such lesions.

Blood supply

The pineal gland is supplied by the posterior choroidal artery, a branch of the posterior cerebral artery.

Thymus gland

The thymus gland is described in detail with endocrine glands in Chapter 11 on pg 159, Introduction and History of Anatomy.

Hormone secreted by thymus gland

The thymus gland secretes a hormone called **thymosin** which is required for the development of T lymphocytes for cell-mediated immunity.

Scattered masses of endocrine cells in exocrine glands

In addition to the presence of endocrine tissues in distinct endocrine glands such as the pituitary, thyroid, etc., some endocrine tissues such as **islets of Langerhans** of the pancreas, **interstitial cells (Leydig cells)** of the testis, **corpus luteum** of ovary occur as a scattered mass within an exocrine gland.

Islets of langerhans of pancreas

The pancreas is a gland with both exocrine and endocrine functions. The major exocrine function is performed by **pancreatic acini** which manufacture digestive enzymes, viz. lipase to breakdown fat, protease to breakdown

proteins and amylase to breakdown starches into sugar. Its endocrine function is executed by **islets (islands) of Langerhans**. The islets are highly vascular epithelial masses scattered among the exocrine glandular tissue.

The well-defined cell types of islets include alpha (α) cells and beta (β) cells. The β cells are far more numerous than the α cells. Other types of cells are also now recognized, namely delta cells, C cells, etc. (Fig. 13.9). The B cells produce **insulin** which plays an important role in carbohydrate metabolism. Without this hormone, the cells of the body cannot utilize glucose to form glycogen. As a result, there occurs a decrease in blood sugar level and an increase in glycogen level in the liver. The A cells produce **glucagon**. Its effect is opposite to that of insulin. The glucagon increases the blood sugar level by promoting glycogenolysis in the liver.

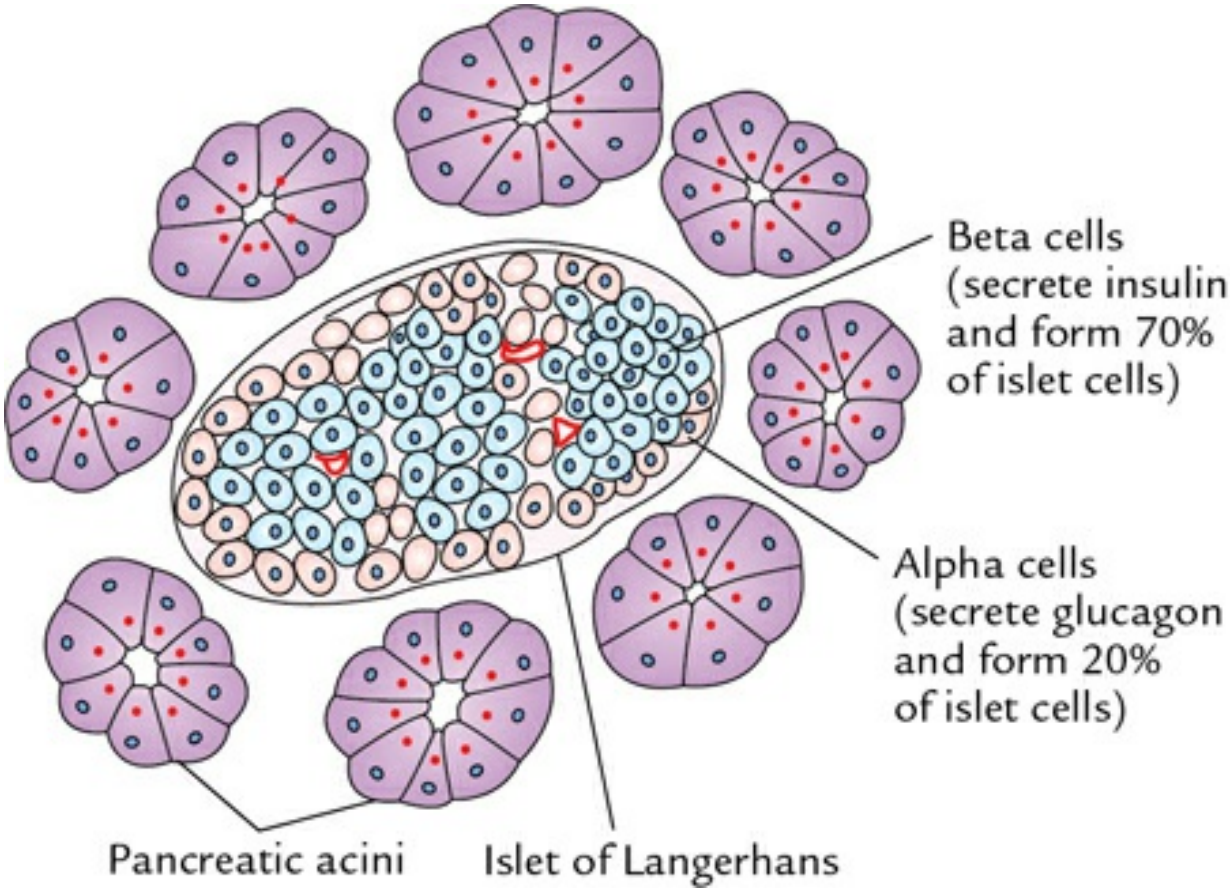


FIG. 13.9 ■ Microscopic structure of the pancreas. Note that alpha cells are towards the periphery and beta cells are towards the centre.

N.B.

The blood sugar level is controlled by the opposing actions of insulin and glucagon:

- Insulin decreases blood sugar levels.
- Glucagon increases blood sugar levels.

Clinical Correlation

Diabetes mellitus: It is a clinical condition that results from the deficiency of insulin. It is characterized by hyperglycaemia and glycosuria of variable severity. Clinically, it presents as polyphagia (excessive eating), polydipsia (excess drinking of water) and polyuria (excessive urine).

Gonads

Testes

The testes, two in number, are small ovoid organs, about 5-cm long and 2.5-cm wide located within the scrotum. The testis has both exocrine and endocrine functions. The exocrine function of the testis is the production of spermatozoa, whereas the endocrine function of the testis is the production of steroid hormones (e.g. testosterone).

The testis is made up of a large number of seminiferous tubules which produce spermatozoa. In between these tubules, there are loose interstitial cells also known as **Leydig cells**. These cells are endocrine cells. They produce the male hormone **testosterone**. It is classified as an androgen (andro means male) because it stimulates the development of secondary sexual characteristics of a male at puberty. Other functions of testosterone are as follows:

1. It plays an important role in the development of male reproductive organs during embryonic life.
2. It is essential for the maintenance of sperm production.
3. It influences sexual behaviour.
4. It regulates the production of GnRH from the hypothalamus.

The **Sertoli cells** of seminiferous tubules produce a polypeptide hormone called **inhibin** which inhibits FSH secretion from the anterior pituitary.

Ovary

The ovaries, two in number, are small almond-shaped organs about 2.5-cm long and 1.25-cm wide. They lie in the ovarian fossa at the lateral pelvic wall one on each side. Each ovary is attached to the posterior surface of the broad ligament of the uterus by a short peritoneal fold called **mesovarium**.

As an endocrine gland, ovary secretes the **steroid hormones** which are required to prepare the endometrium suitable for the implantation of the fertilized ovum.

The hormones are produced by stromal cells which are arranged into two distinct zones around the ovarian follicles:

1. The inner zone, known as **theca interna**.
2. The outer zone, known as **theca externa**.

The *theca interna cells secrete oestrogen hormone* which stimulates the proliferation of the endometrium. The *theca externa remains small and compact, and has no known secretory function*.

After ovulation, the granulosa cells of the follicle undergo some changes. They divide rapidly and enlarge followed by progressive organization and fibrosis to form **corpus luteum**. *The corpus luteum acts as an endocrine gland*. The corpus luteum consists of the central area of the fibrosing blood clot and the peripheral broad area made up of yellow lipid-rich granulosa lutein cells. The enlarged granulosa cells secrete **progesterone**. If fertilization takes place, corpus luteum increases in size and continues secreting progesterone needed for maintaining the pregnancy till the placenta is formed and takes over its function.

Diffuse neuroendocrine cells

There are certain scattered neuroendocrine cells such as (a) rennin-producing

juxtaglomerular cells of the kidney and (b) gut-associated endocrine cells or enteroendocrine cells, found scattered mainly in the epithelial layer of the stomach and small intestine.

The **enteroendocrine cells** of the stomach produce **gastrin** which acts on the fundic glands of the same organ, i.e. stomach to secrete hydrochloric acid (HCl).

The enteroendocrine cells of the duodenum produce four hormones:

1. **Secretin** causes secretion of pancreatic juice.
2. **Cholecystokinin** causes secretion of bile.
3. **Pancreozymin** causes the secretion of pancreatic enzymes.
4. **Enterogastrone** inhibits peristalsis of the stomach to reduce its acid secretion.

Golden Facts to Remember

• **Most complex endocrine gland in the body**	Pituitary gland
• **Most variable position of endocrine gland in the body**	Inferior parathyroid
• **All endocrine glands pour their secretion directly into the bloodstream *except***	The thyroid gland which first stores its secretion within its follicles and then releases it into the bloodstream according to the need
• **Third eye**	Pineal gland
• **Master endocrine gland**	Pituitary gland
• **Gland responsible**	Pineal gland for circadian rhythm

Multiple choice questions

1. **Select the *incorrect statement*** regarding the pituitary gland:
   (a) Develops from two different sources

(b) Is the largest endocrine gland
(c) Secretes ADH
(d) Is located on the inferior aspect of the brain

2. **Regarding the thyroid gland, all are true *except:***
   (a) It is the largest endocrine gland
   (b) Its unit structure is called thyroid acinus
   (c) It secretes three hormones
   (d) Dietary iodine is essential for the synthesis of T3 and T4
3. **Thyroid gland secretes all of the following hormones *except:***
   (a) Tri-iodothyronine
   (b) Tetra-iodothyronine
   (c) GH
   (d) Calcitonin
4. **Regarding the parathyroid glands, which of the following statements is *not correct*?**
   (a) They are four in number
   (b) They are located on the posterior surfaces of thyroid lobes
   (c) Their removal leads to an increase in blood calcium level
   (d) Their size is roughly equal to a split-pea
5. **Regarding the adrenal glands, which of the following statements is *not correct*?**
   (a) Right suprarenal gland is semilunar in shape
   (b) They are retroperitoneal in location
   (c) They secrete epinephrine and norepinephrine
   (d) Cortex of each gland is divided into three distinct zones
6. **All are correct regarding the pineal gland *except:***
   (a) It is a small outgrowth from the root of the diencephalon
   (b) It is supplied by sympathetic fibres
   (c) It secretes calcitonin
   (d) It is photosensitive
7. **The hormone insulin:**
   (a) Is secreted by alpha cells of the islets of Langerhans
   (b) Is secreted by beta cells of the islets of Langerhans
   (c) Plays an important role in carbohydrate metabolism
   (d) Stimulates the production of glycogen
8. **The hormone testosterone is not responsible for**:
   (a) Development of male reproductive organs during embryonic life
   (b) Maintenance of sperm production

(c) Production of GnRH from the hypothalamus
(d) Maintaining blood calcium level

9. **All are correct regarding the pituitary gland *except:***
   (a) It weighs about 25 g
   (b) Develops from two entirely different sources
   (c) It is located within the cranial cavity
   (d) It secretes GH
10. **A clinical condition called tetany occurs due to**:
   (a) Hyperthyroidism
   (b) Hypothyroidism
   (c) Hyperparathyroidism
   (d) Hypoparathyroidism

Answers

1. *b*, **2.** *b*, **3.** *c*, **4.** *c*, **5.** *a*, **6.** *c*, **7.** *a*, **8.** *d*, **9.** *a*, **10.** *d*.

Chapter 14: Digestive and respiratory systems

Specific learning objectives

After studying this chapter, the student should be able to:

- Describe the parts of digestive system and enumerate their functions.
- Describe salivary glands and discuss their functions.
- Elucidate the location and functions of the pharynx, oesophagus and stomach.
- Delineate the parts of the small intestine and enumerate its functions.
- Describe the accessory glands of the digestive system and discuss their role in digestion.
- Define the respiratory system and its two divisions.
- Enumerate the components of conducting and respiratory portions of the respiratory system.
- Name the air passage of the bronchial tree in descending order of the size of their lumen.
- Describe the location of the gross features of the lungs.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

Digestive system

The digestive system consists of the **gastrointestinal tract** and **associated organs of digestion** such as *teeth, tongue, salivary glands, liver, gallbladder* and *pancreas*.

It provides water, electrolytes, vitamins and nutrients to the body with the help of the circulatory system.

The functions of the digestive system are as follows:

1. **Ingestion:** taking in food through the mouth.
2. **Mastication:** movements of the lower jaw during chewing to pulverize food and mix it with saliva.
3. **Deglutition:** swallowing of food so that it passes from mouth to stomach.
4. **Digestion:** chemical breakdown of food material into smaller components, until they are absorbed into the body.
5. **Absorption:** nutrient molecules are absorbed into the circulatory system through the mucous membrane of the small intestine.
6. **Peristalsis:** rhythmic wave-like intestinal contractions that move food through the digestive tract.
7. **Defaecation:** elimination of solid/semisolid/-liquid waste material of food (i.e. faeces) through the anus.

Digestive tract

The digestive tract extends from the mouth to the anus. Roughly, it is a tubular passage and measures about 10 m (30 ft) in length.

The digestive tract consists of the following parts from proximal to distal ends in succession (Fig. 14.1):

1. Mouth (oral cavity)
2. Pharynx
3. Oesophagus
4. Stomach
5. Small intestine
6. Large intestine
7. Rectum

8. Anal canal.

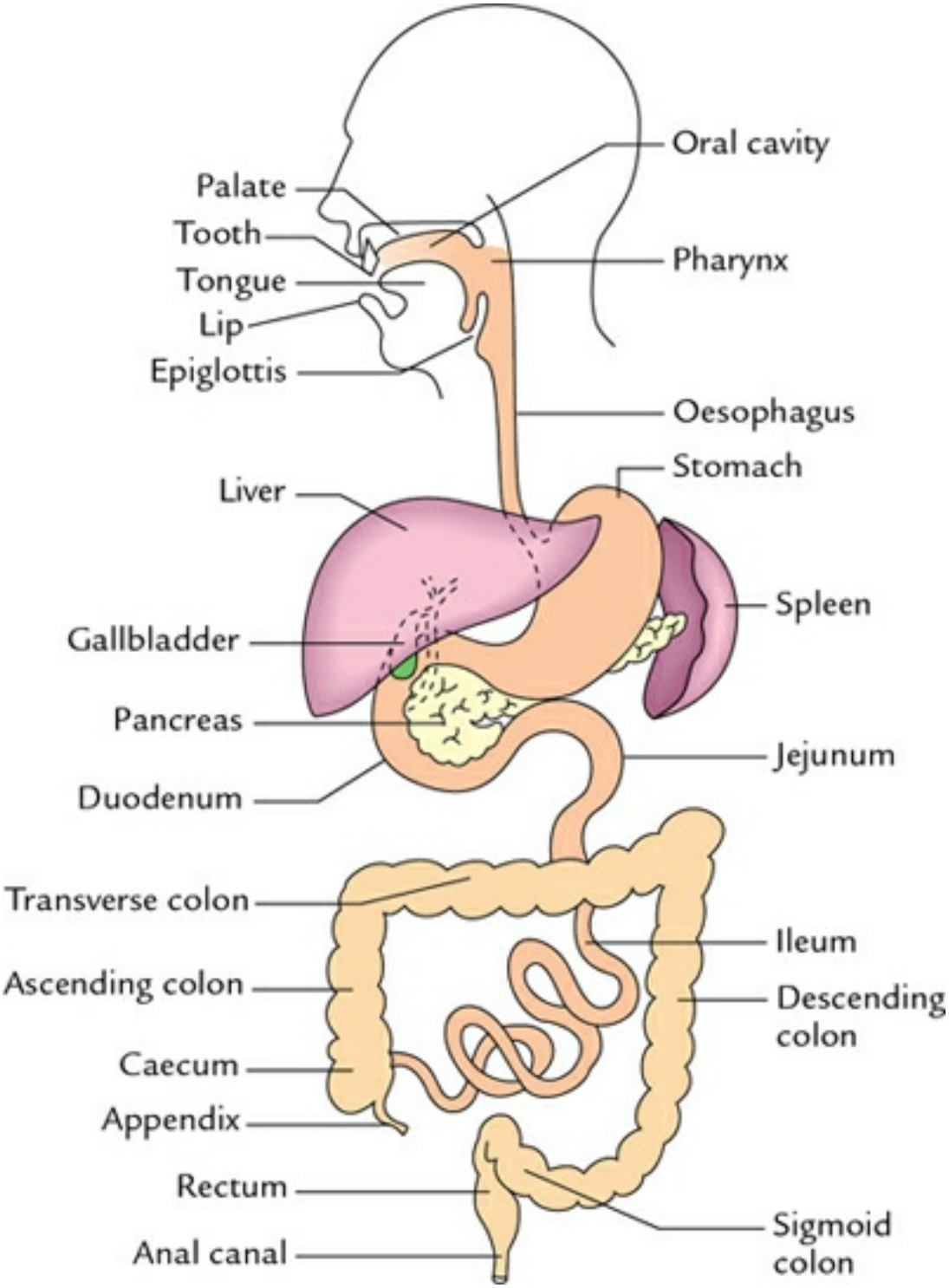


FIG. 14.1 ■ Digestive system.

Mouth (oral cavity)

The mouth or oral cavity is the first part of the digestive tract. It is bounded anteriorly by **lips**, laterally by **cheeks**, superiorly by **palate** and inferiorly by a **muscular floor**.

The oral cavity communicates externally through a cleft, between the upper and lower lips, called oral orifice and internally through fauces into the pharynx.

The oral cavity is divided into two parts: (1) vestibule and (2) oral cavity proper.

The **vestibule** is a horseshoe-shaped space outside the gums and teeth and inside the lips and cheeks.

The **oral cavity proper** is a space surrounded by teeth and gums. It contains a tongue which is attached to its floor.

The **teeth** form two dental arches: one set in the upper jaw and the other set in the lower jaw.

N.B.

- The oral cavity is lined by protective stratified squamous non-keratinized epithelium.
- The mucous lining of the palate, lips and cheeks contain minor salivary glands of the size of pinheads which keep the epithelial lining of the oral cavity moist.

Lips and cheeks

The lips are muscular folds guarding the oral orifice and the cheeks form lateral walls of the oral cavity. The lips and cheeks are lined internally by mucosa and externally by the skin.

The lips and cheeks play an important role in the process of mastication. They help manipulate the food within the oral cavity and hold the food in place for proper crushing and cutting by the teeth.

Teeth

The teeth are embedded in the sockets of the alveolar process of the mandible and maxilla. In an adult individual, there are 32 teeth, 16 in each jaw.

In humans, the teeth are replaced only once **(diphyodont)** in contrast to non-mammalian vertebrates where the teeth are constantly replaced throughout life **(polyphyodont)**.

The teeth in humans are **heterodont**, i.e. they vary structurally and are adapted to handle food in different ways. The teeth are of the following four types:

1. **Incisors** (four pairs, upper and lower)-are chisel-shaped and adapted for cutting and shearing food.
2. **Canines** (two pairs, upper and lower)-are cone-shaped and adapted for holding and tearing.
3. **Premolars**/bicuspids (four pairs, upper and lower).
4. **Molars**/tricuspids (six pairs, upper and lower).

The premolars and molars have irregular rounded surfaces called cusps and are adapted for crushing and grinding food.

Tongue

The tongue is a large muscular organ that occupies most of the oral cavity proper. It is made up of two types of muscles: **intrinsic muscles**, which are within the tongue itself, and **extrinsic muscles**, which are outside the tongue but attached to it.

The intrinsic muscles are responsible for changing the shape of the tongue, such as during drinking and swallowing, whereas the extrinsic muscles move the tongue.

The tongue is the major sensory organ for taste. The taste buds containing these receptors are located on the dorsal surface of the tongue. The ventral surface of the tongue is covered by the thin mucous membrane which is reflected onto the floor of the oral cavity proper. There is a median fold of mucous membrane between the tongue and floor of the mouth called **frenulum linguae**. The oral cavity along with lips and cheeks holds the food

in place during mastication. The tongue also plays a major role in swallowing food and water, etc.

Clinical Correlation

Sublingual route of drug administration: Certain drugs which are lipid-soluble can diffuse through the mucous lining of the oral cavity and can be absorbed into the blood. An example is nitroglycerin, a vasodilator that is placed under the tongue in *angina pectoris*. In less than 1 min, nitroglycerin dissolves and reaches the circulation.

Pharynx

The pharynx is a funnel-shaped passageway, approximately 5 in. (12.5 cm) long, which connects oral and nasal cavities to the oesophagus and larynx. It receives a bolus of food from the oral cavity and passes it to the oesophagus. Pharyngo-oesophageal junction is the narrowest site of the digestive tract.

For descriptive purposes, the pharynx is divided into three parts: **nasopharynx**, **oropharynx** and **laryngopharynx** according to the location of the part behind the nasal cavity, oral cavity and laryngeal cavity, respectively. The nasopharynx is part of the respiratory system, whereas the oropharynx and laryngopharynx are passages common to both the respiratory and digestive systems. (For details refer to Textbook of Anatomy Volume III by Vishram Singh.)

N.B.

- The musculature of the pharynx is made up of voluntary muscles but it is not under voluntary control.
- The interior of the pharynx is lined by protective stratified squamous epithelium.

Oesophagus

The oesophagus is a collapsible muscular tube about 25 cm (10 in.) long. It has a diameter of 2 cm. It connects the pharynx to the stomach. The

oesophagus transports bolus of food from the pharynx to the stomach by peristaltic movements.

The oesophagus is the most muscular part of the digestive tract. The musculature in the upper half of the oesophagus is made up of voluntary muscles but they are not under voluntary control. The musculature in the lower half of the oesophagus is made of involuntary muscles. The lumen of the terminal portion of the oesophagus is narrowed due to the thickening of circular muscle fibres in its wall, forming the **gastro-oesophageal/lower oesophageal sphincter**. The sphincter prevents the reflux regurgitation of food from the stomach into the oesophagus.

The presence of food in the oesophagus causes the gastro-oesophageal sphincter to relax and allows the food to enter the stomach. The swallowed food takes about 5–9 s to travel to the stomach.

The sphincter at the upper end of the oesophagus (upper oesophageal sphincter) is formed by the cricopharyngeus muscle of the pharynx. It prevents the air from passing into the oesophagus during inspiration.

The lumen of the oesophagus is lined by protective non-keratinized stratified squamous epithelium. Numerous mucous glands in the submucosa produce thick lubricating mucus.

Function

The main function of the oesophagus is swallowing, i.e. to carry food and liquid from mouth to stomach.

Stomach

The stomach (Gk. g*aster* = belly) is the most distensible part of the GI tract and lies in the epigastric region of the abdominal cavity below the diaphragm. It is a 'J-shaped' pouch that connects the oesophagus with the duodenum.

About 2 L of gastric juice is secreted daily by secretory cells in the gastric mucosa. It consists of water, mineral salts, mucous, hydrochloric acid, intrinsic factor and pepsinogens. Hydrochloric acid kills ingested microbes and converts inactive pepsinogen into active pepsin.

Functions

The functions of the stomach are as follows:

1. To store food as it is mechanically churned with gastric secretions
2. To initiate the digestion of proteins
3. To move food into the small intestine as a pasty material, called **chyme**.

The food is stored in the stomach until it passes at a controlled rate into the duodenum. The outlet of the stomach, the ***pylorus*** (Gr. = a gatekeeper) is guarded by a strong sphincter of circular muscle fibres called the **pyloric sphincter**.

N.B.

The stomach can accommodate volumes from 0.5–5 L.

Small intestine

The small intestine is a long hollow muscular tube about 6 m (20 ft) that connects the stomach with the large intestine. It is located in the centre of the abdominal cavity surrounded by the large intestine.

Functions

- Digestion of food (90%)
- Absorption of nutrients (90%).

Parts

The small intestine is divided into three parts:

1. Duodenum
2. Jejunum
3. Ileum.

Duodenum

The duodenum is a fixed C-shaped tube about 25 cm (10 in.) long that

connects the pylorus of the stomach to the jejunum.

The concavity of the duodenum faces towards the left and is occupied by the head of the pancreas.

The duodenum receives **bile** from the liver and gallbladder through the **common bile duct (CBD)** and **pancreatic secretions** through the pancreatic duct. Both these ducts unite to form a common entry into the duodenum, called **hepatopancreatic ampulla** which enters into the duodenum through its left concave aspect. In the duodenum, digestion continues and absorption of water and digestive products begins.

Jejunum and ileum

Clinically, the jejunum and the ileum together form the small intestine.

The jejunum is about 2 m (6 ft) long and extends from the duodenum to the ileum. The ileum is about 3 m (9 ft) long and connects the jejunum with the caecum.

The small intestine is supported by mesentery proper. Since the root of the mesentery is only 15 cm (6 in.) long, the small intestine is thrown into folds called **loops**. The loops of the jejunum tend to be located in the left lateral region of the abdominal cavity while the ileal loops tend to be located in the pelvic cavity.

The main function of the small intestine is the absorption of nutrients from digested food. In order to suit this function, the surface area of the mucosa of the small intestine is extensively increased by: (1) circular folds of mucosa and submucosa called **plicae circularis** and (2) the presence of ***villi.*** The villi are finger-like projections of the mucosa.

The intestine is exposed to toxins and microorganisms. To protect the intestine from toxins and microorganisms, there are aggregations of lymphoid tissue in the mucosa, called **Peyer's patches**, which are usually concentrated along the antimesenteric border. The concentration of Peyer's patches is maximum in the terminal portion of the ileum. The Peyer's patches get ulcerated in typhoid fever if not treated timely and may cause intestinal perforation.

Large intestine

The large intestine is 1.5 m (5 ft) long and extends from the ileocaecal junction to the anal orifice. It is called the large intestine not only it is longer than the small intestine but also its diameter is larger than that of the small intestine.

The large intestine is divided into the following parts:

1. Caecum and appendix
2. Ascending colon
3. Transverse colon
4. Descending colon
5. Sigmoid colon
6. Rectum
7. Anal canal.

The large intestine has no digestive function, but it absorbs water and electrolytes from the chyme, which it receives from the small intestine, a process that forms faeces. The faeces are stored in the sigmoid colon and then evacuated through the rectum and anal canal.

The mucous membrane of the large intestine does not have folds except in the rectal portion. There are also no villi in the large intestine. The intestinal glands are long and characterized by a great abundance of goblet and absorptive cells. In the submucous layer, there are more lymphoid tissues than in any other part of the alimentary tract, providing non-specific defence against resident and other microbes.

After a meal, the motility of the large intestine increases and as a result, the faecal matter (faeces) is pushed into the rectum. The distension of the rectum acts as a stimulus to initiate the defaecation reflex for the defaecation to occur. But this local reflex is modified by higher centres so that defaecation occurs at an appropriate time and place. For rectum and anal canal, see *Textbook of Anatomy: Abdomen and Lower Limb,* Vol. III, 2E by Vishram Singh.

Major digestive glands

Salivary glands

These are accessory glands of digestion that produce saliva. The saliva acts as a solvent in cleaning the teeth and dissolving the food chemicals so that they can be tasted. It also contains enzymes (*ptyalin, lysozymes*, etc. and mucous). The *ptyalin* digests starch, *lysozymes* are bactericidal, and mucus lubricates the food and the oral cavity.

The salivary glands can be classified into two types:

1. Minor salivary glands
2. Major salivary glands.

Minor salivary glands

The minor salivary glands are numerous and are of the size of pinheads. They are located in the mucous membranes of the palate, cheeks and lips, hence named as **palatine, buccal** and **labial glands** respectively. They produce a small quantity of saliva.

Major salivary glands

There are three pairs of major salivary glands: parotid, submandibular and sublingual which lie outside the oral cavity (Fig. 14.2).

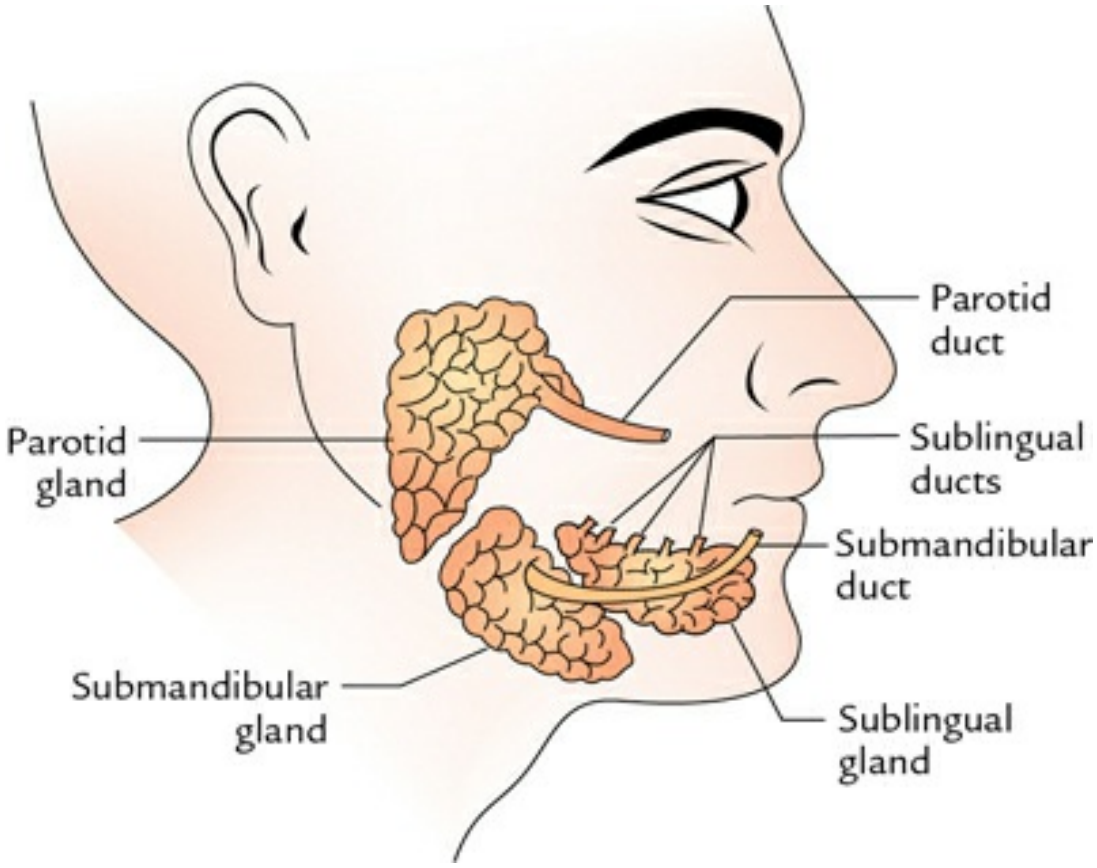


FIG. 14.2 ■ Three major salivary glands: parotid, submandibular and sublingual.

The **parotid gland** is the largest and is located below and in front of the external ear.

The **submandibular gland** is located inside and below the mandible.

The **sublingual gland** lies underneath the mucosa of the floor of the mouth on the side of the tongue.

The **parotid duct** opens into the vestibule of the mouth opposite the second upper molar tooth.

The **submandibular duct** opens on the floor of the oral cavity proper onto a papilla on the side of the root of the frenulum of the tongue behind the lower incisor teeth.

The **sublingual ducts**, several in number and small in length open into the floor of the mouth on a ridge posterior to the papilla of the submandibular duct.

N.B.

In humans, 1–1.5 L of saliva is secreted in a day.

Clinical Correlation

Diseases of salivary glands: The commonest surgical diseases of the salivary glands are viral infections, calculi, and development of tumours.

Mumps (acute viral parotiditis) is the commonest medical disease of the salivary glands.

Liver

The liver (Gk. *hepar* = liver) is the largest internal organ of the body weighing about 1500 g (1.5 kg) in an adult. It is reddish-brown and is located in the upper right portion of the abdominal cavity, immediately below the diaphragm in the right hypochondriac and epigastric regions of the abdominal cavity.

The liver is roughly triangular (wedge-shaped). The base is directed towards the right while the apex is pointed and reaches the 5th intercostal space in the mid-clavicular line. Its diaphragmatic surface is related to the diaphragm and adjacent body walls and its visceral surface is related to the abdominal organs. It is divided into two major lobes: left and right, and two minor lobes: caudate and quadrate (Fig. 14.3). The vessels, ducts and nerves enter and exit the liver through a depressed area on its inferior surface called 'porta hepatis' (porta = gate).

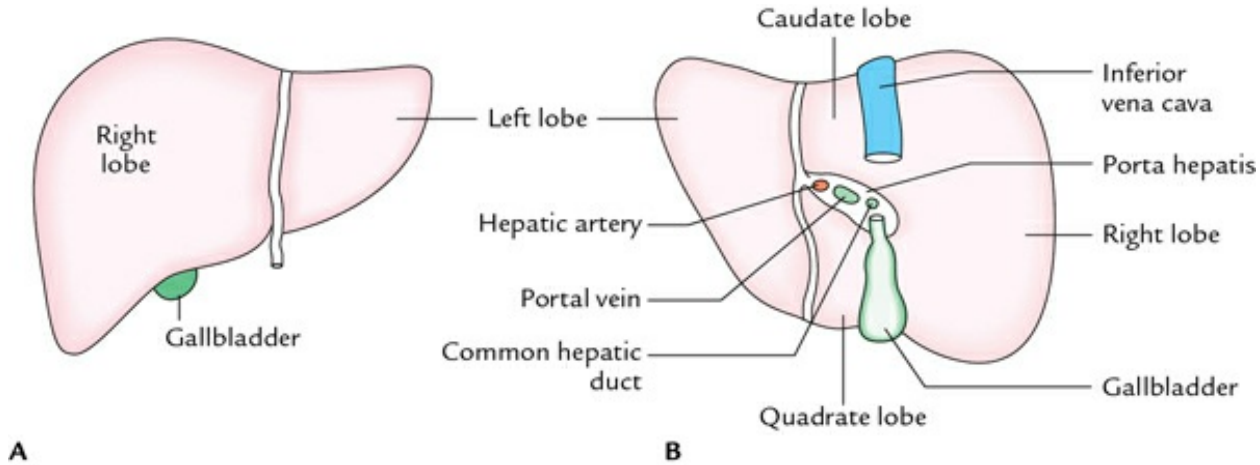


FIG. 14.3 ■ Liver: **A**, anterior view and **B**, inferior view.

The internal substance of the liver is divided into segments (hepatic segments) on the basis of the ramification of the bile duct and hepatic

vessels.

Structure

The liver has a uniform structure consisting of anastomosing sheets of the hepatic cells, called **hepatic plates**. These plates are only one or two cells thick and separated from each other by large capillary spaces called **sinusoids**. The sinusoids are lined with phagocytic **Kupffer's cells**.

The hepatic plates are arranged into functional units called **liver lobules**. Each lobule is hexagonal. In the centre of each lobule is a central vein and at the periphery of each lobule are branches of the portal vein and hepatic artery and interlobular bile duct which together form a portal triad.

The liver has a dual blood supply from the hepatic artery and portal vein. The blood of the portal vein (nutrient-rich and deoxygenated) and hepatic artery circulates through sinusoids and supplies the liver cells and then leaves the liver through hepatic veins into the inferior vena cava.

Recently and more correctly, it is found that **portal lobules** form the functional units of the liver. It consists of the area of liver tissue supplied by one of the branches of the portal vein. However, there are still smaller units in the liver called **portal acini**. Each portal acinus consists of an area of liver tissue supplied by one hepatic arteriole running along the line of junction of two hepatic lobules. At each end of the acinus lies the central vein.

The hepatic cells secrete bile into thin channels called **bile canaliculi** located within each hepatic plate. These canaliculi are merely spaces present between plasma membranes of adjacent liver cells. Bile canaliculi join to form **interlobular ducts,** which in turn form larger interlobar ducts of the portal triad. The larger interlobular ducts join to form hepatic ducts that carry bile away from the liver.

Functions of liver

The liver is an extremely active organ. The important functions of the liver are:

1. Metabolism of fats, proteins and carbohydrates

2. Detoxification of drugs, viz. alcohol and noxious substances.
3. Production and synthesis of plasma proteins.

Bile secretion

The liver secretes about 1 L of bile every day into the biliary tree. Among the constituents of bile are **bile salts** and **bile pigments**. The bile pigments produce the distinctive colour of faeces. Bile salts help in the digestion of fat by emulsification.

Clinical Correlation

Common liver diseases: They include **hepatitis** (viral and amoebic), **cirrhosis of the liver, amoebic liver abscess, tumours**, etc.

Liver diseases often present with jaundice. Jaundice is a yellow discolouration of the skin caused by excess bile pigment in the blood plasma.

N.B.

Any obstruction of the biliary tree may produce *jaundice*, but the two most common causes are: (1) gallstones in the CBD and (2) carcinoma head of the pancreas obstructing the CBD.

Gallbladder

The gallbladder is a pear-shaped sac attached to the inferior surface of the right lobe of the liver. The gallbladder stores and concentrates bile which it receives from the liver through hepatic ducts and cystic ducts (Fig. 14.4).

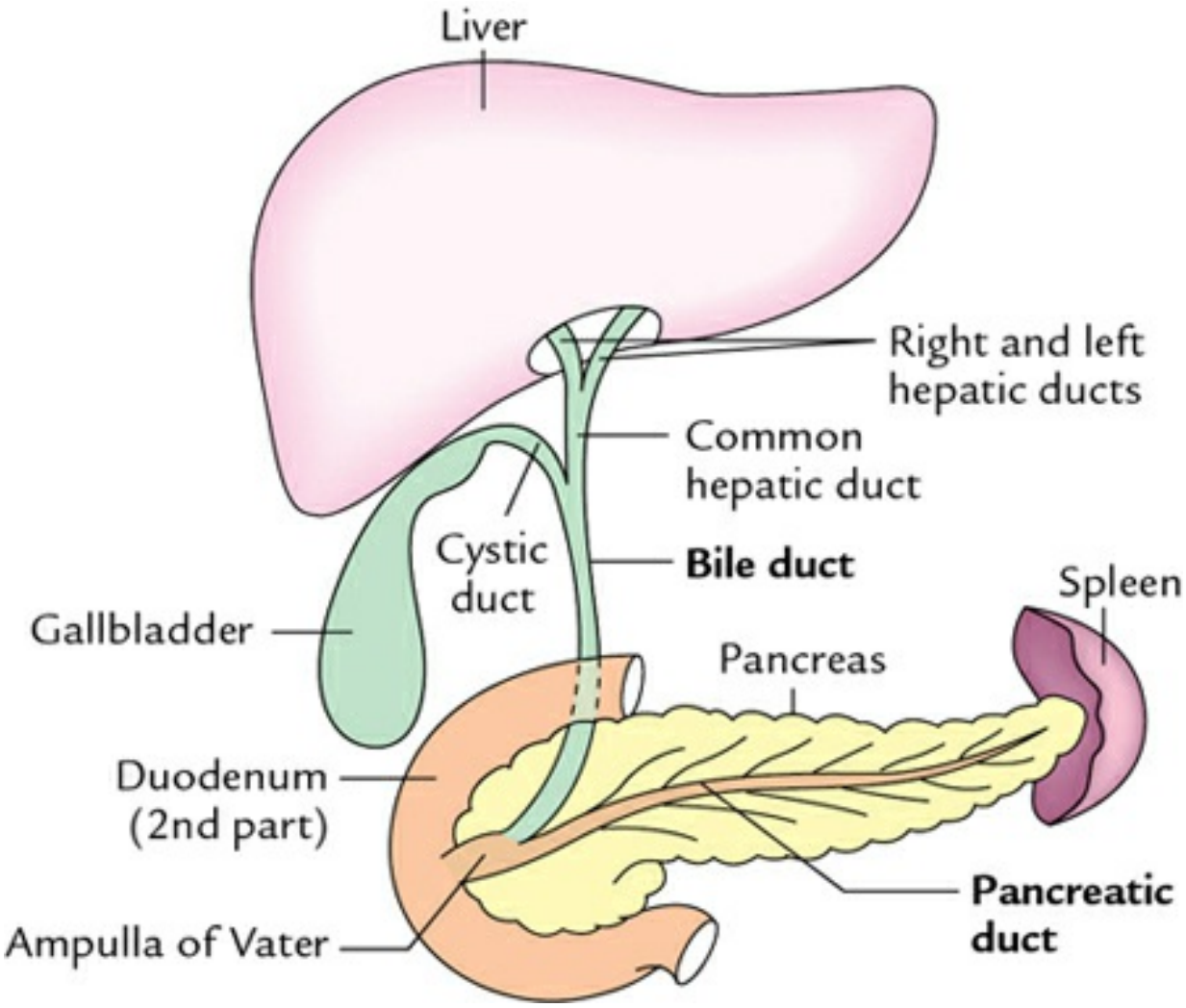


FIG. 14.4 ■ Ducts of major digestive glands.

Bile is a yellowish-green fluid containing **bile salts and bile pigments**. When the fatty chyme enters the duodenum from the stomach, the intestinal glands in the duodenal mucosa release a hormone, called **cholecystokinin** which induces contraction of gallbladder musculature and bile is poured into the duodenum to break down fats.

Function

Storage and concentration of bile.

Clinical Correlation

Gallstones: A common clinical problem of the gallbladder is the development of gallstones. The bile consists of various salts, pigments and cholesterol which becomes concentrated as water is removed. Normally,

cholesterol remains in the form of solution but under certain conditions, it precipitates to form solid crystals called *gallstones.*

Extrahepatic biliary apparatus

It consists of the following structures (Fig. 14.4):

1. Right and left hepatic ducts
2. Common hepatic duct
3. Gallbladder and cystic duct
4. Bile duct.

The right and left hepatic ducts after emerging from porta hepatis join to form a common hepatic duct, which in turn joins the cystic duct to form the bile duct (commonly called CBD by the clinicians).

Pancreas

The pancreas is a long, soft and lobulated gland that extends across the posterior abdominal wall behind the stomach. It has an expanded head near the duodenum, a centrally located body, and a tapering tail near the spleen. It acts both as exocrine and endocrine glands. The pancreatic acini secrete **pancreatic juice** (**exocrine secretion**) that passes to the duodenum through the pancreatic duct. The pancreatic duct joins the CBD to form the **ampulla of Vater**, which opens into the second part of the duodenum. The pancreatic juice is highly alkaline (pH = 8) due to the presence of carbonates. This helps to neutralize the acidic chyme as it enters the duodenum. The enzymes in the pancreatic juice are trypsin, amylase and lipase. The trypsin helps in the digestion of proteins, amylase in the digestion of starch and lipase in the digestion of fat.

Pancreatic **islets of Langerhans** secrete hormones, namely insulin and glucagon (endocrine secretion). Insulin plays a major role in carbohydrate metabolism.

Clinical Correlation

Pancreatic cancer: It is extremely fatal because of its vital exocrine and

endocrine functions. Moreover, pancreatic surgery is a problem because the pancreas is made of spongy vascular tissue, hence it is difficult to suture.

Respiratory system

The respiratory system is concerned with oxygenation of blood by lungs. It involves breathing, which is the process of inhalation and exhalation of air during respiration. Respiration consists of the following two processes:

1. Movement of air in and out of lungs (i.e. ventilation).
2. Gaseous exchange between air in the lung alveoli and the blood in lung capillaries, i.e. transportation of oxygen (O_2) into blood and removal of carbon dioxide (CO_2) from blood into lung alveoli.

The respiratory tract thus allows oxygen from atmospheric air to enter into the blood in the lungs and carbon dioxide to leave the blood within lung capillaries into lung alveoli to enter the atmospheric air.

Components of respiratory system

Anatomical subdivision

Anatomically, the respiratory system is broadly divided into the following two parts (Fig. 14.5):

1. **Upper respiratory tract** (URT): It comprises:
   (a) Nasal cavities
   (b) Pharynx and associated structures
2. **Lower respiratory tract** (LRT): It comprises:
   (a) Larynx
   (b) Trachea
   (c) Bronchi
   (d) Lungs.

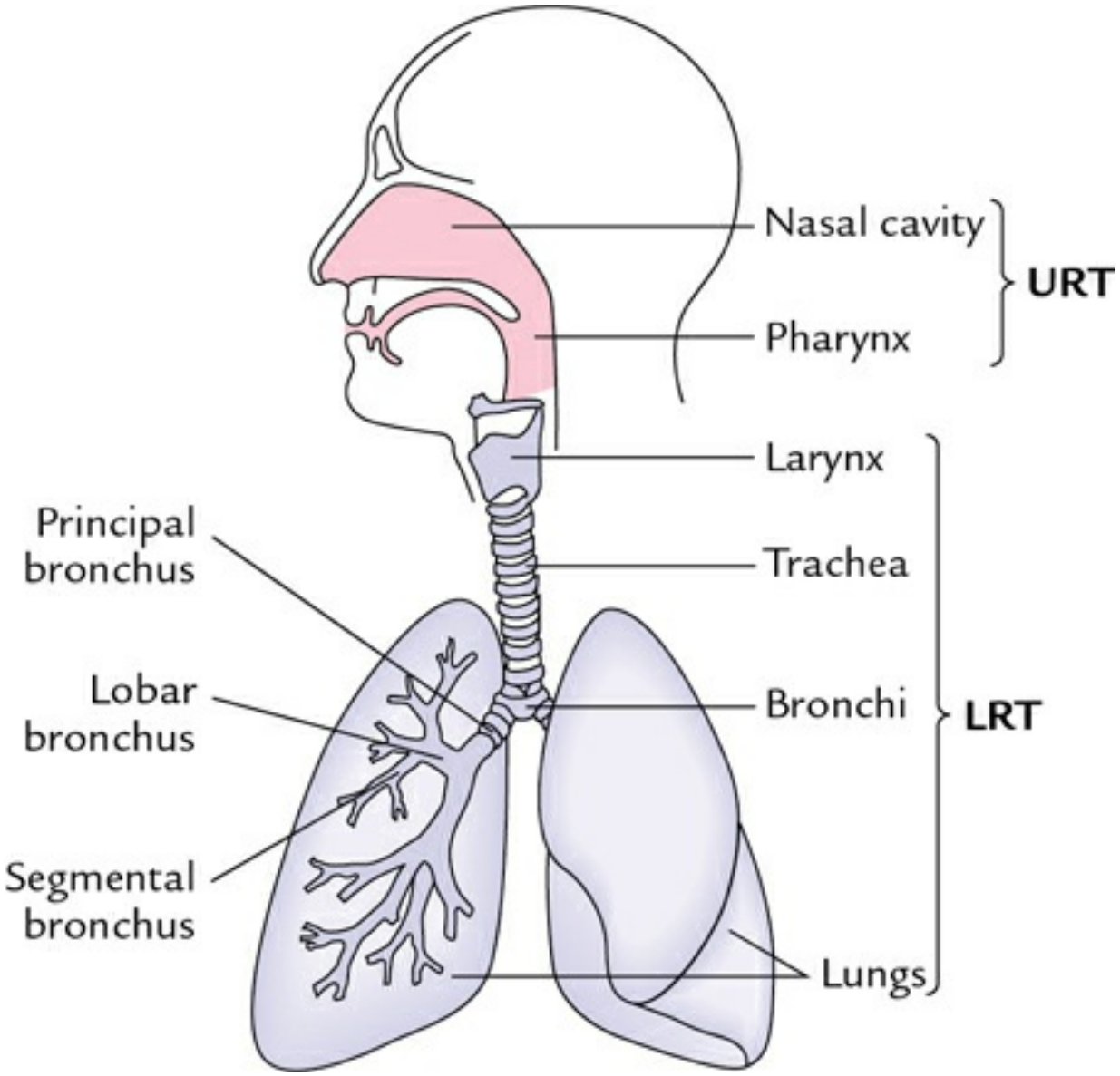


FIG. 14.5 ■ Anatomical subdivisions of the respiratory system. The upper respiratory tract (URT) is shown in pink while the lower respiratory tract (LRT) is shown in violet.

Functional subdivision

Functionally, however, the respiratory system is divided into the following two portions (Fig. 14.6):

1. Upper conducting portion
2. Lower respiratory portion.

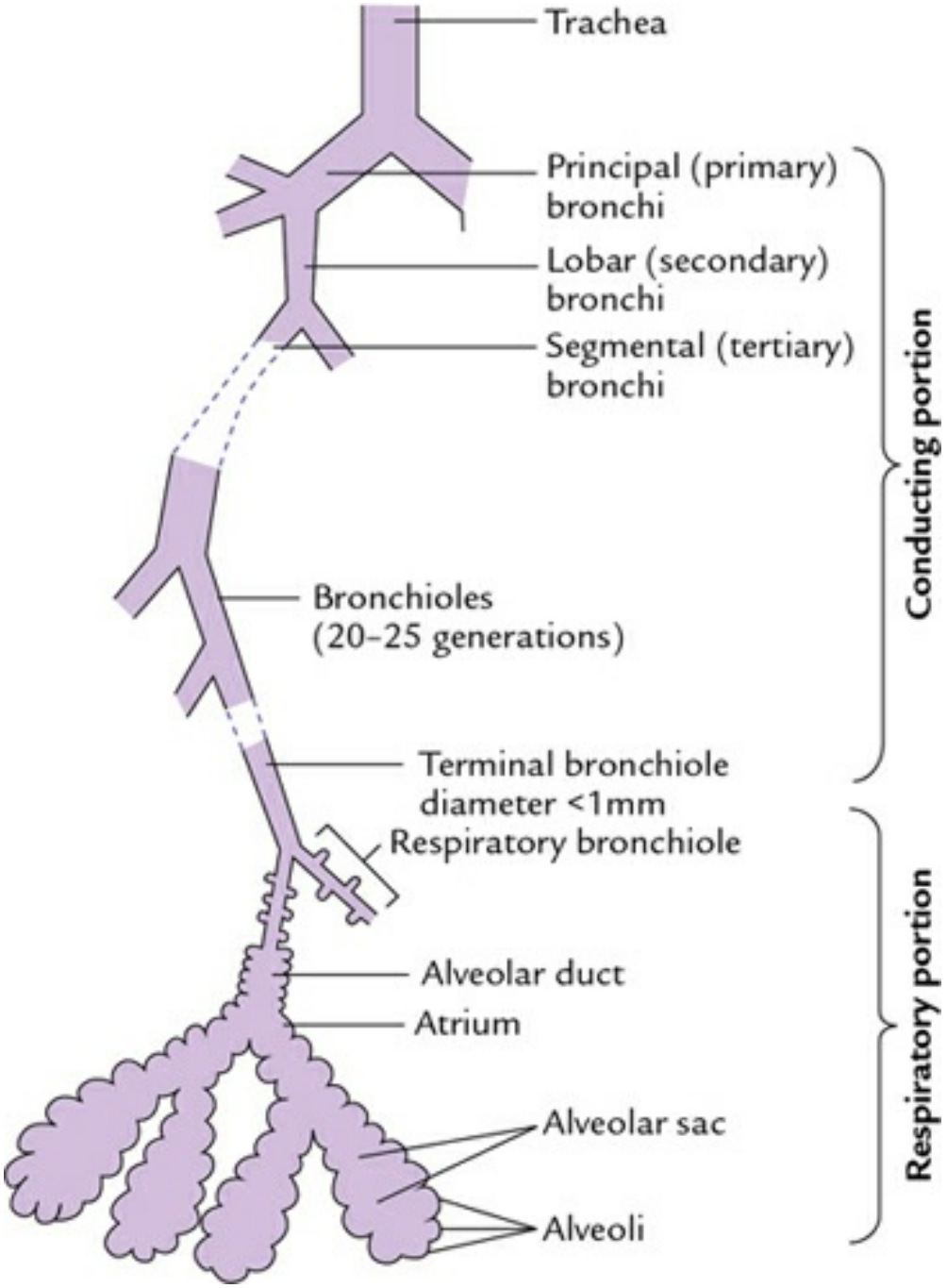


FIG. 14.6 ■ Conducting and respiratory portions of the trachea and lungs.

The **conducting portion of the respiratory system** comprises:

1. Nasal cavities
2. Pharynx
3. Larynx
4. Trachea
5. Bronchi
6. Bronchioles

7. Terminal bronchioles.

The *main functions of the conducting portions* of the respiratory system are as follows:

1. Provide a conduit through which air can travel to and from the lungs.
2. Condition the inspired air, i.e. filters, warms and moistens the air while it is passing through it.

The **respiratory portion of the respiratory system** comprises:

1. Respiratory bronchioles
2. Alveolar ducts
3. Alveolar sacs
4. Alveoli.

The main function of respiratory portion of the respiratory system is exchange of gases (oxygen and carbon dioxide) between air and blood, i.e. the air is absorbed and carbon dioxide is eliminated.

The following section describes the upper conducting portion and the lower respiratory portion of the respiratory system in detail.

Conducting portion of the respiratory system

Nasal cavity

The nasal cavity is located inside the external nose. It is divided into two nasal cavities, a right and a left by the nasal septum. The external and internal openings of each nasal cavity are called nostril (external nare) and choana (internal nare), respectively. Each nasal cavity has floor, roof, medial wall and lateral wall. The lateral wall of the nasal cavity presents three characteristic curved bony shelves called **conchae** which overhang three anteroposteriorly running passages called **meatuses**.

Lining of the nasal cavity

The features of the lining of the nasal cavity are as follows:

1. A small dilated area immediately above the nostril (**vestibule**) is lined by skin (*stratified squamous epithelium*) having coarse hair called **vibrissae**. The vibrissae filter large dust particles that might otherwise be inhaled.
2. The uppermost part (2 cm^2 in each nasal cavity) of medial and lateral walls where they meet to form a narrow roof (**olfactory region**) is lined by specialized **olfactory epithelium** concerned with the sense of smell.
3. The remaining large area of the nasal cavity (**respiratory region**) is lined by pseudo-stratified ciliated columnar epithelium with goblet cells called the **respiratory epithelium**.

Fine particles such as dust, pollen or smoke are trapped in the moist mucus lining of the nasal cavity. The cilia are microscopic hair-like projections from cell surfaces that waft the mucus and entangle foreign particles in it, posteriorly into the nasopharynx.

The mucous membrane covering the inferior and middle conchae contains dilatable venous sinuses called **swell bodies**, which warm and humidify the inhaled air.

Thus, the respiratory functions of the nose are to warm, moisten and filter the air.

Clinical Correlation

Rhinorrhoea: The allergic reactions and inflammation of nasal mucosa lead to abnormal engorgement of *swell bodies* in nasal cavities causing difficulty in nasal breathing and excessive discharge of watery exudates from the nose *(rhinorrhoea)*.

Pharynx

The pharynx is a funnel-shaped fibromuscular tube extending from the base of the skull to the lower border of the 6th cervical vertebra, where it becomes continuous with the oesophagus.

It acts as a passageway for both the digestive and respiratory systems. It communicates anteriorly with nasal, oral and laryngeal cavities. Accordingly, it is divided into the **nasopharynx** (upper part), **oropharynx** (middle part) and **laryngopharynx** (lower part):

1. The nasopharynx has only a respiratory function, hence it is lined by respiratory epithelium. The paired auditory or eustachian tubes connect it with the middle ear cavities. The pharyngeal tonsils (or adenoids) are situated in the posterior wall.
2. The oropharynx has both respiratory and digestive functions. The paired palatine tonsils are located in its lateral walls near the oropharyngeal entrance.
3. The laryngopharynx directs the food into the oesophagus, and air into the larynx. The air is further warmed and moistened as it passes through the pharynx.

Larynx ('voice box')

It connects the laryngopharynx with the trachea. The lumen of the larynx is kept patent by its rigid walls formed by hyaline and elastic cartilages that are united by membranes. The cartilages of the larynx are nine; out of which three are unpaired, namely *epiglottis*, *thyroid* and *cricoid*, and three are paired, namely *arytenoid*, *corniculate* and *cuneiform*. The thyroid cartilage is the largest and forms prominence on the front of the neck (**Adam's apple**) in males. The cricoid cartilage completely encircles the lumen of the larynx.

The larynx is lined internally by mucous membrane and covered externally with voluntary muscles. Two pairs of strong connective tissue bands are stretched anteroposteriorly across its lumen. The upper bands are called **false vocal cords** and the lower bands are **true vocal cords**. The space between the false vocal cords is called **rima vestibuli,** whereas the space between the true vocal cords is called **rima glottidis**. The latter is the narrowest part of the laryngeal cavity.

The true vocal cords produce sounds whereas false vocal cords support the true vocal cords. The whole of the laryngeal cavity is lined with pseudo-stratified squamous epithelium *except* the vocal cords which are lined by stratified squamous epithelium.

The larynx serves three main functions:

1. It serves to prevent food or fluid from entering the trachea and lungs from the pharynx during swallowing and thus it protects the lower respiratory tract.

2. It allows the passage of air into the lungs during breathing.
3. It serves to produce sounds hence the name **voice box**.

The humidifying, filtering and warming of air continue as the inspired air travels through the larynx.

Trachea

The trachea or **windpipe** is a flexible fibro-elastic cartilaginous tube about 10 cm (4 in.) long and 2.5 cm (1 in.) in diameter. It lies in front of the oesophagus partly in the neck and partly in the thoracic cavity. About 5 cm (2 in.) below the jugular notch, the trachea bifurcates into the right and left bronchi.

The lumen of the trachea is kept patent by 16–20 incomplete C-shaped rings of hyaline cartilages. The gap between the posterior free ends of the C-shaped cartilage is bridged by a band of smooth muscle (trachealis) and a fibro-elastic ligament. It is lined by pseudo-stratified ciliated columnar epithelium containing many mucous-secreting goblet cells.

The arrangement of cartilages and elastic tissue in the trachea prevents the kinking and obstruction of the airway during the movements of the head and neck. The cartilages prevent the collapse of the tube when internal pressure is less than intrathoracic pressure, i.e. at the end of forced expiration.

Clinical Correlation

Tracheostomy (creating an opening in the trachea and inserting a tube in it): It is a life saving measure for obstruction in the upper respiratory passages. It is done in the cervical part of the trachea behind the isthmus of the thyroid gland through the 2nd and 3rd tracheal rings.

Bronchi, bronchioles and terminal bronchioles

After a short oblique course, each bronchus enters the respective lung and gives off branches to each lobe of the lung called **lobar bronchi** which in turn branch and rebranch like a tree forming bronchioles. When the segmental bronchi are reduced to the diameter of 1.0 mm, they are called **bronchioles**. Bronchioles divide again and give rise to **terminal bronchioles** which are less

than 0.5 mm in diameter. The terminal bronchioles are the last stage in the conducting portion of the respiratory system (Fig. 14.6).

Respiratory portion of respiratory system

It consists of: *Respiratory Bronchioles, Alveolar Ducts, Alveolar Sacs and Alveoli*

The terminal bronchioles branch to form respiratory bronchioles (Fig. 14.6), the level at which gaseous exchange begins. The respiratory bronchioles give rise to alveolar ducts which in turn lead to alveolar sacs. The wall of these sacs being sacculated resembles a bunch of grapes called alveoli (L. *alveolus* = a bunch of grapes). The alveoli are the actual site of gaseous exchange and are called functional units of the lungs. The alveoli form the parenchyma of the lung. The alveolar wall has characteristic elastic tissue made up of mainly elastin fibres. Because of these fibres, the alveoli can accommodate and expel air during inhalation and exhalation.

Lungs

The lungs are the organs of oxygenation of blood in adults. They lie in the pleural cavity, one on either side of the mediastinum within the thorax. Lungs are largely made up of spongy tissue and feel like a rubber sponge. In this highly elastic framework, the bronchus, pulmonary artery and pulmonary veins branch out.

Each lung is divided into lobes and lobules (segments):

1. The **right lung** is divided by two fissures (oblique and horizontal) into three lobes: superior, middle and inferior.
2. The **left lung** is divided by a single oblique fissure into two lobes- superior and inferior.

Each lobe is divided into segments called, **broncho-pulmonary segments**. Each lung has 10 broncho-pulmonary segments. The lobes are supplied by lobar bronchi, whereas broncho-pulmonary segments are supplied by tertiary bronchi.

The lungs are closely covered by a delicate and inseparable serous membrane called **visceral pleura**. Another layer of the serous membrane

lining the wall of the thoracic cavity, diaphragm and mediastinum is called **parietal pleura**.

The two layers are continuous at the root of the lungs formed by structures entering and leaving the lung.

The potential space between the visceral and parietal layers of the pleura is called the **pleural cavity**. Thus, each lung is covered by a pleural cavity.

Clinical Correlation

Asthma: It is an acute airway obstruction due to narrowing of its lumen following contraction of the smooth muscle in the wall of bronchioles (bronchospasm). It occurs due to increased secretion of *mucus* and swelling of mucosa in response to allergy caused by a variety of substances such as *dust*, *pollen* or a particular food, etc.

Here, it is important to note that bronchioles forming the distal part of the respiratory tree are devoid of cartilage in their wall and are made up of only smooth muscle and mucous lining.

In patients suffering from asthma, the inspiration is normal but there is difficulty in expiration only partial expiration is possible. Consequently, the lungs become hyperinflated and there is severe difficulty in breathing (dyspnoea) and wheezing. Asthma is treated with drugs such as epinephrine that relax the smooth muscles of the bronchioles.

Golden Facts to Remember

• **Length of the digestive tract**	10 m (30 ft)
• **Most dilated part of the digestive tract**	Stomach
• **Most muscular part of the digestive tract**	Oesophagus
• **Longest part of the digestive tract**	Small intestine (6 m)
• **Narrowest site of the digestive tract**	Pharyngo-oesophageal junction
• **Largest internal organ of the body**	Liver (1.5 kg)
• **Largest salivary gland**	Parotid gland

• **Most important function of the small intestine**	Absorption of nutrients from digested food
• **Most important function of the large intestine**	Formation of faeces
• **Ducts of all major salivary glands open in the oral cavity proper except**	Ducts of parotid glands which open in the vestibule of the oral cavity
• **Part of the small intestine having a maximum concentration of Peyer's patches**	The terminal part of the ileum
• **Largest cartilage of the larynx**	Thyroid cartilage
• **Narrowest part of the laryngeal cavity**	Rima glottidis
• **Commonest site of tracheostomy**	Cervical part of the trachea through the 2nd and 3rd tracheal rings

Multiple choice questions

1. **Gastrointestinal tract includes all of the following structures *except*:**
   (a) Oesophagus
   (b) Stomach
   (c) Small intestine
   (d) Large intestine
2. **Most of the digestion of food occurs in:**
   (a) Mouth
   (b) Stomach
   (c) Small intestine
   (d) Large intestine
3. **All of the following are the accessory glands of the digestive system *except*:**
   (a) Salivary glands
   (b) Liver
   (c) Spleen
   (d) Pancreas
4. **Ducts of all of the following glands open in the oral cavity *except*:**

(a) Parotid gland
(b) Submandibular gland
(c) Sublingual gland
(d) Liver

5. **Mumps is related to which of the following glands?**
   (a) Submandibular gland
   (b) Sublingual gland
   (c) Parotid gland
   (d) Lacrimal gland
6. **The conducting portion of the respiratory system consists of all *except*:**
   (a) Bronchi
   (b) Bronchioles
   (c) Terminal bronchioles
   (d) Respiratory bronchioles
7. **The term 'lower respiratory tract' includes all of the following structures *except*:**
   (a) Pharynx
   (b) Larynx
   (c) Trachea
   (d) Bronchi
8. **The term 'upper respiratory tract' consists of all of the following structures *except*:**
   (a) Nasopharynx
   (b) Oropharynx
   (c) Laryngopharynx
   (d) Larynx
9. **Regarding larynx, all of the following statements are correct *except*:**
   (a) Connects laryngopharynx with trachea
   (b) Prevents food from entering the trachea
   (c) Is kept patent by its rigid walls formed by fibrocartilages
   (d) Serves to produce sound
10. **The gaseous exchange takes place in all of the following structures *except*:**
    (a) Terminal bronchiole
    (b) Respiratory bronchiole
    (c) Alveolar ducts
    (d) Alveolar sacs

Answers

1. *a*, **2.** *c*, **3.** *c*, **4.** *d*, **5.** *c*, **6.** *d*, **7.** *a*, **8.** *d*, **9.** *c*, **10.** *a*.

Chapter 15: Urogenital system

Specific learning objectives

After studying this chapter, the student should be able to:

- Identify the structures forming the urogenital system.
- Discuss the structure and functions of the kidneys, ureter and urinary bladder.
- Characterize the structure and functions of the urethra in males and females.
- Describe main organs comprising the male reproductive system.
- Outline structure and functions of accessory glands of the male reproductive system.
- Compare and contrast the male and the female reproductive systems.
- Elucidate location, structure and functions of the ovary, uterus, fallopian tubes and vagina.
- Describe main structures comprising the female external genitalia.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

The urinary and genital organs develop together to constitute the *urogenital system*. The male urethra serves as a common outlet for urinary and genital products, i.e. urine and semen. Therefore, urinary and genital systems are discussed together in the same chapter.

Urinary system

The urinary system is the major/main excretory system of the body. It plays a vital role in excreting waste products and maintaining the homeostasis of water and electrolyte concentrations within the body.

Components of the urinary system

The urinary system includes the following structures (Fig. 15.1):

1. Kidneys, paired
2. Ureters, paired
3. Urinary bladder, unpaired
4. Urethra, unpaired.

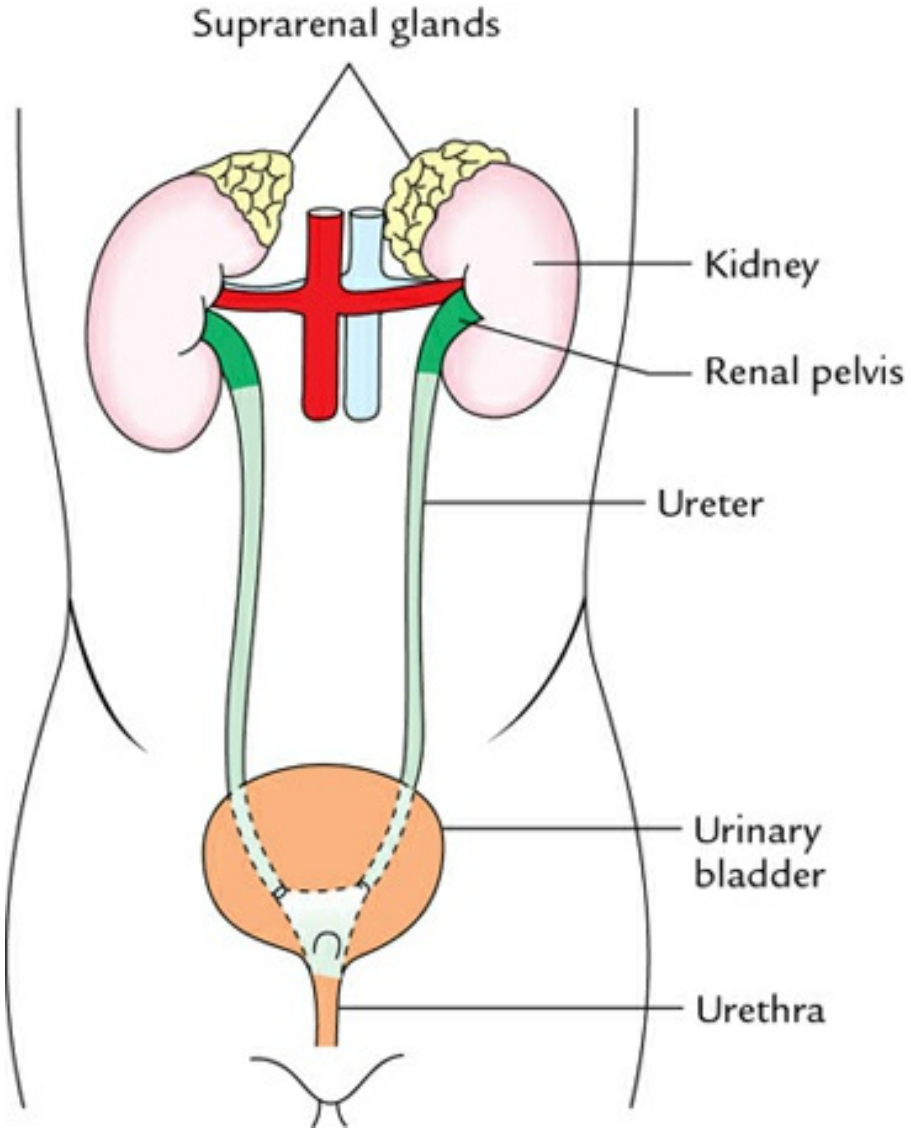


FIG. 15.1 ■ Components of the urinary system.

The kidneys secrete urine, ureters convey urine from kidneys to the urinary bladder. The urinary bladder collects and stores urine. The urethra discharges urine from the urinary bladder to the exterior.

Functions of urinary system

Following are the functions of the urinary system:

1. Formation and excretion of urine.
2. Maintenance of water and electrolyte balance to establish the internal environment of body cells.
3. Excretion of toxic metabolic products such as urea and

creatinine.
4. Removal of various drugs that have been taken into the body.

N.B.

The end product of the urinary system is urine, which is discharged (voided) from the body during micturition.

The *decreased level of glomerular filtration rate (GFR) and increased level of serum creatine* (metabolic product of muscle) are indicative of kidney disease.

Kidneys

Kidneys are the major excretory organs of the body. They filter the blood to remove metabolic waste products of the body (many of which are toxic) and produce urine.

They are reddish-brown bean-shaped organs measuring 10 × 6 × 3 cm.

They lie retroperitoneally in the lumbar region, one on either side of the vertebral column between T11 and L3 vertebral levels. The right kidney is slightly lower than the left due to the presence of the liver above it. Each kidney is surrounded by a thin fibrous capsule—the **renal capsule**, which in turn is surrounded by dense adipose tissue —the **perinephric fat**. The perinephric fat is enclosed in a thin fascial sheath—the **renal fascia**. The perinephric fat protects the kidney from mechanical shock.

The concave medial border of the kidney presents the hilum, through which the renal artery and nerves enter the kidney and the renal vein and ureter leave the kidney.

Macroscopic structure of kidney

The naked eye examination of the coronal section of the kidney (Fig. 15.2) presents the following features:

1. The inner two-thirds of the cut surface of a kidney is occupied by darkly stained pyramidal-shaped areas, called **pyramids** (8–15 in number). The tips of pyramids called *papillae* project into the minor calyces.
2. The outer one-third of the cut surface of a kidney, that is the part lying external to the bases of the pyramids is called the **cortex**.
3. The *renal columns* similar to cortical tissue extend between the pyramids. The *renal columns* and *pyramids* constitute the **medulla**.

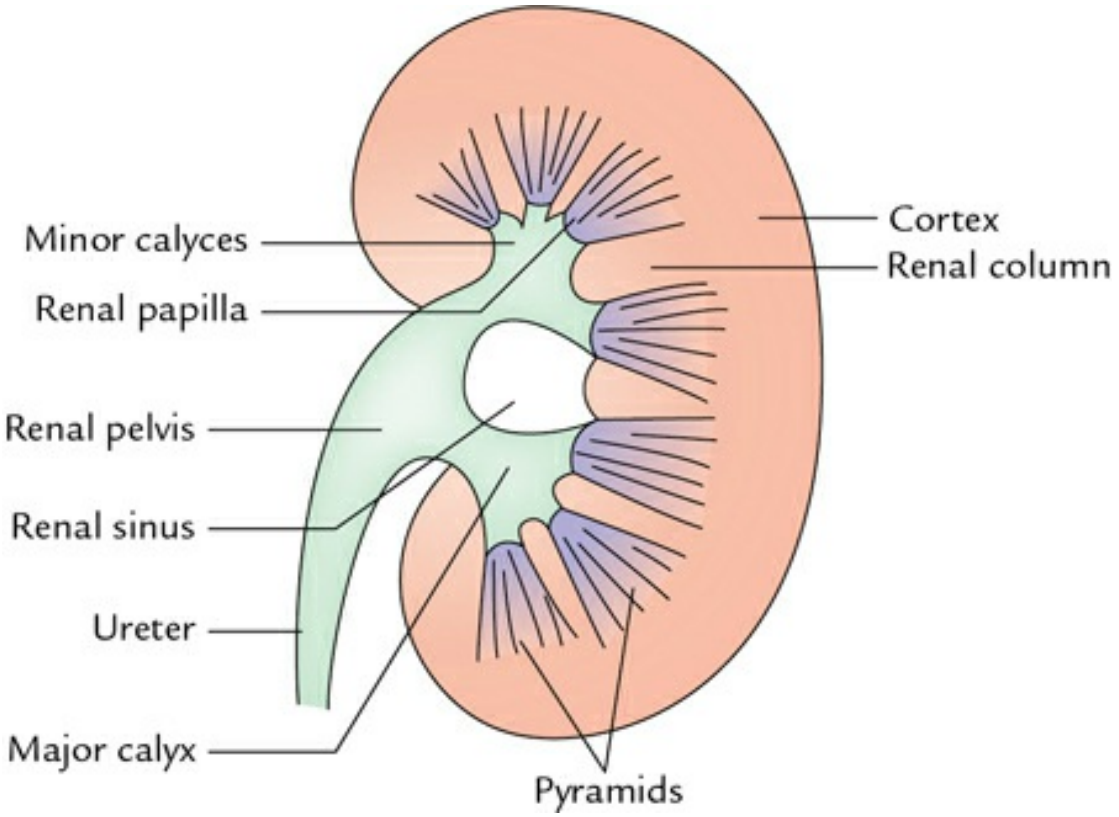


FIG. 15.2 ■ Cross-section of a kidney showing the macroscopic structure. Pelvicalyceal system consisting of minor calyces, major calyces and renal pelvis is shown in green colour.

The minor calyces surround the renal papillae. These minor calyces from several pyramids join together to form two or three major calyces. The major calyces converge to form a funnel-shaped channel called the **renal pelvis.** The renal pelvis then narrows to form a narrow tube, the ureter, which leaves the kidney and connects it to the urinary bladder.

Microscopic structure of kidney

Each kidney is made of two main components: (a) excretory component and (b) collecting component.

The **excretory component** consists of about 1 million (1,000,000) microscopic units called **nephrons**. Each nephron (Fig. 15.3) consists of the *renal corpuscle, proximal convoluted tubule, loop of Henle,* and *distal convoluted tubule*.

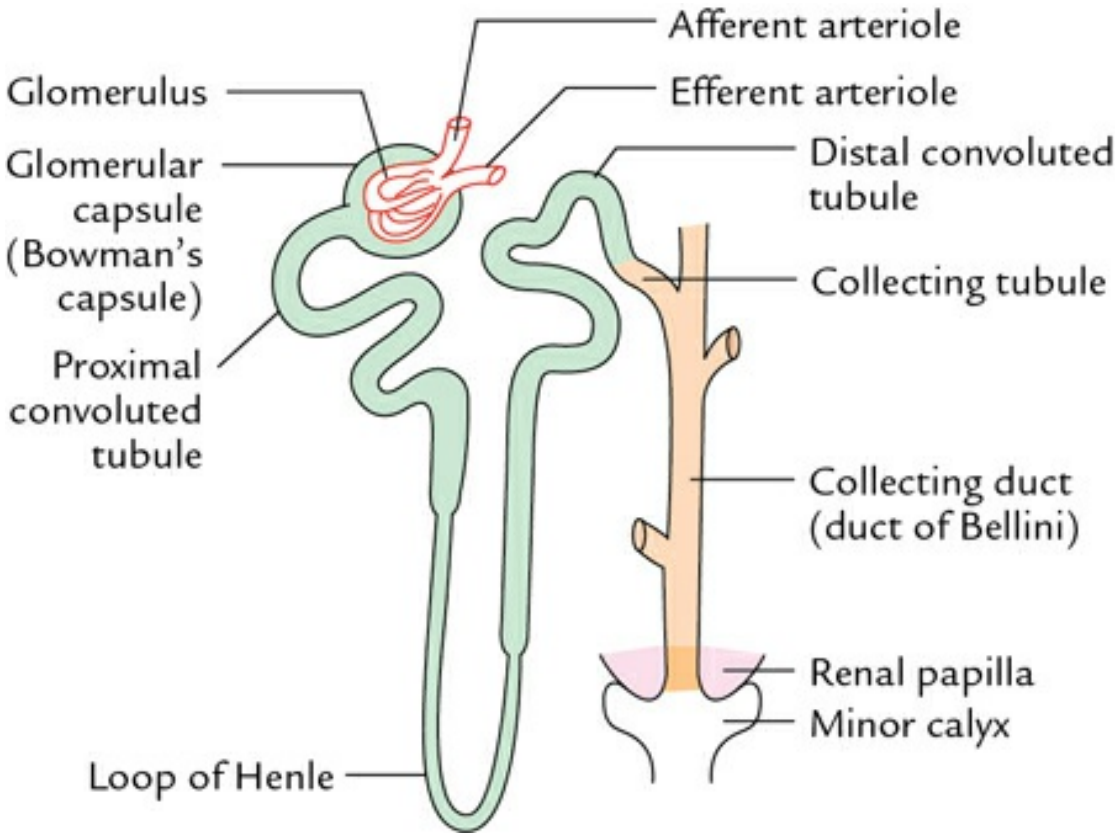


FIG. 15.3 ■ A uriniferous tubule consisting of nephron (green colour), and collecting ducts (brown colour).

The **collecting component** consists of collecting tubules, and collecting ducts. The nephron along with collecting ducts forms a **uriniferous tubule**.

Nephrons are the structural and functional units of a kidney. A **glomerulus** (a small ball) is a **spherical bunch of looped capillaries**, which invaginates the expanded blind end of the uriniferous tubule called the **glomerular capsule or Bowman's capsule**.

The uriniferous tubule consists of the nephron and collecting ducts. This renal capsule is succeeded by the proximal convoluted tubule, Henle's loop, and distal convoluted tubule. Finally the collecting tubule communicate with the collecting duct.

The urine is formed as a filtrate from the blood by nephrons. The **collecting tubules** are the continuation of distal convoluted tubules. Several collecting tubules join to form a large duct called the collecting duct/papillary duct/**duct of Bellini**. The collecting duct opens on the apices of pyramids (renal papillae) to pour urine into the minor calyces.

N.B.

The collecting duct system not only collects the urine and pour it into the pelvicalyceal system but also participates in electrolyte and fluid balance through reabsorption and excretion processes.

Ureters

Each ureter is a 25 cm (10 in.) long narrow muscular tube, which connects the renal pelvis with the urinary bladder. The renal pelvis is the upper funnel-shaped portion of the ureter within the kidney. The ureter conducts urine from the renal pelvis to the urinary bladder by peristaltic contraction of smooth muscle in its wall.

Through a cystoscope, jets of urine are seen to squirt/spurt into the bladder from ureteral orifices, 2 or 3 times a minute. The peristaltic waves are initiated by the presence of urine in the renal pelvis.

The lumen of the ureter is lined by transitional epithelium. The superficial cells of this layer secrete a proteinous material (uroplakin) that coats the lumen of the ureter like a protective film, thus preventing the absorption of toxic substances.

 Clinical Correlation

- **Renal injury:** Even if kidneys are damaged extensively, they can still perform their important function of maintaining homoeostasis as long as one-third of one kidney remains functional and thus survival is possible.
  The kidneys may be injured by a hard blow in the lumbar region leading to haemorrhage within the kidney. As a result, such injury may produce blood in the urine.
  The urine from a healthy individual is virtually bacteria-free but easily becomes contaminated after voiding because its organic components serve as nutrients to the contaminating microbes. The breakdown of its organic components by bacterial action produces ammonia.
- **Kidney disease or renal failure:** It is typically characterized by *proteinuria* and an *increased level of creatinine and urea* in the blood. It often occurs due to diabetes and high blood pressure.

Urinary bladder

The urinary bladder is a muscular reservoir for urine. It is located in the true pelvis between the pubic symphysis and rectum in the male and between the pubic symphysis and uterus in the female.

The bladder has a widely varying capacity (average about 200–300

mL). In the male, the prostate gland is positioned below the urinary bladder. The shape of the urinary bladder is determined by the volume of urine it contains. An empty bladder is pyramidal in shape with an apex, body, fundus and neck. The neck is the most fixed part of the urinary bladder. The apex is secured by the median umbilical ligament. The body receives the ureters along with the superolateral angles and the urethra exists at its neck.

The strong muscular coat in the wall of the urinary bladder is made up of smooth muscle fibres forming **detrusor muscle** in which muscle fibres are arranged in the form of whorls. The mucous membrane lining the cavity of the bladder is composed of transitional epithelium that decreases in thickness, as the urinary bladder distends and the cells are stretched. It is thrown into folds called **rugae** when the bladder is empty.

N.B.

The trigone of the urinary bladder develops from the mesoderm, whereas the rest of the bladder develops from the endoderm.

A triangular area between the two ureteric openings and a single urethral opening is called the **trigone of the urinary bladder**. Over the trigone, the mucous membrane remains smooth even if the bladder is empty.

In males, a small grape-like bulging produced by the median lobe of the prostate gland (**uvula vesicae**) lies behind the internal urethral orifice. Uvula vesicae, if enlarged due to prostatic hypertrophy, obstruct the internal urethral orifice.

Urethra

The urethra is a tubular continuation of the neck of the urinary bladder. It conveys urine from the urinary bladder to the outside of

the body. The urethra has two muscular sphincters: (a) internal and (b) external.

The **internal urethral sphincter** at the junction of the bladder and urethra is formed by the detrusor muscle of the urinary bladder. It is **involuntary in nature** and well developed in females. The **external urethral sphincter** is formed by the sphincter urethrae muscle of the urogenital diaphragm. It is made up of skeletal muscle fibres, hence **voluntary in nature**.

The **female urethra** is short, about 4 cm (1.5 in.) long, and empties urine into the vestibule of the vagina. In females, the urethra is exclusively a part of the urinary system.

The male urethra is long, about 18–20 cm, long. It is described later in this chapter.

 Clinical Correlation

Cystitis: It is the inflammation of the urinary bladder that typically occurs due to infections. Urinary bladder infections often occur when bacteria from outside the body enter the bladder. Therefore, cystitis is more common in females because the female urethra is short and opens on the surface of the body in the vestibule of the vagina.

Genital/reproductive system

The reproductive system is concerned with the production of offspring, that is perpetuation of species. There are striking differences in the anatomy and physiology of male and female reproductive systems.

The **male reproductive system** produces male gametes called

spermatozoa and transfers them to the female through the process of coitus (sexual intercourse or copulation).

The **female reproductive system** not only produces female gametes called **oocytes** and receives spermatozoa from males but is also involved in the development of the embryo and foetus and nourishes the baby even after birth by breast milk.

N.B.

The reproductive organs become functional at puberty, whereas the organs of other systems of the body become functional at birth or shortly thereafter.

In spite of these striking differences in the male and female reproductive systems, each sex has the following similar features:

1. Have a symmetrical pair of sex glands to produce gametes
2. Develop from similar embryonic tissue
3. Have accessory glands
4. Have external genitalia.

N.B.

In early foetal life, the male and female organs of reproduction are very similar.

Male reproductive system

The *male reproductive organs* are:

1. Testes
2. Epididymis
3. Ductus deferens
4. Seminal vesicles (accessory glands)

5. Ejaculatory ducts
6. Prostate gland (accessory gland)
7. Bulbourethral glands (accessory glands)

The *male external genitalia* includes:

1. Penis
2. Urethra
3. Scrotum.

Figure 15.4 depicts the structures of the male reproductive system.

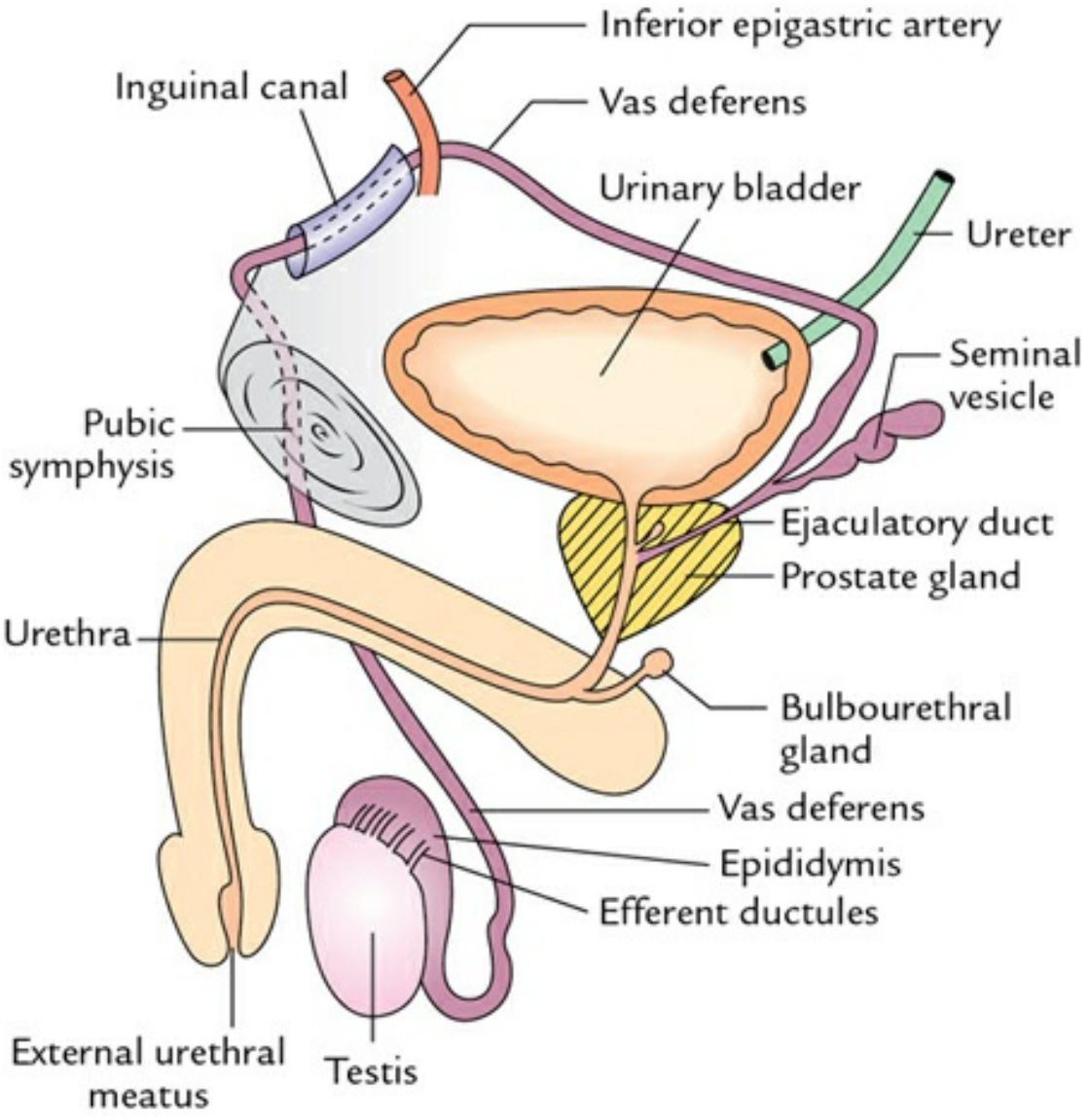


FIG. 15.4 ■ Male reproductive system.

N.B.

All the male reproductive organs and male external genitalia are *secondary sex organs* except the testes, which are *primary sex organs.*

Testes

The testes are male sex glands, located one on each side within the scrotum.

Each testis is a whitish ovoid organ, about 4 cm (1.5 in.) long and 2.5 cm in diameter. Each one consists of 200–300 lobules. Each lobule contains 1–4 seminiferous tubules. Between the tubules are the groups of interstitial cells (of Leydig), which secrete **testosterone** (hormone) at and after puberty. The seminiferous tubules contain only two types of cells: **germ cells** and **Sertoli cells**. The **germ cells** produce spermatozoa by progressive differentiation and **Sertoli cells** provide mechanical support and nourishment to the spermatozoa.

Testosterone regulates spermatogenesis and the development of secondary sex organs. The testosterone also influences the brain, and is responsible for the aggressive behaviour and positive attitude of the males.

After production in the seminiferous tubules, the sperms leave the testis through 6–12 **efferent ductules**, which emerge from the superior part of the testis and open into the duct of epididymis.

Epididymis

The duct of epididymis, although 6 m long is so folded as to form a compact comma-shaped body called the epididymis. The epididymis caps the superior pole of the testis and is applied to its

posterior border. The spermatozoa are stored in the epididymis until released either by masturbation or coitus. During the storage period, the spermatozoa mature and become motile.

Clinical Correlation

The final maturation of sperms occurs in the epididymis. The sperms taken directly from the testis in experimental animals are not capable of fertilizing but after spending one or several days in the epididymis, they develop the capacity to fertilize.

Ductus deferens

The ductus deferens/vas deferens emerges from the tail of the epididymis. It is a fibromuscular tube about 45 cm long that conveys spermatozoa from epididymis to the ejaculatory duct. The end of the ductus deferens enlarges to form the *ampulla*. It is said to store sperms.

The spermatozoa are transported along the vas deferens by muscular contractions of its walls.

Seminal vesicles

These are sac-shaped glands adjacent to the ampullae of ductus differentia. In fact, they are tubular outgrowths from the last part of the ductus deferens. Each gland is about 5 cm long and its short duct joins the ductus deferens to form the **ejaculatory duct**. The fluid secreted by seminal vesicles contain **fructose** which provides energy to sperms and **alkaline fluid** which helps keep the sperm alive in vagina.

From this point onwards, the male urethra is a common passage for the urinary and genital systems. This is because the duct

systems of both testes and kidneys develop from a common embryonic structure called the mesonephric duct.

Ejaculatory duct

It is formed on either side near the prostate gland by the union of ductus deferens and duct of the seminal vesicle. The ejaculatory duct, is about 2.5 cm long, pierces the prostate gland and opens into the urethra on colliculus seminalis close to its fellow of the opposite side about 2.5 cm distal to the bladder.

 Clinical Correlation

Vasectomy: It is a surgical procedure in which a short segment of ductus deferens in upper part of scrotum is cut and the cut ends of the ductus deferens are crushed and tied so that the sperms do not pass from the testis to the urethra. Vasectomy is a common method to render males permanently incapable of fertilization (i.e. they become sterile).

N.B.

As sperms form only a small volume of the ejaculate, the vasectomy has little effect on the volume of the ejaculated semen. The sperms are reabsorbed in the epididymis.

Prostate gland

The prostrate is the largest accessory sex genital gland in male and weighs about 20 g in an adult male.

It is a cone-shaped gland about the size of a chestnut, located below the neck of the urinary bladder with an apex directed downward. It surrounds the first 3 cm of the urethra just distal to

the urinary bladder. It is partly glandular, partly muscular and partly fibrous. The glandular tissue of the prostate gland consists of three types of glands, namely mucosal, submucosal and main prostatic gland. Its glands secrete milky opalescent liquid, free from mucus which is nutritive to the sperms and forms the bulk of the semen. The prostate glands open into the prostatic part of the urethra. The prostatic secretion contains acid phosphatase, citric acid, amylase, fibrinolysin and prostatic-specific antigen (PSA). Fibrinolysin liquefies semen after ejaculation.

 Clinical Correlation

- **Benign hypertrophy of prostate (BHP):** It occurs due to hypertrophy of mucosal and submucosal glands of median lobe of prostate in almost 50% of males after 50 years of age. The enlarged prostatic tissue compresses the prostatic urethra causing partial or total obstruction. This leads to difficulty in passing urine.
- **Carcinoma of prostate gland:** It occurs due to malignant hypertrophy of the main prostatic glands in posterior lobe of prostate. It is the second most common cancer in elderly men.

Bulbourethral glands (or Cowper's glands)

These are two small glands of the size of a pea, which lie one on each side of the membranous urethra. Their ducts are 2–3 cm long and open into the penile urethra. They secrete mucous-like fluid that lubricates the penile urethra before ejaculation.

 Clinical Correlation

Semen: The secretions of accessory glands of the male reproductive system along with spermatozoa form the semen/seminal fluid. The seminal fluid contains high concentration of fructose, which

provides nutrition to the spermatozoa.

It is white opalescent thick fluid produced by male reproductive glands and ejaculated by the penis. The volume of semen in a single ejaculation is about 2.5 mL (1.5 to 6 mL). The approximate contribution by various glands to make it is as under:

- Seminal vesicles, 60%
- Prostate, 30%
- Testes, 5%
- Bulbourethral glands, 5%.

Penis

Penis (L. *penis* = a tail) is a male organ of copulation and transfers sperms from the male to the female genital tract. In order to accomplish this, the penis needs to be rigid (erect) so that it can enter the vagina. The penis consists of three fibrous columns of erectile tissue: two paired and one unpaired (Fig. 15.5). Each column of erectile tissue is surrounded by a thick fibrous connective tissue sheath called **tunica albuginea**. These columns have innumerable cavernous spaces filled with blood. The three columns are enclosed in a single loosely fitting tube of skin. Note that there is no subcutaneous tissue around the penis. The paired columns are called **corpora cavernosa** and the unpaired column, **corpus spongiosum**. The corpus spongiosum is traversed by the urethra. The expanded proximal end (*bulb*) of the corpus spongiosum is attached to the perineal membrane, (which stretches between the sides of the pubic arch) and the expanded distal end of the corpus spongiosum forms the **glans of the penis**. A loose fold of skin covering the glans is called **foreskin or prepuce.** The corpora cavernosa are fused side by side. Distally, they present tapering ends; whereas proximally they diverge into **right and left crura**, which are firmly attached to the pubic arch on the respective

sides.

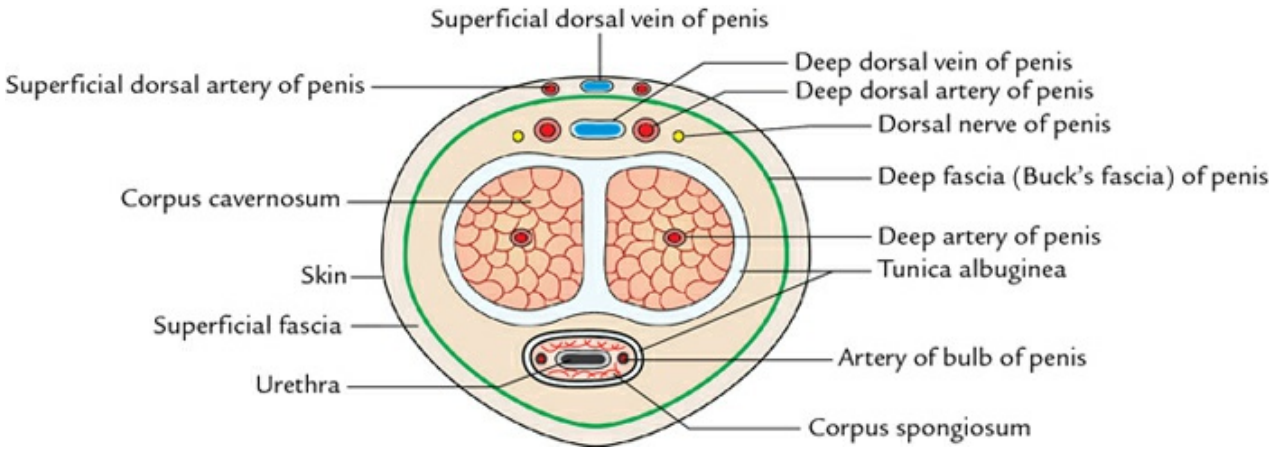


Fig. 15.5 ■ Transverse section through the body of penis.

During sexual arousal, the arteries feeding the cavernous spaces become dilated; consequently, there is a great increase in blood volume flowing into the cavernous spaces and they expand. Meanwhile, the veins draining the sinuses are compressed and prevent the blood from leaving the penis. Thus, the cavernous spaces become turgid and the penis becomes stiff and erect.

Urethra

The **male urethra** is long, about 18–20 cm (8 in.) in length and S-shaped. It traverses the prostate gland, urogenital diaphragm and penis to empty outside the body (Fig. 15.6). Accordingly, it is divided into three parts: **prostatic part** (3 cm long), **membranous part** (2 cm long) and **penile/spongy part** (15 cm long).

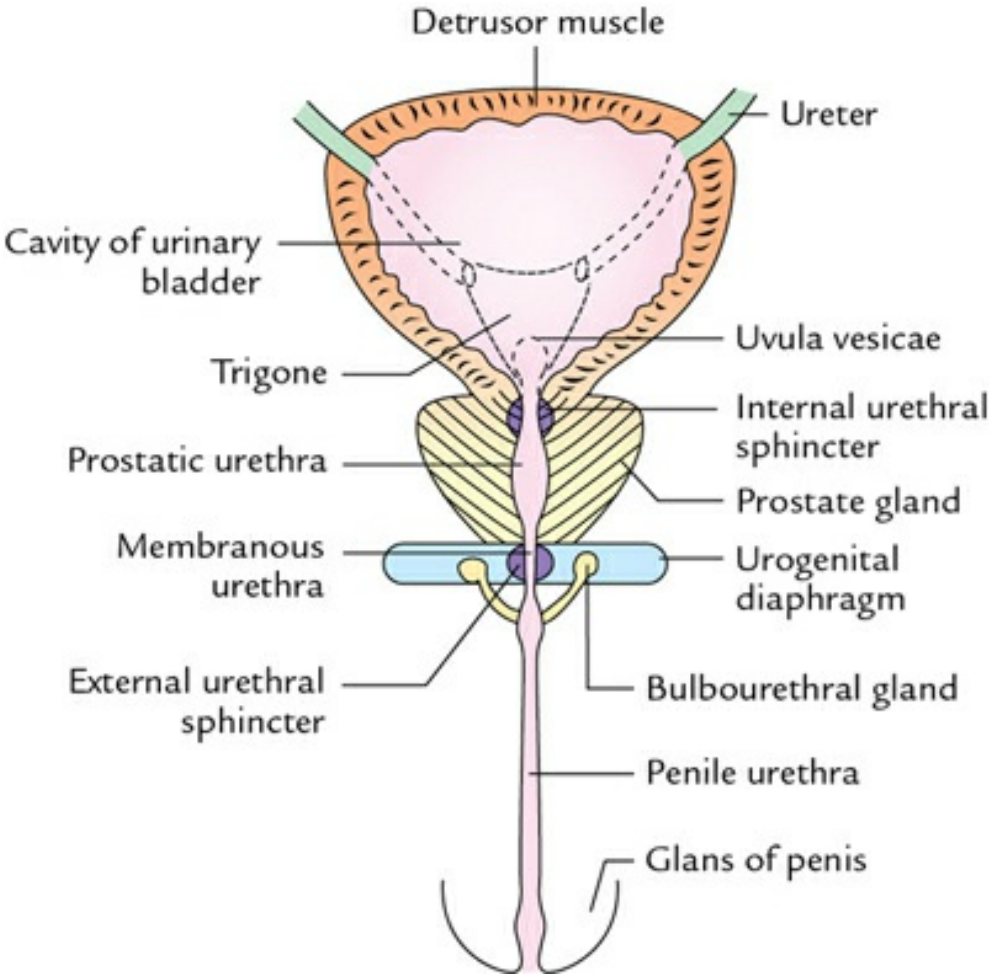


Fig. 15.6 ■ Male urethra.

N.B.

The male urethra provides passage to both, urine and semen, that is it serves both the urinary and reproductive systems.

Scrotum

It is a bag/pouch of skin and subcutaneous tissue located below the penis. It is divided into two internal compartments by a connective tissue septum. Each compartment contains the testis and lower part of spermatic cord.

Female reproductive system

The *female reproductive organs* are:

1. Ovaries
2. Uterine tubes
3. Uterus
4. Vagina

The *female external genitalia* includes:

1. Clitoris
2. Labia majora
3. Labia minora
4. Greater vestibular (Bartholin) glands
5. Mons pubis
6. Vaginal orifice.

Structures of the female reproductive system are depicted in Figure 15.7.

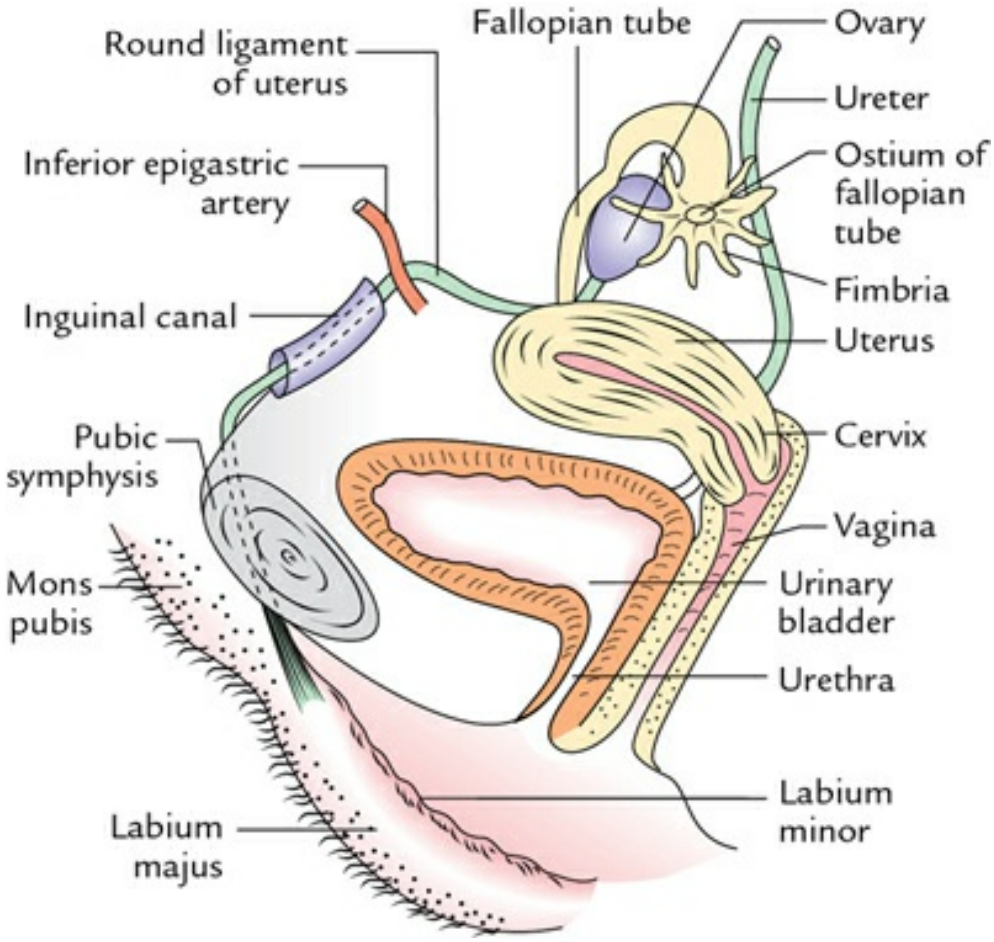


Fig. 15.7 ■ Female reproductive system.

Ovaries

The ovaries are female sex glands, one on each side, lying on the lateral wall of the pelvis. Each ovary is an almond-shaped, solid body about half the size of the testis. It is attached to the posterior surface of the broad ligament by a fold of peritoneum called **mesovarium** (i.e. mesentery of the ovary).

The ovary produces female gametes called **ova** and female sex hormones (oestrogen and progesterone).

At birth, each ovary contains about 2 million (2,000,000) immature ova. From puberty to the end of the reproductive period (15–45 years of age), one ovum is shed into the peritoneal cavity once in a lunar month. In all, about 400 ova are shed in the whole

reproductive life of a female and the rest undergo degeneration and are absorbed in the ovary. The period between successive ovulations is called the **ovarian cycle**.

Uterine tubes

There are two uterine tubes, one on each side of the uterus. Each tube is about 10 cm long and lies on the free edge of a fold of the peritoneum, the **broad ligament**.

Its narrow medial end opens in the uterus and the expanded distal (ovarian) end called the **infundibulum** opens into the abdominal cavity beside the ovary.

The opening of the infundibulum, the **ostium**, is surrounded by long thin finger-like processes called **fimbriae**. When an ovum is shed, the mouth of the ostium lies ready to receive the ovum with the help of fimbriae and propelled into the tube with the peristaltic action of the wall of the tube and movements of carpet of cilia in the mucous lining of the tube.

In the tube, the ovum may meet and fertilized by a sperm, which is able to reach this site through the vagina and uterus. The ovum is fertilized in the widest and longest part of the tube near the infundibulum called the **ampulla**. The part of the tube nearer the uterus is narrower and called the **isthmus**.

Clinical Correlation

Tubectomy: It is a surgical procedure in which uterine tubes are ligated and cut/clamped on both sides so that the pathway between the sperm and oocyte is sealed. The tubectomy is a common method to render females permanently incapable of fertilization (i.e. they become sterile).

Uterus

The uterus is a thick-walled hollow muscular organ located nearly in the centre of the true pelvis between the urinary bladder and the rectum. It is shaped like an inverted pear and flattened anteroposteriorly. Its rounded upper part is called the **fundus** and the narrower inferior part is called the **cervix**. The main part of the uterus is between the fundus and the cervix. A slight constriction called **isthmus** marks the junction between the cervix and the body. The fallopian tube opens into the uterus, one on either side at the junction of the fundus and the body of the uterus. The fertilized ovum is transported into the uterine cavity by the fallopian tube where it is implanted and develops into the foetus.

Vagina

The vagina (L. *vagina* = a sheath) is a thin-walled fibromuscular canal about 3–4 in. (7.5–10 cm) long, which forms the organ of copulation in a female. The cervix of the uterus projects into it superiorly, inferiorly the vagina opens into the vestibule of the external genitalia. Its functions are: to receive the penis during intercourse and allow menstrual flow and childbirth.

The interior of the vagina is lined by protective, moist stratified squamous epithelium. The smooth muscle in the vaginal wall can stretch to a great extent to accommodate the penis during intercourse and allow the passage of the baby during its birth. The lubricating fluid found in the vagina comes from the glands of the uterine cervix.

Clitoris, labia minora and labia majora

The female external genitalia (also called vulva or pudendum) consists of the vestibule and its surrounding structures (Fig. 15.8).

The **vestibule** is an elliptical space into which the vagina opens posteriorly and the urethra opens anteriorly.

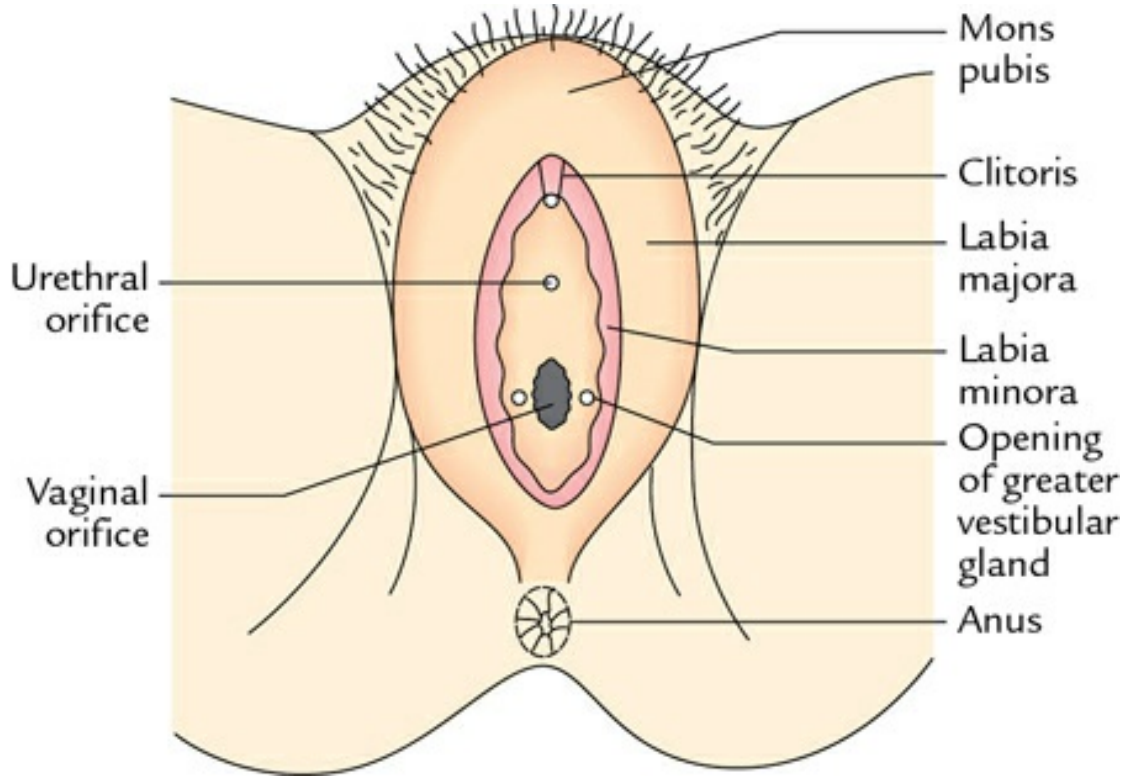


Fig. 15.8 ■ Female external genitalia.

The vestibule is guarded by a pair of thin longitudinal folds of skin called **labia minora**.

Clitoris

It is a small erectile structure, which is located in the anterior margin of the vestibule. It is less than 2 cm in length and consists of a shaft and glans. It is made up of erectile tissue such as that forming the penis (embryologically penis and clitoris are homologous structures). The clitoris is richly supplied with sensory receptors and functions to initiate and intensify sexual pleasure. Anteriorly, the labia minora unite over the clitoris to form a fold of skin called the **prepuce**. Lateral to the labia minora are two prominent rounded folds of skin called the **labia majora**. The prominence of the labia majora is primarily caused by the presence

of subcutaneous fat within the labia.

Greater vestibular glands

These are paired glands, which open into the vestibule on either side between the vaginal orifice and labia minora. Their secretion lubricates and helps to maintain the moistness of the vestibule.

Mons pubis

The two labia majora unite anteriorly to form an elevation over the pubic symphysis called mons pubis, which acts as a fatty cushion. The space between the labia majora is called the **pudendal cleft**.

The lateral surfaces of the labia majora and the surface of the mons pubis are covered with coarse hair.

Vaginal orifice

The vaginal orifice is located in the posterior part of the vestibule of external genitalia. The vaginal orifice is covered in virgin females by a thin mucous membrane called **hymen** (the word 'hymen' is named after a Greek mythological god of marriage and nuptial song, Hymen). Generally, the hymen is perforated by one or several holes to allow menstrual flow. The hymen is completely perforated during first sexual intercourse. When ruptured, the remnants of the hymen are seen as round tags called **carunculae hymenales** along the margin of the vaginal orifice.

 Golden Facts to Remember

• **Most important function of the urinary system**	Maintenance of water and electrolyte concentration within the body (homeostasis)

• **Most important excretory organ of the body**	Kidney
• **Structural and functional units of kidney**	Nephrons
• **Number of nephrons in each kidney**	1 million
• **All the organs in the body become functional at birth or shortly after birth except**	Reproductive organs which become functional at puberty
• **Primary sex organs in males**	Testes
• **Primary sex organs in females**	Ovaries
• **Longest duct of the male reproductive system**	Duct of the epididymis (6 m long)
• **Largest accessory gland of the male reproductive system**	Prostate gland
• **Strongest smooth muscle in the body**	Uterine muscle
• **Largest accessory glands of the female reproductive system**	Mammary glands
• **Most sensitive part of male external genitalia**	Glans of penis
• **Most sensitive part of female external genitalia**	Glans of clitoris
• **Most common cancer of the male reproductive system**	Carcinoma prostrate
• **Most common cancer of the female reproductive system**	Carcinoma cervix
• **Most of the bulk of semen is formed by**	Secretions of seminal vesicles (60%)

Multiple choice questions

1. **Which of the following statements regarding the kidneys is *false*?**

(a) They are retroperitoneal.
(b) Each kidney has distinct cortical and medullary regions.
(c) They are located between T11 and L3 vertebral levels.
(d) Each kidney contains 3–6 renal pyramids.

2. **Which of the following statements about renal pyramids is *incorrect*?**

(a) They are located in the renal medulla.
(b) They are separated from each other by renal columns.
(c) Their tips are called renal papillae.
(d) They do not contain nephrons.

3. **Which of the following statements about ureter is *incorrect*?**

(a) It is about 25 cm long.
(b) It is intraperitoneal.
(c) Its lumen is lined by transitional epithelium.
(d) It transports urine from the kidney to the urinary bladder.

4. **The detrusor muscle is located in the:**

(a) Kidneys
(b) Ureters
(c) Urinary bladder
(d) Urethra

5. **All of the following are accessory glands of the male reproductive system *except:***

(a) Prostate gland
(b) bulbourethral glands
(c) Bartholin glands
(d) Seminal vesicles

6. **Which of the following statements about the prostate gland is *false*?**

(a) It surrounds the first 3 cm of the urethra.
(b) It is roughly the size of a walnut.
(c) Its secretion forms the bulk of ejaculated semen.

(d) It is shaped like an inverted cone.

7. **Female external genitalia include all *except:***
   (a) Labia majora
   (b) Labia minora
   (c) Greater vestibular glands
   (d) Vagina
8. **The number of immature ova in the ovary at birth is:**
   (a) 4 million
   (b) 3 million
   (c) 2 million
   (d) 1 million
9. **The fertilization most commonly occurs in:**
   (a) Ovary
   (b) Uterine tube
   (c) Uterus
   (d) Vagina
10. **The cervix is the portion of:**
   (a) Vulva
   (b) Vagina
   (c) Uterus
   (d) Uterine tube

Answers

1. *d*, **2.** *d*, **3.** *b*, **4.** *c*, **5.** *c*, **6.** *b*, **7.** *d*, **8.** *c*, **9**. *b*, **10.** *c*

Chapter 16: Radiological (imaging) anatomy

Specific learning objectives

After studying this chapter, the student should be able to:

- Define radiological (imaging) anatomy and list various methods used for its study.
- Describe X-rays and their properties.
- Outline the shadows cast by different objects on the radiographic film.
- Describe simple radiographic procedures and discuss their use in clinical medicine.
- Discuss contrast radiography and list the contrast media used in it.
- Outline the criteria for a good contrast medium and discuss the choice of different contrast media.
- Describe CT scan, spiral CT and MRI, and discuss their properties.
- Present a brief account of positron emission tomography and discuss its main use.
- Briefly describe the ultrasonography and discuss its properties.
- Correctly solve the Multiple Choice questions given at the end of the chapter.

Radiological anatomy (or radiology) is the science of medical imaging to diagnose and sometimes even treat diseases using X-rays. It has its origin on one evening in November 1895 when

Wilhelm Conrad Röentgen observed that a photographic plate was glowing when a high voltage current was passed through an evacuated glass tube. Medical imaging provides a way of observing structures within the body without intervention. It is based on the principle that substances of different densities absorb different amounts of X-rays, resulting in a differential exposure of the photographic film. Since the traditional radiograph had limitations as a diagnostic tool, a large number of new techniques have been developed to produce images of structures within the body. Some of them even do not use X-rays. Consequently, the term 'radiological anatomy' is replaced by **imaging anatomy**.

The imaging anatomy deals with different techniques/methods used to provide the images of internal organs of the human body to demonstrate the pathological lesions within them.

The imaging techniques used can be classified as follows:

1. **Methods using ionizing radiation**
    (a) Conventional imaging
        (i) Plain radiography
        (ii) Contrast radiography
    (b) Computed tomography (CT) scanning/computerized axial tomography (CAT) scanning
        (i) CCT
        (ii) SCT
    (c) Radioisotope scanning (nuclear medicine imaging)
        (i) SPECT
        (ii) PET
2. **Methods not using ionizing radiation**
    (a) Ultrasonography (USG)
    (b) Magnetic resonance imaging (MRI).

Overview

X-rays were discovered in 1895 by Wilhelm Conrad Röentgen, a German physicist, who won the first Nobel Prize in physics in 1901. This was the starting point of modern medical radiology and radiotherapy.

X-rays are produced by passing a high voltage electric current across a vacuum tube called an X-ray tube. This induces a stream of electrons from an electrically heated metal element (*tungsten filament*) called the **cathode**. When they strike a metal target (*tungsten plate*) called **anode** after passing across a vacuum tube, X-rays are produced (Fig. 16.1). At the time of discovery, nothing was known about X-rays. Thus, they were named X-rays. The term 'X-ray' stands for unknown rays.

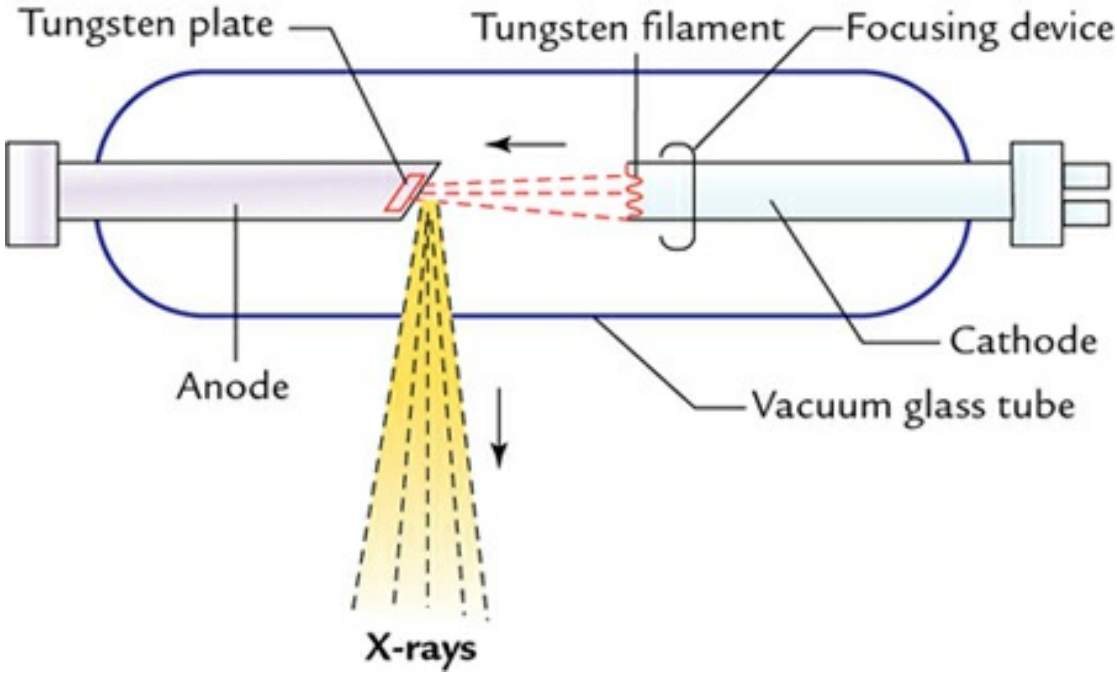


FIG. 16.1 ■ X-ray tube (cathode ray tube) for the production of X-rays.

The X-rays are part of the spectrum of electromagnetic radiation (Fig. 16.2) where long electric waves are found at one end (long-wavelength end) and cosmic rays at the other end (short-wavelength end) of the spectrum. The radio waves, infrared waves, visible light rays, ultraviolet rays, X-rays and gamma rays are found

in the middle of the spectrum, in order of increasing frequency, between electric waves and cosmic rays. All these radiations travel at the same speed (300,000 km/s) in straight lines.

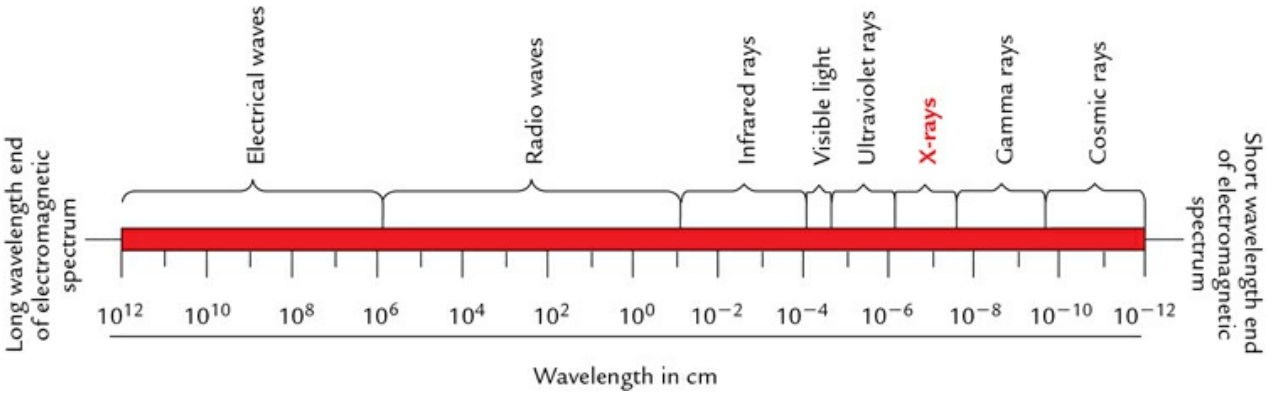


FIG. 16.2 ■ The position of X-rays in the electromagnetic spectrum.

The X-rays are electromagnetic waves similar to the visible light, but with a much shorter wavelength (1/10,000). It is this characteristic that empowers the X-rays to penetrate materials that otherwise would absorb or reflect the light.

Properties of X-rays

The X-rays have the following properties:

1. **Penetrating power:** X-rays have the power to penetrate different materials and tissues to a variable extent, and the X-ray beam emerging from other side of the body affects a photographic film, or a fluorescent screen, forming a shadow picture of different parts of the body structures. The degree of penetration depends on the atomic weight and density of different substances. The higher the atomic weight and density and thickness of a substance, the greater the absorption, e.g. the less dense tissues such as soft tissues are readily penetrated than the more dense tissues such as bone, i.e. X-rays are absorbed more in dense tissues than in soft tissues. The scale of

absorption of X-rays in an increasing order in various substances is as follows:

(a) Air
(b) Fat
(c) Water/fluid
(d) Soft tissues, viz. muscles, vessels, nerves, viscera etc.
(e) Bone
(f) Enamel of teeth
(g) Metals (ornaments, metallic fillings in teeth etc.) and radiopaque contrast media.

From the above scale it is deduced that air absorbs X-rays a little, and fat absorbs X-rays more than air but less than water. These differences in absorption (attenuation) of X-rays result in differences in the level of exposure of the film. Thus, substances that absorb X-rays little appear more transparent (**radiolucent**) and those which absorb more appear opaque (**radiopaque**). For example, the bone appears white (radiopaque) in the radiograph because this region of the film has been exposed to the maximum number of X-rays, whereas air in the trachea, lungs etc. appears dark (radiolucent) because these regions of the film have been exposed to the least number of X-rays.

Radiology is, therefore, based on the principle of differential absorption of X-rays.

N.B.

Penetrating power/effect is the fundamental property of X-rays.

2. **Photographic effect:** The X-rays affect the photographic emulsions of the film in much the same way as light waves.

After penetrating the tissue/substance, when the X-rays strike the photographic film, the film gets sensitized. The development of such film gives a radiographic image called **radiograph** (Fig. 16.2). The X-ray (radiographic) image is also

called skiagram (*skia* = shadow) or röentgenogram (named after the discoverer of X-rays, Röentgen).
The X-ray-sensitive film emulsion consists of silver bromide in the form of a crystal or grains suspended in a suitable emulsion. This sensitive emulsion is coated on both sides of the film.

N.B.

The **skiagram is a negative picture**, and it is in this form that the skiagram is examined by radiologists and clinicians.

3. **Fluorescent effect:** When X-rays strike certain metallic salts such as phosphorus, zinc sulphide, cadmium sulphide etc., they cause these substances to fluoresce, i.e. light rays are produced. This is called fluorescence. This property of X-rays is used in fluoroscopy.
4. **Biological effect (or radiobiological effects):** The X-rays can destroy abnormal cells (e.g. malignant cells) much more readily than the adjacent normal cells because malignant cells are more radiosensitive than the normal surrounding tissue cells. This property of X-rays is utilized in the treatment of various cancers (*radiotherapy*).

Side effects of radiations (radiation hazards)

On repeated exposures, radiation can cause:

1. burns,
2. genetic mutations,
3. carcinogenesis etc.

The effects of radiation are always destructive. Therefore, the X-rays are potentially dangerous. The radiobiological effects depend

on the magnitude of the radiation doses and the radiosensitivity of irradiated tissues.

The cells are most radiosensitive at the time of cell division. The rapidly growing cells, such as cancer cells, are usually more radiosensitive than normal or resting cells. This difference in radiosensitivity between normal and cancer cells is the basis of radiation therapy called **radiotherapy**.

Radiosensitivity of normal tissues and cells

The most sensitive cells in the human body are lymphocytes, followed by leucocytes and reproductive cells of the testis and ovary. Moderately radiosensitive is the epithelial lining of the gastrointestinal tract (GIT) and epithelial lining of the skin. The least sensitive tissues are fibrous tissue, muscles, bones and nervous tissue.

 Clinical Correlation

Protective measures to avoid or minimize radiation hazards:

1. Doctors and technical staff in radiological units should strictly follow the protective measures (radiological protection principles). These include:
    (a) Use of protective materials, viz. lead screens, protective aprons etc.
    (b) Personal monitoring of radiation doses.
2. *The 10-day rule*: In women of reproductive age, there is always a possibility of pregnancy; therefore, in such women, an X-ray examination of the lower abdomen and pelvis should be carried out within 10 days following the first day of menstruation.
3. *During pregnancy*, only essential X-ray examinations have to be carried out and every care should be taken to protect the

foetus from exposure to radiation.
4. Avoid unnecessary X-ray examinations.

N.B.

Keeping in view the radiosensitivity of cells and tissues, adequate protective measures must be taken against repeated exposures to X-rays. The basic principle of radiation protection is '***ALARA***', i.e. *A*s *L*ow *A*s *R*easonably *A*chievable. This means that only permissible doses of radiation should be given at permissible intervals (for details consult radiology books).

Radiographic views

The radiographs are taken by passing an X-ray beam through the patient onto the photographic film (Fig. 16.3).

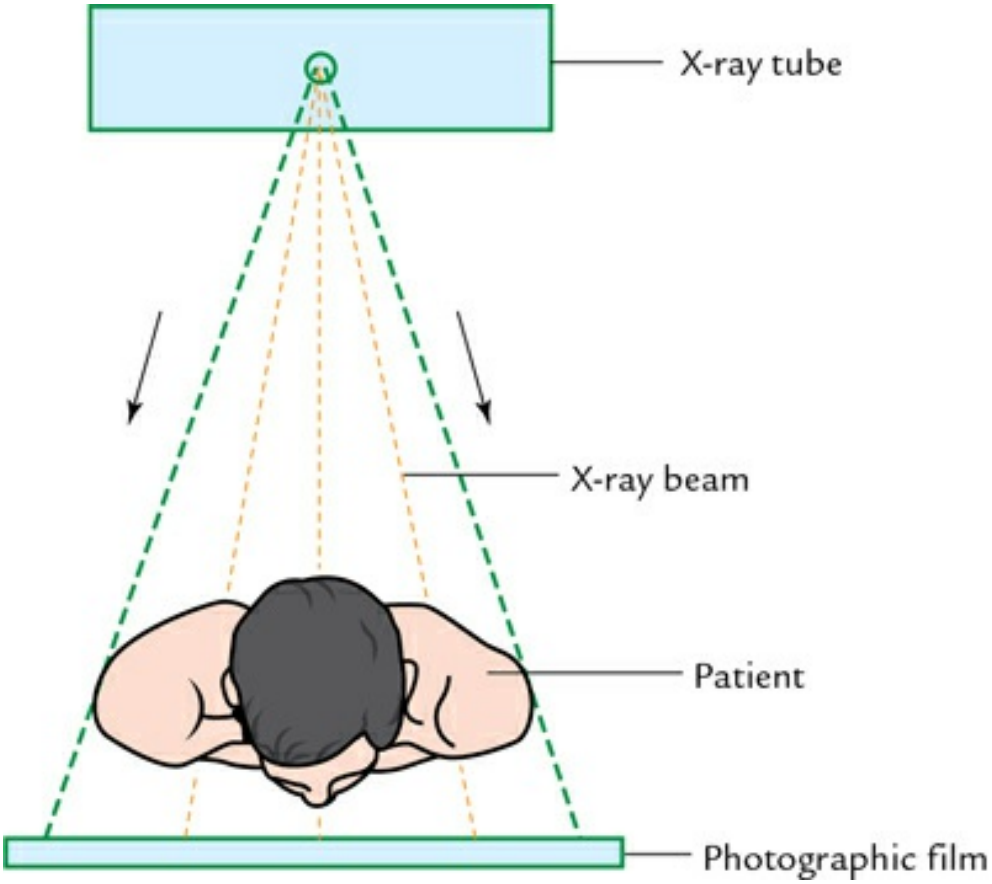


FIG. 16.3 ■ Simple X-ray. Note that the X-rays are passed

from the posterior aspect of the body, and the photographic film is in front of the body. The view of the photograph thus taken will be PA (PA view). (*PA*, posteroanterior.)

The radiographs are taken at different positions of the subject in relation to the source of X-rays and photographic film, to have complete information about the entire structure by eliminating some particular overlapping shadow in a particular view. The view denotes the direction of the beam of the X-ray.

Some of the common radiographic views are as follows:

1. **Anteroposterior (AP) view:** In this view, X-rays pass from the anterior aspect of the subject and an X-ray (radiographic) plate is placed posteriorly. The posterior plate structures are better visualized in this view.
2. **Posteroanterior (PA) view:** In this view, X-rays pass from behind (posterior aspect of) the subject and the X-ray (radiographic) plate is placed anteriorly (Fig. 16.4). The anteriorly placed structures are better visualized in this view.

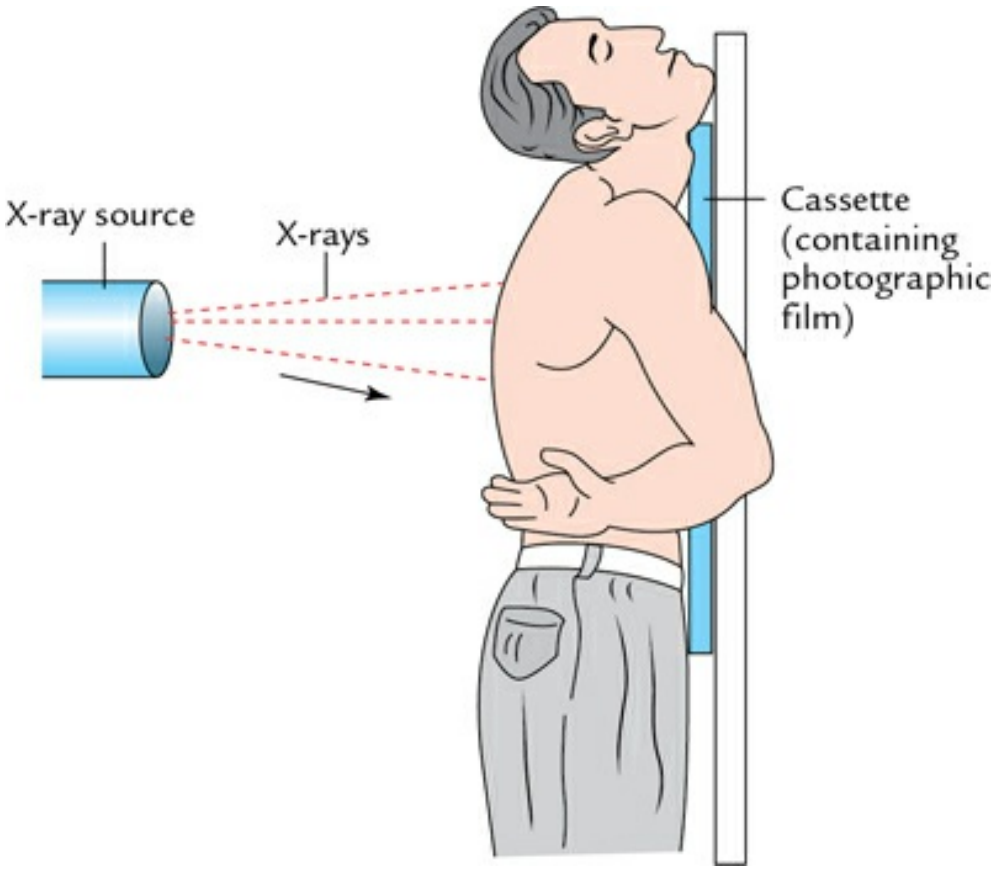


FIG. 16.4 ■ Method of taking chest radiograph; posteroanterior view. Note the position of the X-ray source and cassette containing photographic film.

N.B.

The part of the body closer to the X-ray plate casts a sharper shadow than the part facing the X-ray tube.

For this reason, the chest radiograph for visualizing the lesion in the lungs and heart is taken in PA view, whereas for visualizing the thoracic spine, AP view is preferred.

The more commonly taken radiograph of chest is a PA view.

Imaging techniques: Using ionizing radiation

Simple radiological procedures

The simple radiological procedures include:

1. Fluoroscopy
2. Plain radiography (plain X-ray)
3. Xeroradiography
4. Tomography.

Fluoroscopy

The human eyes cannot see X-rays. But when X-rays strike certain substances, they cause them to fluoresce (i.e. production of light rays) and can be perceived by the human eye. Hence, one can see the fluorescence of the X-ray beam. This forms the underlying principle of fluoroscopy.

The fluoroscopy is done in the darkroom and the fluoroscopic image is directly visualized on the fluorescent screen. The sharpness of the fluoroscopic image is inferior to that of a radiograph.

The fluoroscopy is of special advantage in observing the movements of organs such as lungs, stomach, intestine, diaphragm etc.

The fluoroscopic image can be photographed by a camera in a miniature form. These films are very cheap; hence masses can be surveyed for the detection of widespread diseases such as tuberculosis. This is called **mass miniature radiography**.

Plain radiography (plain X-ray)

In this procedure, an X-ray beam is passed through the patient onto the photographic plate and a natural radiographic image is directly obtained without using any contrast medium.

The plain radiography is useful in the study of normal and abnormal bones, lungs, paranasal air sinuses and gaseous shadows in the abdomen.

Silver bromide is used as the photosensitive material in X-rays.

The characteristic features of plain radiography are as follows:

1. Plain radiograph cannot show the pathological differences among various organs.
2. It can show gross differences between gas, fat, soft tissue and calcification, metal and fluid by different grades of shadows (Table 16.1).

TABLE 16.1

Shadows cast by different substances in a plain radiograph

Substance	Shadow
Gas/air	Black
Fat	Dark grey
Soft tissue	Light grey
Fluid	Hazy (haziness)
Bone/calcification	White
Metal	Brilliant white

Interpretation of common plain radiographs

Although the comprehensive interpretation of plain radiographs is beyond the scope of this book, a brief outline of the interpretation of common radiographs is given here.

Chest radiograph

It is one of the most commonly advised plain radiographs by

clinicians. The most common radiographic study of the thorax is done in X-ray chest PA view. The chest radiograph is obtained in an erect posture on inspiration and includes the upper abdomen to demonstrate the normal ***air bubble in the fundus of the stomach in the left subphrenic area*** (Fig. 16.6A). A good quality chest radiograph will demonstrate the lungs, cardiomediastinal contour, diaphragm, ribcage and peripheral soft tissue (Figs 16.5 and 16.6) as follows:

- *Cardiomediastinal shadow*: A large central radiopaque (white) shadow called *cardiomediastinal shadow/silhouette*.
  (a) *Right border of cardiomediastinal shadow,* from above downwards is formed by: superior vena cava (5) and right atrium (6).
  (b) *Left border of cardiomediastinal shadow* from above downwards is formed by: aortic knuckle/knob (1), pulmonary trunk (2), left auricle (3) and left ventricle (4).
- *Pulmonary shadows*: The large radiolucent (dark) shadows interrupted by radiopaque (white) shadows of ribs on either side of the cardiomediastinal shadow are called pulmonary/lung shadows.
- *Diaphragmatic shadows*: The shadows of the right and left domes of diaphragm are seen as curved lines with convexity upwards below the pulmonary shadows.
- *Tracheal shadow*: It is seen as a midline radiolucent (dark) shadow in front of the neck.
- *Shadow of ribcage*: The shadows of clavicles and ribs are seen as radiopaque shadows. The shadows of the posterior parts of ribs are denser than the anterior parts because of high calcium contents in the posterior parts. The ribs stand out clearly against dark lung shadows.
- *Soft tissue shadows*: The soft tissues including breasts cast shadows of varying density, depending upon their composition and thickness.

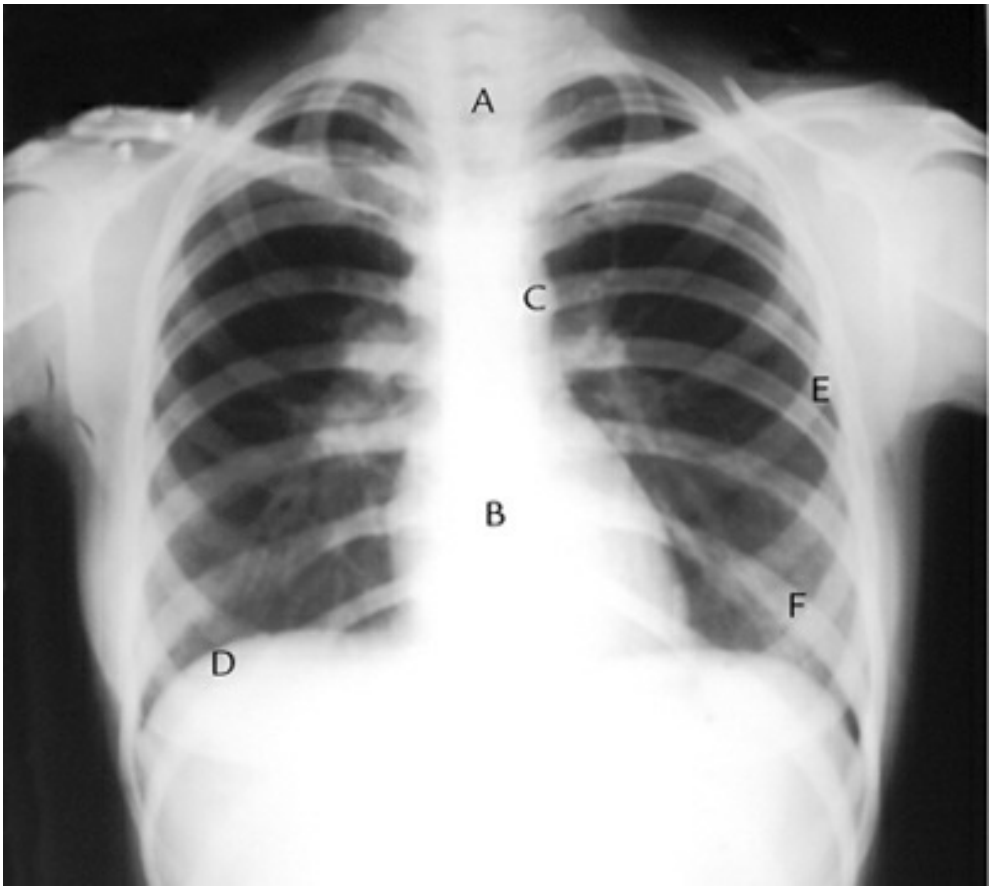


FIG. 16.5 ■ Chest radiograph; posteroanterior view: (A) tracheal shadow; (B) cardiomediastinal shadow; (C) aortic knuckle; (D) right dome of diaphragm; (E) lung shadow and (F) rib.

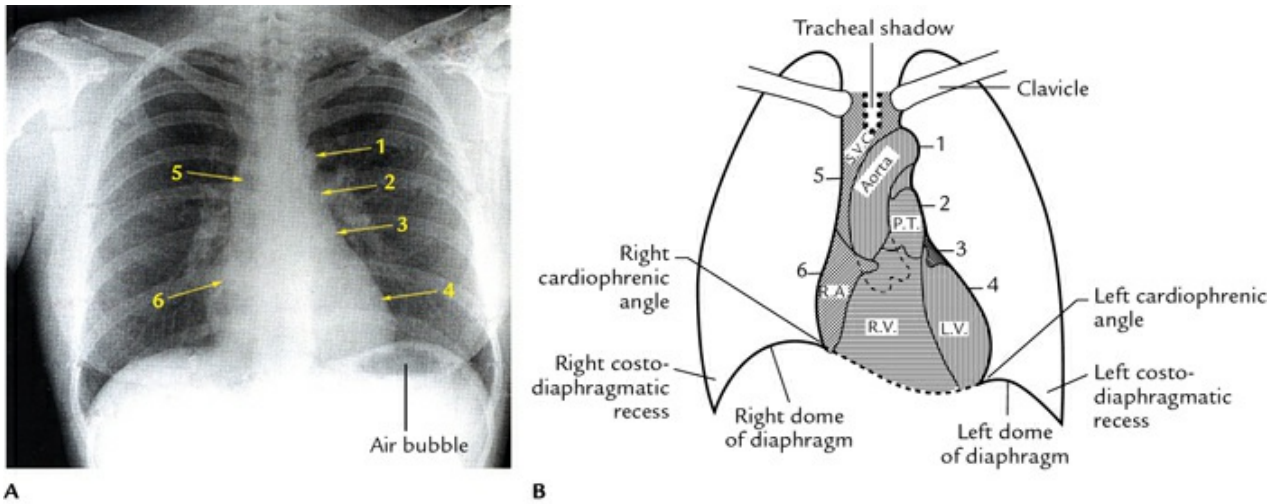


FIG. 16.6 ■ A. Chest radiograph, PA view showing left and right borders of cardiomediastinal shadow and (B) Tracing of the same radiograph for easy understanding. (1 = aortic knuckle, 2 = pulmonary conus, 3 = left auricle, 4 = left

ventricle, 5 = superior vena cava, 6 = right atrium) (*Source*: (A) Fig. 4.1, p. 94, *Integrated Anatomy*, David J.A. Heylings, Roy A.J. Spence, Barry E. Kelly. Copyright Elsevier Limited, 2007. All rights reserved. (B) Fig. 3.19, p. 137, *Clinical and Surgical Anatomy*, 2e, Vishram Singh. Copyright Elsevier, 2007. All rights reserved.)

Figure 16.6 is a schematic diagram to show the margins of the cardiomediastinal/cardiovascular shadow.

N.B.

One should check the following features:

1. The heart is of normal size (less than the width of the chest) or enlarged (greater than the width of the chest).
2. There is a normal outline of the aortic arch called **(aortic knuckle)** or not.
3. The lung fields are seen as translucent shadows (dark areas) on either side of the **cardiomediastinal shadow**, or there are focal mass/masses seen as areas of increased density.
4. The trachea, translucent tract/shadow (dark shadow) in the midline is in normal position or shifted to one side.
5. The ribs are normal or show fracture or malignant destruction.
6. There is free gas under the diaphragmatic shadow or not.
7. The costodiaphragmatic recess is clear or contains fluid.

Abdominal radiograph

It is obtained in a supine position (AP view). The plain radiographs of the abdomen demonstrate intestinal gas pattern and size and contour of the liver and spleen. The position of the kidney is outlined due to the lucency of the perinephric fat surrounding them. The presence of calcified opacities such as biliary and renal

tract calculi may be seen. Areas of abnormal calcification may be seen in the pancreas due to chronic pancreatitis. Then, obstruction of the lumen of the bowel is seen as abnormal air-filled levels on erect film and distended bowel loops proximal to obstruction in the supine position.

Radiographs of limbs

They are obtained in AP, PA and lateral views. The plain radiographs of limbs are widely used to detect fractures. Osteomyelitis and bone tumours are often well seen on plain films.

Xeroradiography

It is a variation of plain radiography. In this procedure, an X-ray beam is passed through a patient onto the aluminium plate which is coated with a thin layer of selenium and electrically charged. This causes an alteration of the electrostatic charge corresponding with the image. The image can be obtained/seen by blowing a thin powder that adheres in proportion to the local charge onto the plate. This is then transferred to a special paper and a permanent record is obtained. This procedure provides better soft tissue contrast than seen in simple plain radiography.

Tomography

It is also a variation of the simple radiography performed to take radiographs of body sections. In this procedure during X-ray exposure, the X-ray tube and X-ray film are moved in the opposite direction so as to produce the equivalent of a body section. The X-ray tube and X-ray film are connected by a rod, which can be made to pivot a variable point.

Special radiological procedures

Contrast radiography

In this procedure, different contrast media (either radiopaque or translucent) which have permeability to X-rays different than that of body tissues are inserted into various cavities and organs or even into blood vessels to achieve greater contrast in a radiograph.

Since the contrast media have different permeability to X-rays than that of the body tissues, X-ray pictures of the interiors of hollow organs and vessels can be obtained.

With the advent of new imaging modalities, contrast media is also used to improve the visibility between a focal mass and the surrounding parenchyma of an organ. This is commonly known as **lesion enhancement**.

Thus, the functions of contrast media include

1. **Delineation of normal structures**, e.g. GIT, biliary tree, thecal sac, joint space and blood vessels.
2. **Lesion enhancement**, e.g. mass in the liver, renal calculus etc.

Contrast media

The contrast media generally used are:

1. **Radiopaque:** The contrast media are ingested or injected into the body. These include
   (a) *Salts of heavy metals*, e.g. barium sulphate
   (b) Organic iodide preparations.
2. **Radiolucent:** It includes gas, e.g. air and other gases.

N.B.

- The barium sulphate and iodine compounds produce

radiopaque shadows, whereas air and oxygen produce radiolucent shadows.
• Barium is the most widely used contrast media in radiography.

Criteria for a good contrast medium

The contrast medium should be:

1. non-toxic,
2. reasonably radiopaque or radiolucent,
3. easily administrable and
4. easily available.

Choices of different media:

1. *Barium sulphate suspension* (emulsion) in water is used for visualizing GIT.
2. The *aqueous solution of iodine compounds* is used to visualize the biliary passage, urinary passage and blood vessels.
3. The *iodized oil* is used for visualizing the bronchial tree and genital passage.
4. The *air and gases* are used for visualizing the body cavities like ventricles of the brain and serous cavities of the body.

N.B.

Air can be used along with barium for *double-contrast studies* of the GIT. The barium coats the mucosa and is studied in detail following air distension of the organ.

Interpretation of common contrast radiographs

Barium meal x-ray (Fig. 16.7)

It is obtained by oral administration of barium meal in an erect

posture. The barium meal contrast radiograph demonstrates a J-shaped shadow of the stomach, with a lucent shadow of air bubble in its fundus, angular notch (incision angularis) at the junction of the pylorus and lesser curvature of the stomach, and narrow pyloric canal at the junction of pylorus and duodenum. The first part of the duodenum typically presents a triangular shadow called the **duodenal cap**. The remaining part of the duodenum presents a floccular appearance; alteration in the mucosa of the oesophagus, stomach and duodenum is seen filling the defects. Peptic ulcers cause craters, called **ulcer craters**, in the wall of the stomach and duodenum.

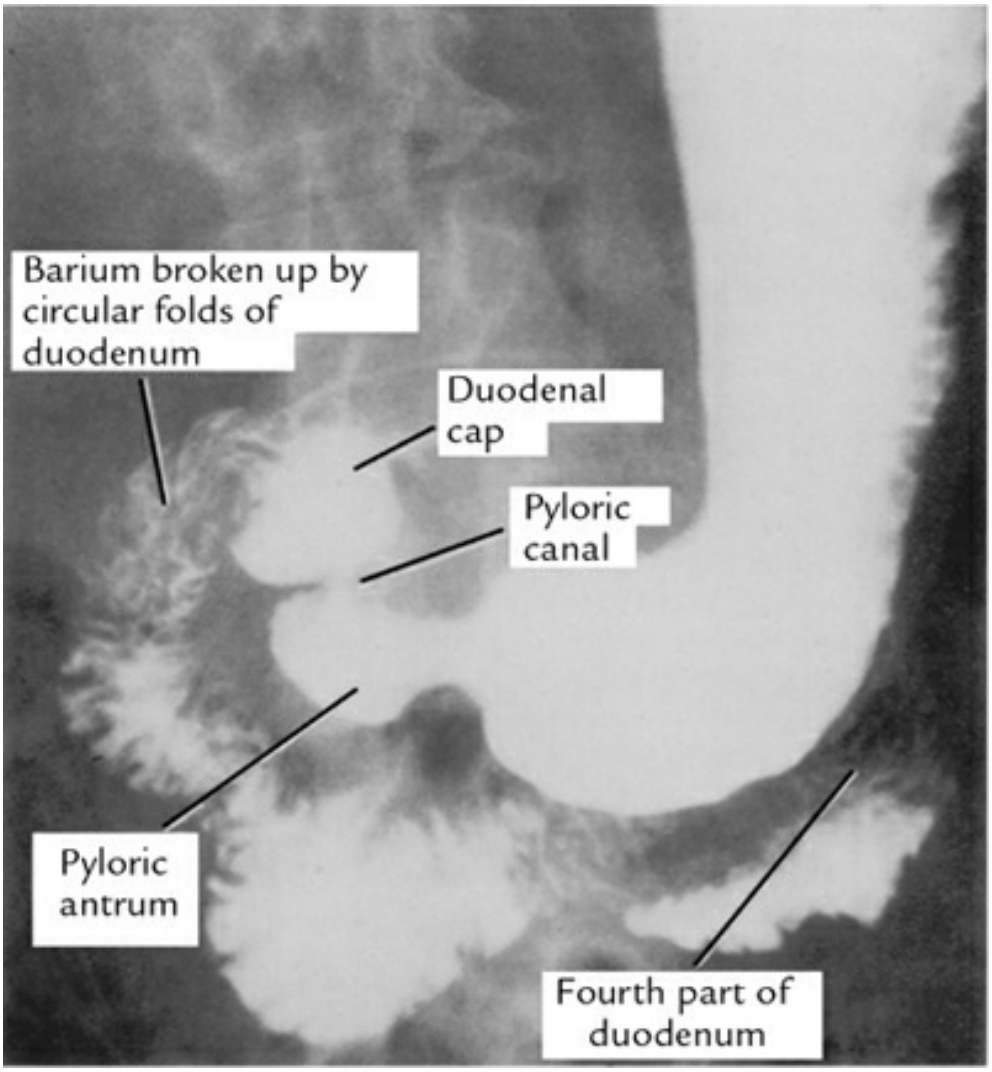


FIG. 16.7 ■ Barium meal X-ray. (*Source*: Fig. 5.25, Page 250, *Last's Anatomy: Regional and Applied*, 12th ed, Chummy S

Sinnatamby. Copyright Elsevier Ltd. 2011, All rights reserved.)

Barium enema x-ray (Fig. 16.8)

It is obtained by the administration of 2–3 pints (1 L) of barium sulphate emulsion through the anal canal. The barium enema X-ray demonstrates the characteristic sacculations in the wall of the large intestine. The rectum is seen to have a wider calibre than the colon. The appendix may sometimes be seen as arising from the base of the caecum.

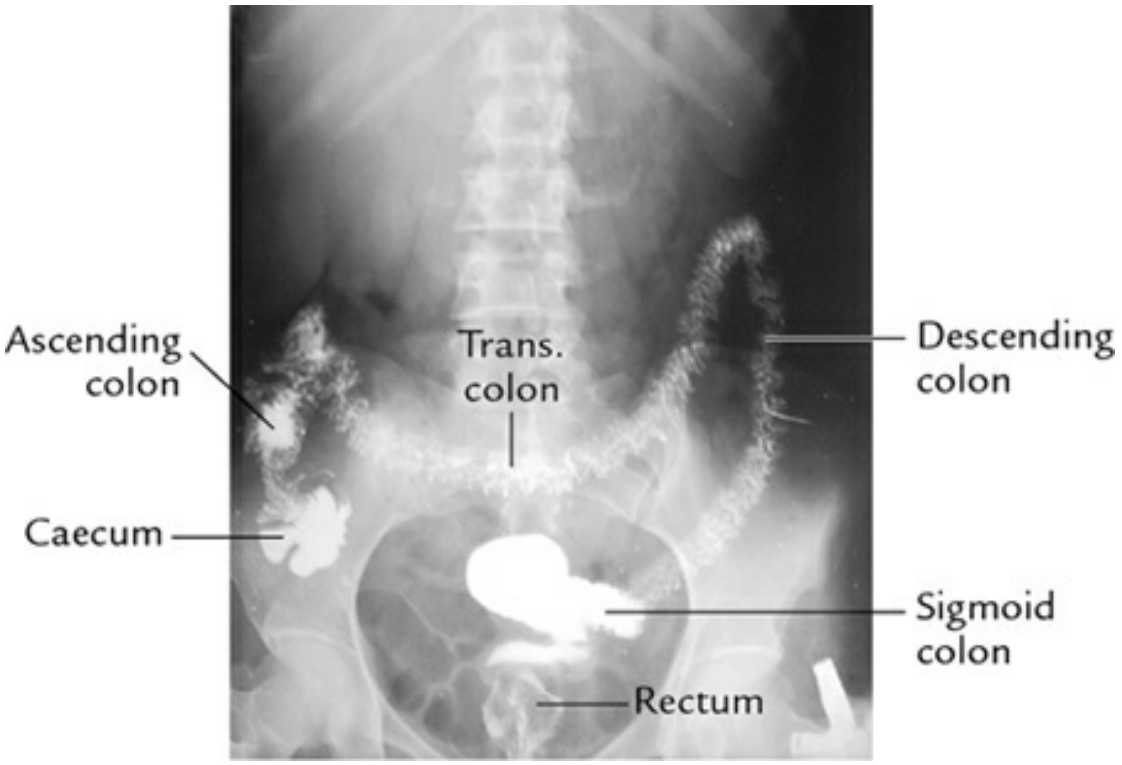


FIG. 16.8 ■ Barium enema X-ray.

The barium enema is used to assess the colon for the presence of carcinomas, diverticulosis and extent of inflammatory bowel disease.

Pyelogram

It is obtained by the administration of iodine-containing contrast

medium in the urinary tract either intravenously or through the catheter, and pyelography thus performed is termed descending (intravenous) and ascending pyelography, respectively. Intravenous pyelography is the standard method to visualize the urinary tract. The pyelogram demonstrates calyces, ureter and bladder. Haematuria, dysuria and loin pain are important indications for intravenous pyelography. The stones in the pelvicalyceal system, ureter and urinary bladder are readily visualized as radiopaque shadows.

Hysterosalpingogram

It is obtained by injecting a contrast medium (lipiodol) into the cervix and uterus through a suitable cannula. The hysterosalpingogram outlines the uterine cavity, fallopian tubes and spilling of contrast medium in the peritoneal cavity through the ostia of fallopian tubes. The hysterosalpingography is useful in cases of sterility to prove or disprove the patency of the uterine tubes.

Computed tomography (CT) scanning/computerized axial tomography (CAT) scanning

Conventional computed tomography (CCT)

It is a new method of forming images from the X-ray. In this method, a movable X-ray tube and computer scanner are used. The CT permits the study of tissue slices so that minor differences in tissue density can be recognized. The X-ray source/tube rotates in an arc around the body part being studied and sends out a beam of X-rays. The X-ray having passed through the part of the body is collected by a special X-ray detector, the scanner. The scanner receives intensity information of the body part from many positions. These data are entered as a matrix and the radiodensity

at each point in the three-dimensional space of the part is calculated. With a sufficiently narrow X-ray beam, sensitive detectors and digital signal processing techniques, a small difference in radiodensity can be converted into an image. Since the information is gathered for the full volume of the part, the computed matrix contains information about the entire part, it is, therefore, possible to generate 'slices' or tomograms (Greek word *tomo* means '*cut*' or '*slice*') of various planes through the part, visualizing internal structures at any desired level. Thus, a CT scan obtains a series of images of the body (slices) in the axial plane and displays a cross-sectional image (Fig. 16.9).

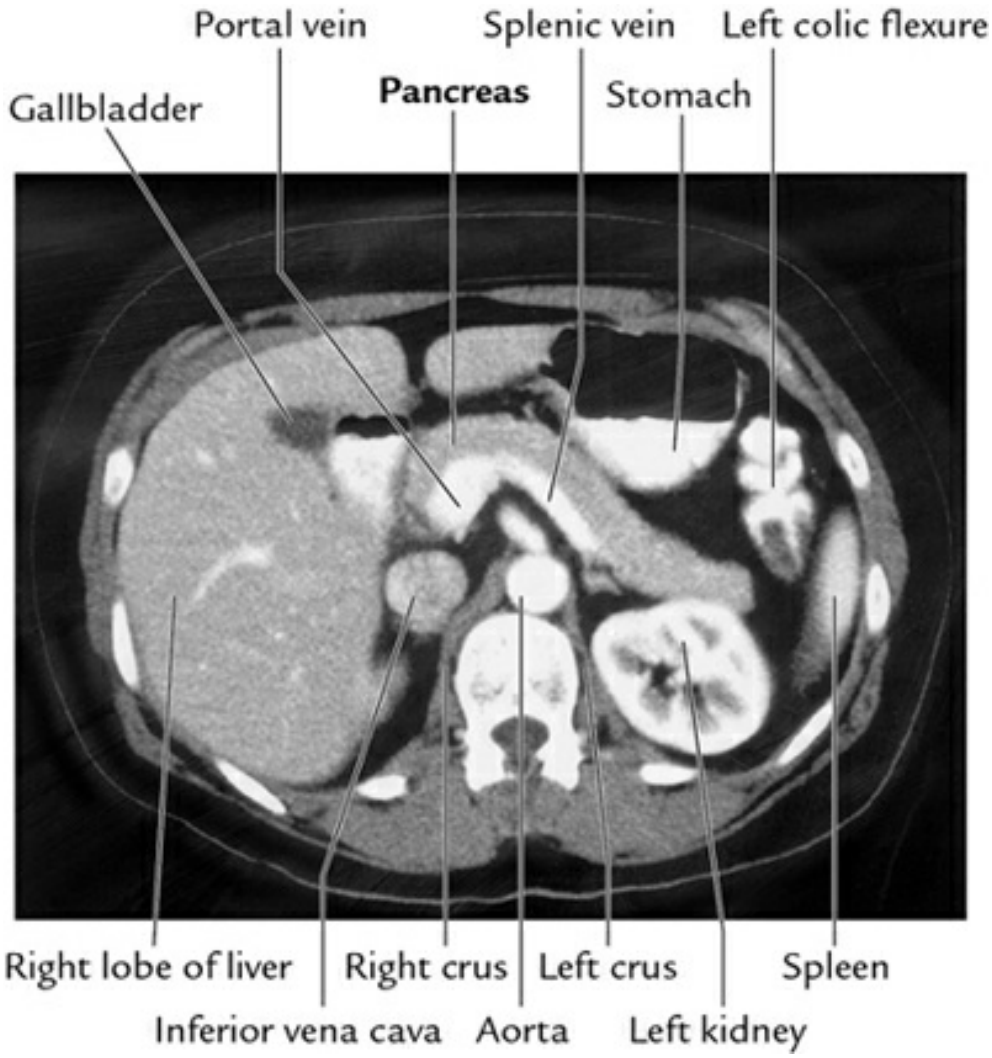


FIG. 16.9 ■ CT scan of the abdomen with contrast in an axial plane. (*Source*: Fig. 4.88A, Page 289, *Gray's Anatomy for Students*, Richard L Drake, Wayne Vogl, Adam WM Mitchell.

N.B.

CT scanning is based on the same principle as conventional X-rays but combines it with computer technology. This procedure is safer as it is quick and lasts only a few seconds to generate each slice.

Features

The characteristics of computed tomographic imaging are as follows:

1. Computerized tomography uses X-rays.
2. It gives an excellent cross-sectional image of internal structures.
3. It is very useful in detecting deep-seated lesions.
4. It is less harmful than conventional X-rays due to a shorter exposure time.
5. It is generally called computed axial tomographic scanning (CAT scan).
6. It was invented and introduced for clinical use by Godfrey N. Hounsfield in 1970.

Spiral CT (SCT)

In this procedure, the patient moves longitudinally, and the X-ray tube moves in a circular motion. As a result, the X-ray beam takes a spiral path through the organ being studied. The vast information thus achieved is manipulated by using a modern computer system to get an image that can be viewed from any angle.

The unwanted tissues, obstructing the details, can also be removed by computer manipulation.

The presentation can be further improved by colour coding.

Radioisotope scanning (Nuclear medicine imaging)

During the last two decades, radioisotopes are being used for organ imaging. Radioisotope imaging (or nuclear medicine imaging) is based on the principle that certain isotopes emit gamma radiation. By introducing isotopes into the body, it is possible to visualize specific regions of interest. Gamma radiation is detected by a gamma camera. The isotopes of an element are nuclides with the same atomic number but with a different mass number.

The technique of scanning depends on the fact that a particular isotope can be so designed as to be selectively taken up by a particular organ.

Lesions of an organ such as tumours may take up more isotopes resulting in so-called hot areas on the scan as in the brain. Alternatively, they may fail to take up the isotope resulting in '*cold*' areas as in the liver and thyroid.

The common isotopes used in nuclear medicine imaging are of iodine (^{123}I, ^{125}I, and ^{131}I) and technetium (^{99m}Tc).

Most nuclear medicine images are functional studies. The images are generally directly interpreted on a computer and a series of representative films are obtained for clinical use.

Single photon emission computed tomography (SPECT)

The SPECT analyses body's organs and tissues. It is a type of nuclear imaging which uses a radioactive substance and a special camera to create 3D pictures. *It is often done to see dopamine active transporter (DAT) in the striatum of the brain* (Fig. 16.10).

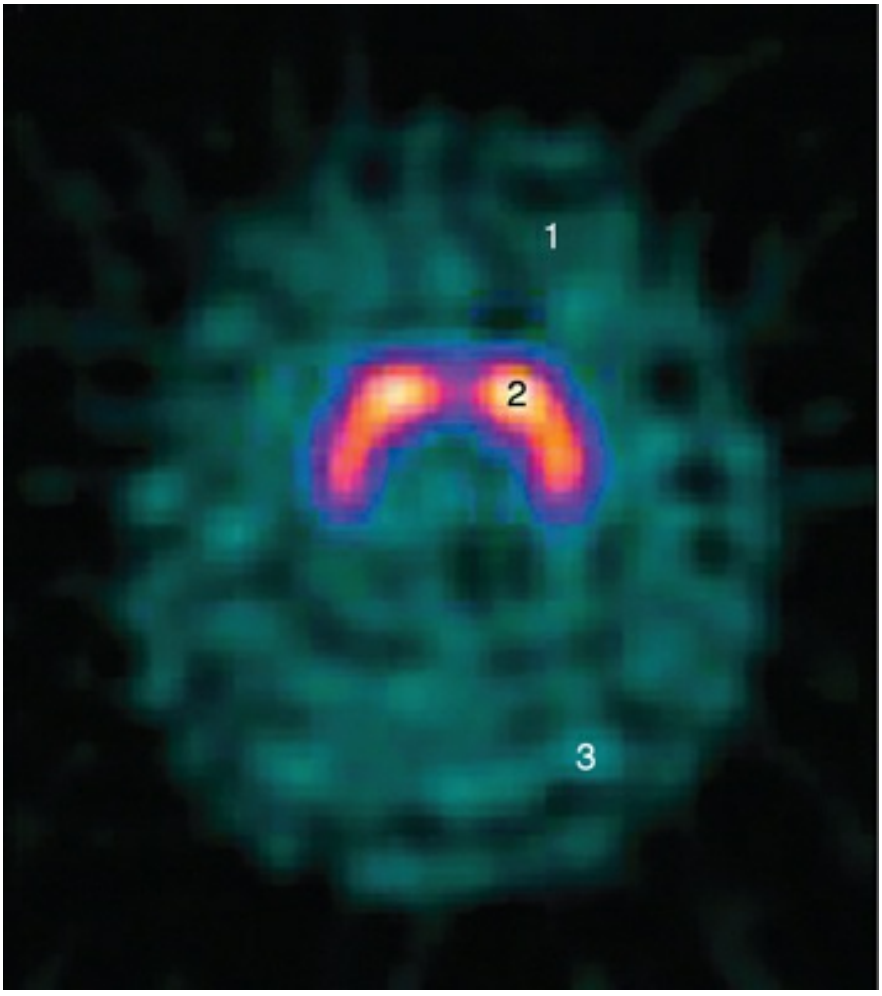


FIG. 16.10 ■ A single photon emission computed tomography (SPECT).

Positron emission tomography (PET)

The PET scan is a radiological technique used to determine the metabolic activity in the organs such as in the brain, heart or other organs, after injecting a radioactive substance into the blood.

The metabolic activity is determined by tracking the movements and concentration of a radioactive tracer that is injected into the blood. A camera records the tracer's signals as it travels. A computer converts these signals into three-dimensional images of the organ under examination.

It is done to diagnose malignancy to evaluate staging of tumour.

The PET provides information about function because of neuronal activity or blood flow (Fig. 16.11).

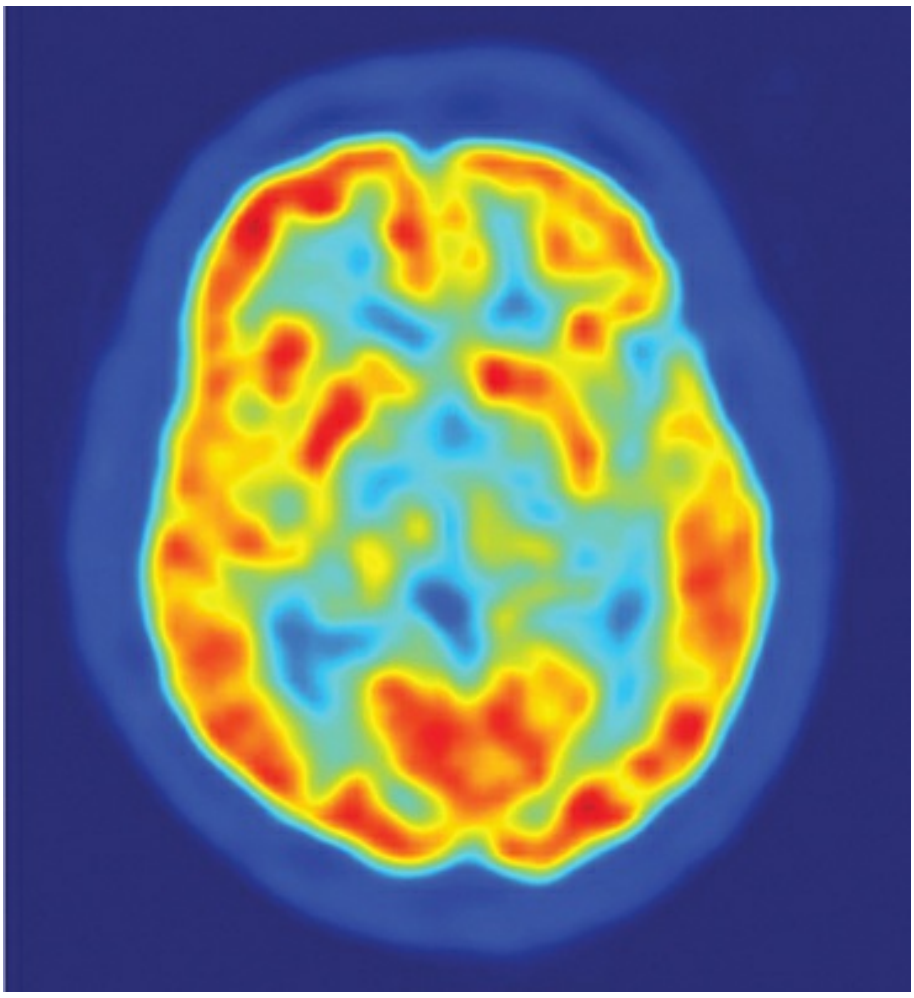


FIG. 16.11 ■ Positron emission tomography (PET).

Features

The characteristics of PET are as follows:

1. PET scan combines CT and nuclear scanning.
2. This reveals the metabolic and functional changes at the cellular level in an organ.
3. PET scan detects these changes very early, whereas a CT scan or MRI detects these changes late when the disease has caused structured changes in the organ.

Imaging techniques: Not using ionizing radiation

Ultrasonography (USG)

In USG, high-frequency sound waves are used. The frequency of waves is so high that they cannot be heard by the human ear, hence the name **ultrasonic waves**.

The principle of medical ultrasonographic imaging lies in the passing of a beam of high-frequency sound into the patient and detecting the returning echoes.

The ultrasonic waves are produced from a **transducer** and travel through the human tissues at a velocity of some 1500 m/s. When the wave reaches an object or surface with a different texture, it is reflected back to the source, the transducer, as echoes. These echoes received by the transducer are amplified and electronically converted into real-time anatomical images, which are shown on a monitor (Fig. 16.12).

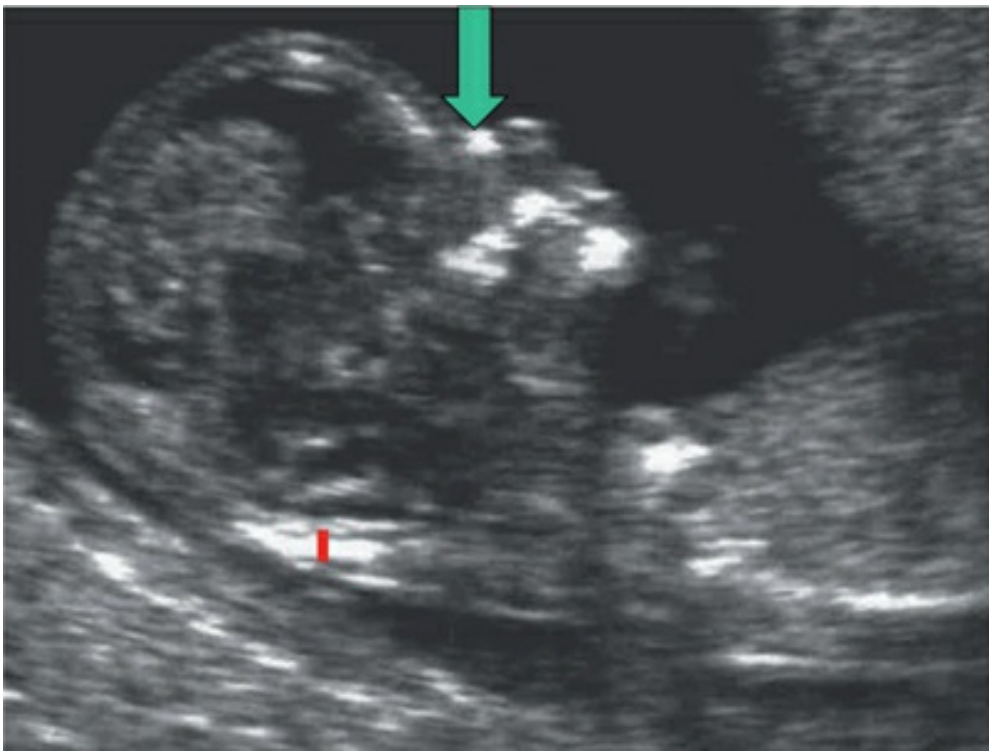


FIG. 16.12 ■ Ultrasonographic image of a foetus (18–20 weeks) to confirm delivery date, presence of foetal anomalies etc. Note nuchal thickness (red line) and nasal bone (green arrow). (*Source: Journal of Crash Course: Obstetrics and Gynaecology:* Prenatal Diagnosis; 2009, Elsevier.)

The sound waves that are passed through gas, solid and fluid-filled structures travel at different rates and are reflected back with differing degrees of echoes. The gas and bone are not suitable for USG; hence, gas-filled structures such as the lungs and bowel are very difficult to be visualized.

The ultrasonography is very useful in assessing the nature of masses in the abdomen and soft tissues because one can differentiate between solid and fluid-filled masses. For example, if a mass in the kidney is first observed by intravenous pyelography, one can more accurately assess it with ultrasonography. During USG, if it is solid, it is likely to represent a tumour, and if cystic, it represents a simple cyst.

Nowadays, ultrasonography is widely used to visualize fluid-filled structures such as gallbladder, urinary bladder etc.

N.B.

The ultrasonography is now the primary means of investigation to assess gallbladder disease since the ultrasonologist can also look at the liver, kidneys and pancreas at the same time. Pathology in these closely related organs, which may mimic biliary pathology, can be detected.

Features

The characteristics of ultrasonographic imaging are as follows:

1. Ultrasonographic imaging of internal organs is non-invasive.
2. Is safe as it does not involve electromagnetic radiation.
3. Can be safely used to evaluate the condition of the foetus such as gestational age, congenital defects (anencephaly, spina bifida) etc.
4. Can detect tumours that differ in density from surrounding tissues.
5. Can provide valuable information regarding the size, location, displacement, etc.
6. Is very useful in diagnosing defects in various internal organs like the heart, kidneys, gallbladder, etc.

Ultrasonography is very useful in assessing the nature of masses either in the abdomen or soft tissues. It is widely used in visualizing fluid-filled structures such as the gallbladder, urinary bladder or abdominal aorta.

It is now the primary mode of investigating suspected gallbladder disease since ultrasonologists can look at the liver, kidneys and pancreas at the same time.

Doppler images are currently being used to assess blood flow in major blood vessels.

Magnetic resonance imaging (MRI)

This new imaging modality is a method of visualizing the physiological distribution of protons of hydrogen ions within the body, enabling high-quality anatomical images to be obtained by using high-powered magnets. MRI is the most exciting advancement in imaging technology since the beginning of medical radiology in 1895. It is based on the generalized phenomenon called nuclear magnetic resonance (NMR). Magnetic resonance is the study of the interaction of molecules (specifically atomic nuclei

such as hydrogen) with the radiofrequency field in the presence of a strong external magnetic field. Since the human body contains nearly 70%–80% of water (H_2O), as it is present in almost all the tissues of the body and water contains hydrogen (H). The hydrogen proton is ideal for MRI. These protons behave like tiny magnets; hence it is possible to get the distribution of these protons present in the body, which is shown in the form of an MRI image.

To take an MRI image, the patient is placed in a strong magnetic field, i.e. he/she is positioned in the centre of the machine which has powerful magnets. When a pulse of radio waves is passed through the patient, the magnets are deflected and as they return to their aligned position they emit small radio pulses. The strength and frequency of emitted pulses and the time taken by protons to return to their pre-excited state produce a signal. These signals are analysed by a powerful computer, and an image is obtained (Fig. 16.13).

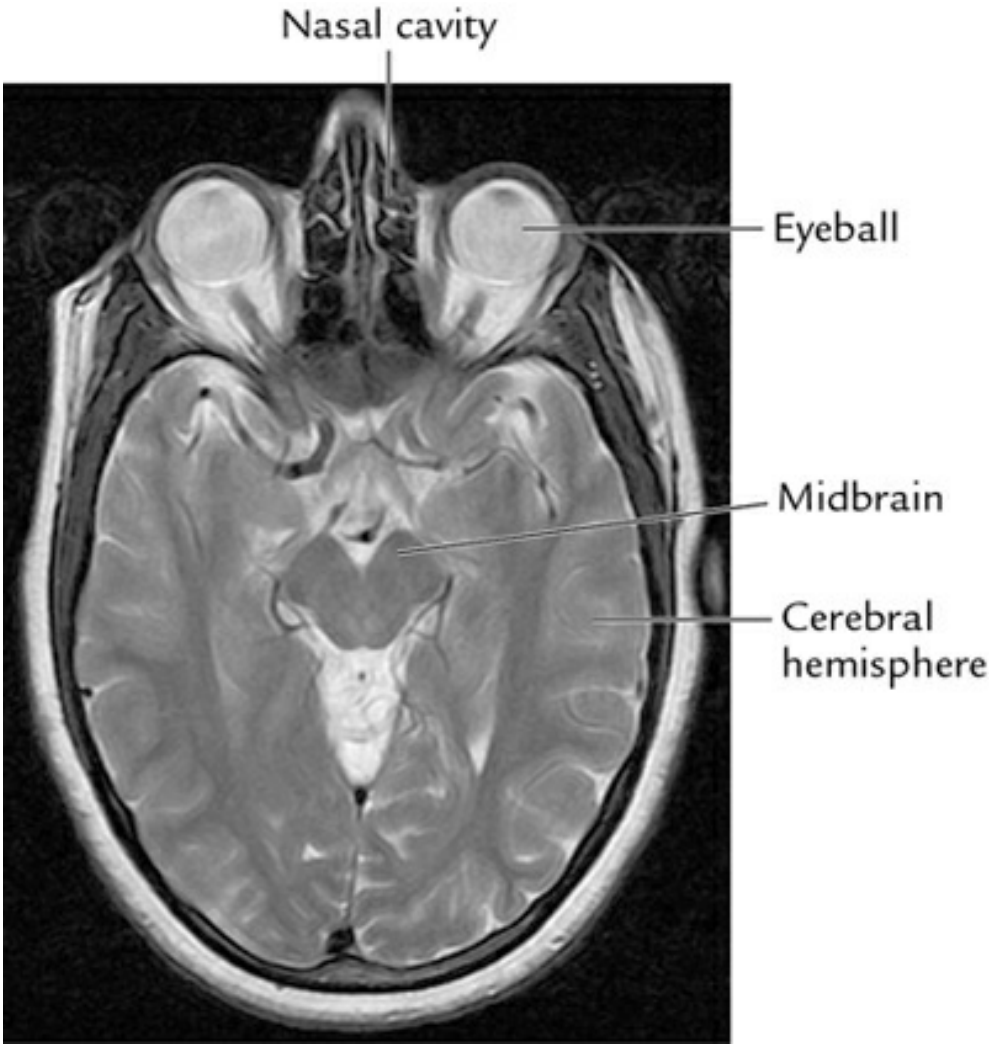


FIG. 16.13 ■ MRI of the head. (*MRI,* magnetic resonance imaging.)

To summarize, the MRI images obtained are from abundant and strong signals of mobile protons (of atomic nuclei of hydrogen ions) of the water and fat present in the body. These images are nothing but a pictorial representation of the spatial distribution of the mobile protons of hydrogen ions. The NMR signals can be altered by introducing new contrast agents (viz. paramagnetic substances). Nowadays, by using these new contrast agents, enhanced images of very small lesions can also be demonstrated within the brain.

Weighting of imaging

The different properties of protons can be assessed by altering the

sequence of pulses subjected to protons. These properties are called *weighting*.

Two types of images are obtained by altering the pulse sequence and scanning parameters, which provide differences in image contrast as under:

1. **T1-weighted images:** They show dark on fluid and bright on fat, e.g. cerebrospinal fluid (CSF) in the brain appears dark.
2. **T2-weighted images:** They show a bright signal on fluid and an intermediate signal on fat, e.g. CSF in the brain appears white.

N.B.

The technique of MRI uses the magnetic properties of the hydrogen nucleus excited by the *radiofrequency radiation* transmitted by a coil around the body part. It provides better differentiation between different soft tissues because some tissues contain more hydrogen in the form of water than the other tissues.

Features

The characteristics of an MRI are as follows:

1. An MRI is completely non-invasive and X-rays are not used.
2. Provides two and three-dimensional pictures of any organ of the human body.
3. Is superior to CT and provides good soft-tissue contrast.
4. Produces not only axial images resembling those of CT but also images of any direction and plane including sagittal and coronal.
5. Absence of ionizing radiation or any other apparent biological hazard.

6. Is the first investigation of choice to detect a tumour in the brain and spinal cord.
7. Can be used to assess the blood flow within the vessels and produce angiograms.

Radiological terms in present perspective

The images on screen or in photographic films are composed of grey shades ranging from white to black. In plain radiograph, only four densities or shades can be distinguished, viz. bone = white, soft tissues = grey fat = a darker grey and air = black. But with the development of new imaging modalities, radiologists use different terminologies to describe the shades of brightness and darkness. The accepted terminologies are listed in Table 16.2.

 TABLE 16.2

Summary of radiological terms

Imaging modality	Brightness (white shade)	Darkness (dark shade)
Plain radiograph	Radiopaque	Radiolucent
Ultrasonograph	Hyperechoic	Hypoechoic
Computed tomographic (CT) scan	High attenuation	Low attenuation
Magnetic resonance imaging (MRI)	High signal	Low signal
Nuclear magnetic resonance (NMR)	'Hot' areas	'Cold' areas

Orientation of images

The radiological images are viewed in standard orientations. In recent years, advent of CT and magnetic resonance has greatly

increased possible orientations so that the final image can be constructed by a process called **multiplanar reformatting**. However, conventional orientations are still based on anatomical planes as under:

1. *Sagittal images* show a slice through the long axis from anterior to posterior.
2. *Coronal images* show a slice through the long axis from the right side to the left side.
3. *Axial (transverse or horizontal) images* show a horizontal slice at a right angle to the long axis of the body. These images are created as if standing at a patient's feet and looking towards his head.

 Golden Facts to Remember

• **X-rays were invented by**	Wilhelm Conrad Röentgen in 1895
• **Most important property of X-rays**	Penetrating power
• **CT scan was invented by**	Hounsfield in 1970
• **Most exciting advancement in imaging technology since the discovery of X-rays in 1895**	Magnetic resonance imaging (MRI)
• **Most sensitive cells in the body to ionizing radiation**	Lymphocytes (followed by leucocytes and reproductive cells)
• **Least sensitive tissue in the body to ionizing radiation**	Fibrous tissue (followed by muscle, bone marrow and nervous tissue)
• **Commonest view of X-ray chest desired by clinicians**	Posteroanterior (PA) view
• **Most commonly used contrast**	Barium sulphate

medium in radiography	
• **Most commonly used isotopes in imaging**	Technetium, radio-iodine
• **Most commonly used imaging technique to visualize the condition of foetus**	Ultrasonography
• **Most efficient imaging technique used to detect gallbladder disease**	
• **Most efficient imaging technique used to detect disc prolapse**	MRI
• **First choice of imaging technique used to detect tumour in brain and spinal cord**	
• **Imaging technique used to detect metabolic activity in the organs**	Positron emission tomography (PET)

Multiple choice questions

1. **Regarding Wilhelm Conrad Röentgen, all of the following facts are true *except*:**
   (a) He was a German physicist
   (b) He discovered X-rays
   (c) He won the Nobel Prize in 1895
   (d) He won the Nobel Prize in 1901
2. **Which of the following structures absorb maximum X-rays?**
   (a) Air
   (b) Bone
   (c) Soft tissue
   (d) Fat
3. **Radiation exposure occurs in all *except*:**
   (a) CT scan
   (b) Fluoroscopy
   (c) MRI
   (d) Plain X-ray

4. **Calcification is best detected by:**
    (a) CT scan
    (b) MRI
    (c) Ultrasound
    (d) Plain X-ray
5. **X-rays are produced when electrons hit:**
    (a) Cathode
    (b) Anode
    (c) Water
    (d) Radium source
6. **X-rays are produced by:**
    (a) Positrons
    (b) Protons
    (c) Electrons
    (d) Neutrons
7. **Imaging technique commonly used to see the condition of the foetus is:**
    (a) Plain X-ray
    (b) Ultrasound
    (c) CT scan
    (d) MRI
8. **X-rays were discovered by Röentgen in:**
    (a) 1885
    (b) 1895
    (c) 1901
    (d) 1907
9. **X-rays are:**
    (a) Electrons
    (b) Protons
    (c) Neutrons
    (d) Electromagnetic waves
10. **CT scan was invented by:**
    (a) Röentgen
    (b) John Snow

(c) Godfrey Hounsfield
(d) Takashita Koba

11. **Xeroradiography is generally used for the detection of tumour in:**
(a) Breast
(b) Stomach
(c) Colon
(d) Pancreas

12. **First investigation of choice to detect tumour in the spinal cord is:**
(a) Plain X-ray
(b) Ultrasound
(c) CT scan
(d) MRI

13. **The photosensitive material used in X-ray films consists of:**
(a) Cellulose
(b) Silver bromide
(c) Zinc sulphide
(d) Cadmium

14. **Most radiolucent substance is:**
(a) Fat
(b) Soft tissue
(c) Brain
(d) Bone

Answers

1. ***c*****, 2.** ***b*****, 3.** ***c*****, 4.** ***d*****, 5.** ***b*****, 6.** ***c*****, 7.** ***b*****, 8.** ***b*****, 9.** ***d*****, 10.** ***c*****, 11.** ***a*****, 12.** ***d*****, 13.** ***b*****, 14.** ***a***

Chapter 17: Medical genetics

Specific learning objectives

After studying this chapter, the student should be able to

- Describe structure of DNA and RNA, and discuss the differences between them.
- Discuss structure and morphological types of chromosomes. **AN 73.1**
- Define karyotyping and discuss its significance in clinical medicine. **AN 73.2**
- Provide a brief account of sex chromatin and Lyon's hypothesis. **AN 73.3**
- Present a brief account of genes and discuss autosomal and sex-linked inheritance.
- Describe in brief the clinical conditions that occur due to chromosomal abnormalities. **AN 75.1**
- Describe Down's syndrome, Klinefelter's syndrome, Turner's syndrome, and Cat's cry syndrome in brief.
- Describe the preparation of pedigree charts of various types of inheritances. **AN 74.2**
- Describe the principles of genetic counseling. **AN 75.5**
- Describe the genetic basis of variations, viz. polymorphism and mutation. **AN 75.4**
- Discuss briefly the single gene inherited diseases.

• Correctly solve the Multiple choice questions given at the end of the chapter.

Introduction

Genetics is the branch of bioscience that deals with the underlying principles of heredity. Heredity/inheritance is a process by which children inherit certain characteristics (traits) from their parents.

The expression of inherited character is however modified by the environment around the individual in which he/she grows. These characteristics (traits) pass from parents to children through the inheritable material (**genetic code**) present in the nucleus of the cell. The genetic code is carried by the deoxyribonucleic acid (DNA) molecules. The functional unit of DNA is called a ***gene***.

The DNA molecules are arranged in linear sequences in chromosomes inside the nucleus of the cell. The total genetic information present in a cell is called the **genome.** The human genome comprises about 50,000–100,000 genes.

Gene expression occurs by the formation of different types of proteins. The protein is synthesized by transcription of genetic code into ribonucleic acid (RNA), perpetuated by DNA replication. The RNA forms protein by translation using the genetic code. Thus RNA is an intermediary molecule to execute gene expression.

Deoxyribonucleic acid

DNA is a double-stranded molecule, made up of two chains of nucleotides, coiled around each other, forming what is commonly described as a **double helix**. The double-helical model of DNA was first introduced by James Watson and Francis Crick in 1953 (Fig. 17.1).

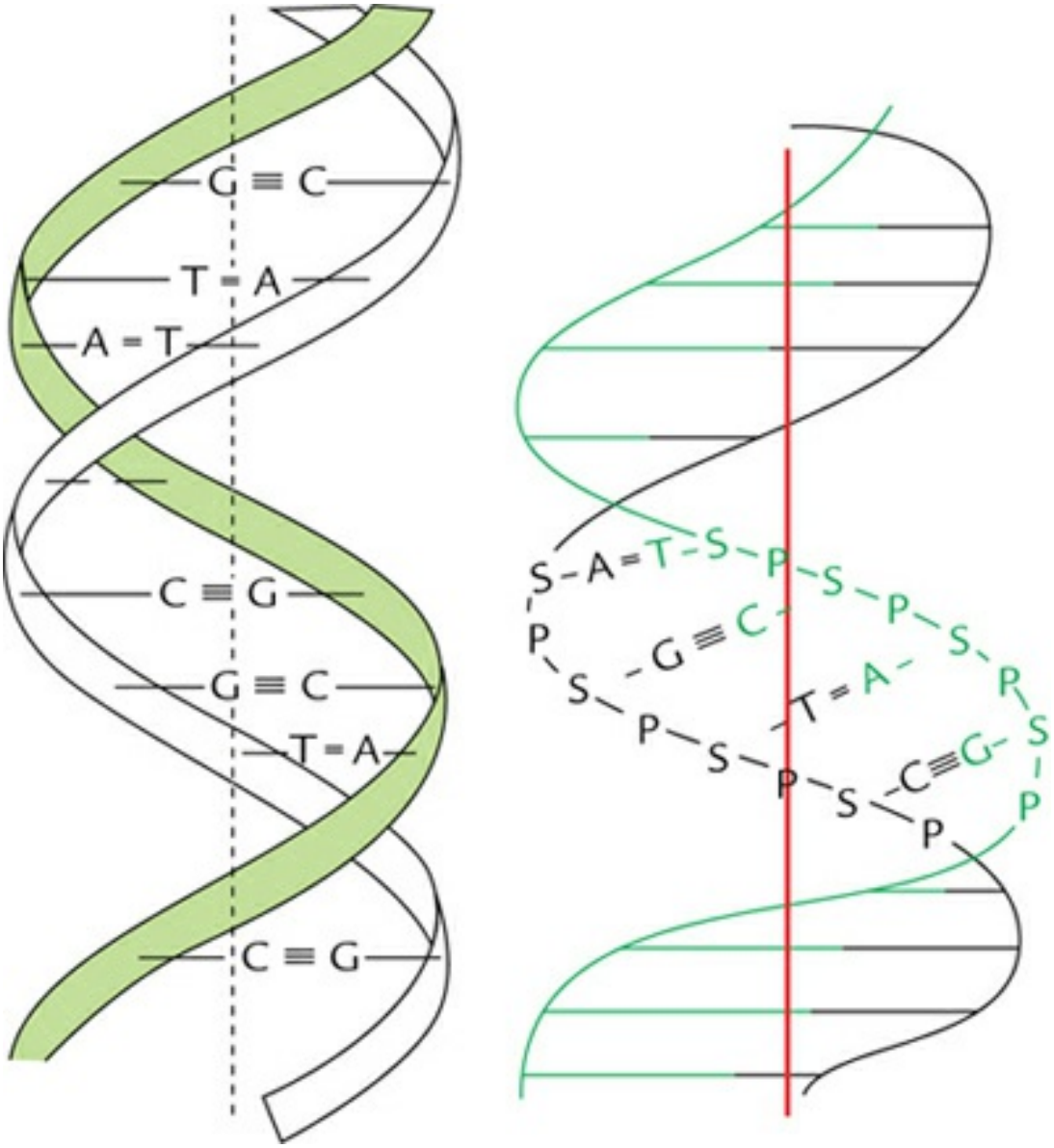


FIG. 17.1 ■ Double helical model of DNA. (DNA, deoxyribonucleic acid.)

The nucleotides are the basic structural units of the DNA.
Each nucleotide consists of three subunits:

1. A sugar
2. A phosphate group
3. A nitrogenous base.

Each strand of the double helix consists of alternate units of sugar and phosphate. The sugar is **deoxyribose**. The two strands are held together by **hydrogen bonds** between the nitrogenous bases which are attached to the sugars as side groups and point towards the centre of the helix. Thus the

structure of a DNA molecule is likened to a twisted ladder. The nitrogenous bases are adenine (A), guanine (G), thymine (T) and cytosine (C). The nitrogenous base of two strands in normal conditions pairs with hydrogen bonds in a specific manner. For example,

1. Adenine binds with thymine by two hydrogen bonds (A=T).
2. Guanine binds with cytosine by three hydrogen bonds (GIC).

However, under abnormal conditions when the bases are in **enol form**, adenine may pair with cytosine and guanine with thymine. This is the basis of the **mutation of genes**.

The two strands of a DNA molecule are complementary to each other, i.e. if the base sequence of one strand is known, then the base sequence of another strand can be formulated.

The functions of a DNA molecule are as follows:

- **Self-replication:** During nuclear division, the two strands of DNA separate and each strand acts as a template to form a new complementary strand (Fig. 17.2).
- **Synthesis of RNA and proteins:** Certain regions of DNA serve as a template for the synthesis of RNA which in turn synthesizes proteins.
- **Recombination:** During crossing over in meiosis, there is an exchange of genetic material between homologous chromosomes, which leads to the shuffling of genes, and the process is called recombination.
- **Mutation:** It is the major source of genetic variation. The change of base sequence in a gene or gene sequence in the DNA molecule is called **gene mutation**. The mutation may be spontaneous or induced. The inducing agents include chemicals, radiation etc.

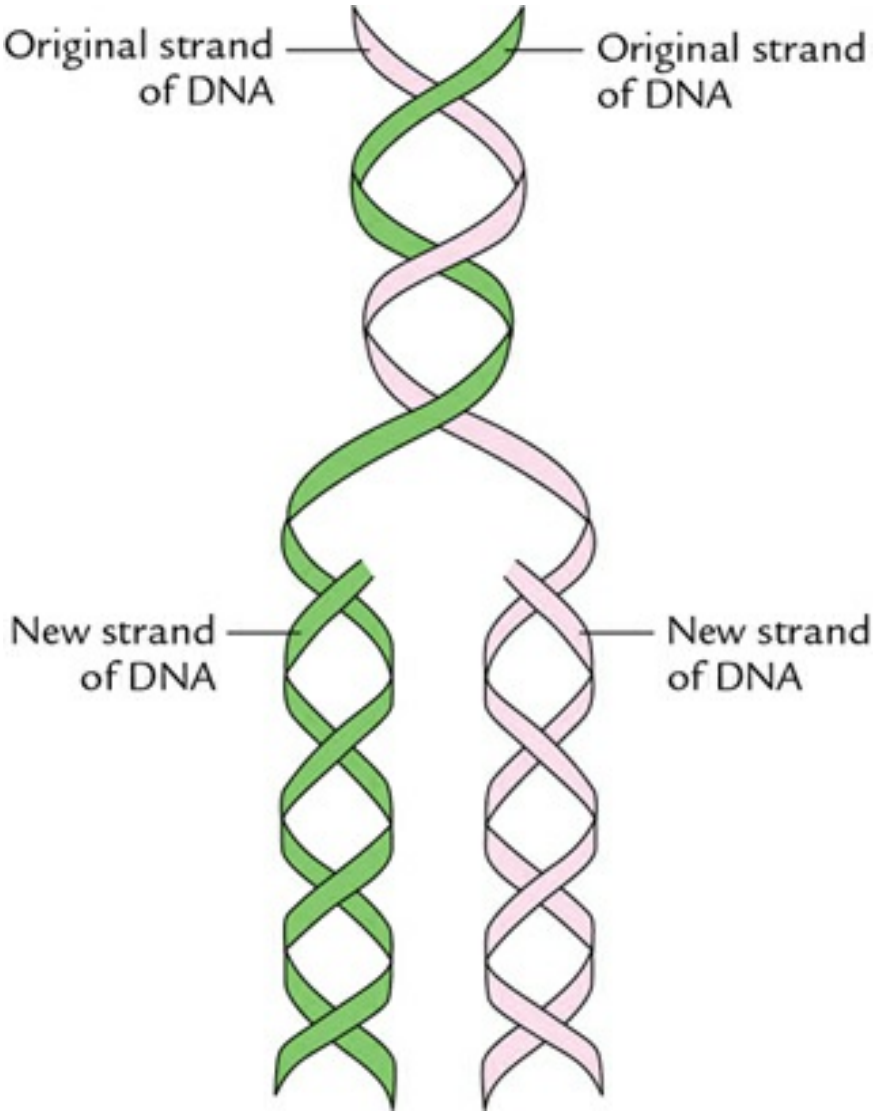


FIG. 17.2 ■ DNA replication. (DNA, deoxyribonucleic acid.)

N.B.

The DNA molecules are associated with globular histone proteins to form chromatin. The histone proteins are involved in regulating the function of DNA. Normally, the chromatin is organized as a string with beads within the cell nucleus but during cell division, the chromatin condenses into structures called *chromosomes*.

Ribonucleic acid

RNA is synthesized in the nucleus by the transcription of one strand of DNA. RNA is structurally related to DNA. Its structure is similar to a single strand of DNA with the difference that the sugar molecule in RNA is **ribose**

sugar and **uracil** substitutes for thymine. The uracil can bind only to adenine.

Biosynthesis of RNA and proteins

The DNA molecule acts as a template for the synthesis of RNA (Fig. 17.3) and the latter conveys the genetic message and deciphers genetic codes for the synthesis of the specific polypeptide chain of proteins by linear linkage of amino acids. Therefore, the central dogma of molecular genetics is that genetic information flows from DNA to proteins during gene expression.

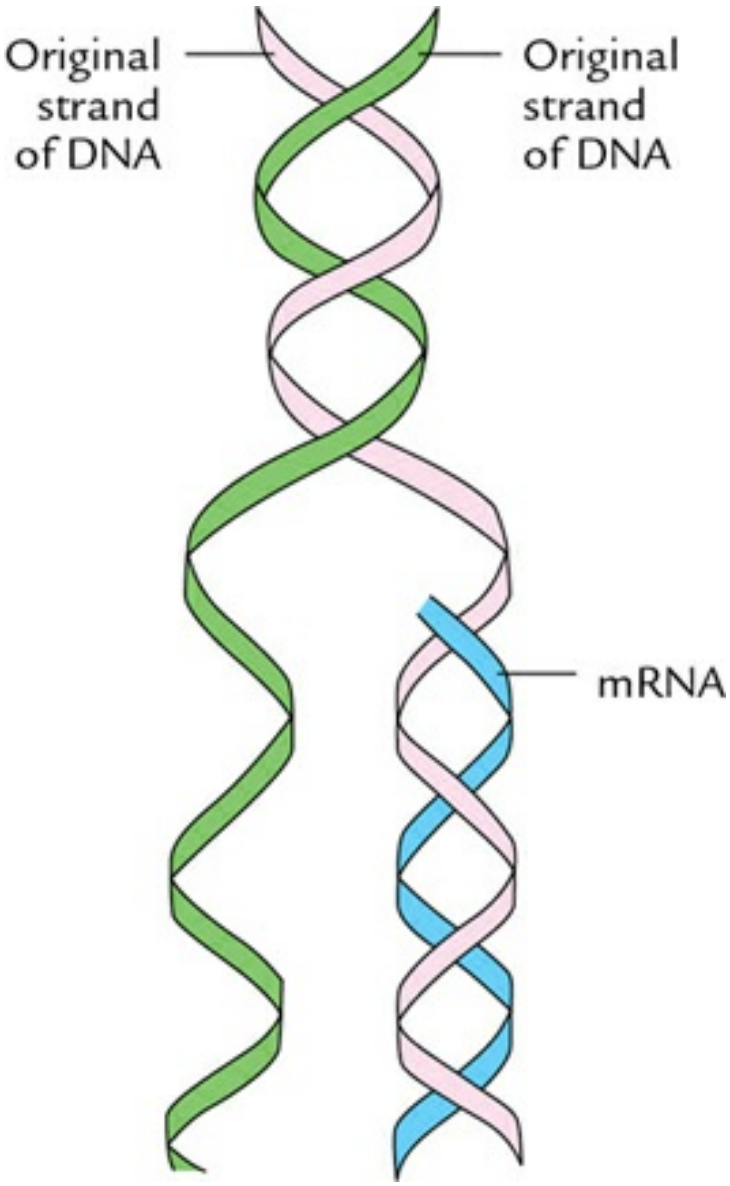


FIG. 17.3 ■ Transcription of mRNA. (mRNA, messenger RNA.)

The flow of information from DNA to protein occurs in the following two

steps:

1. DNA → RNA (by transcription)
2. RNA → protein (by translation)

N.B.

RNA plays a key role in gene expression.

Types of RNA

There are three types of RNA that play important roles in protein synthesis:

1. **mRNA (messenger RNA):** It is synthesized in the nucleus from DNA and copies the nucleotide sequence from DNA. It moves into the cytoplasm through the nuclear pores and then dictates the sequence of amino acids in polypeptide chains.

The mRNA contains the information required to determine the sequence of amino acids in the protein. The information, called **genetic code**, is carried in groups of three nucleotides known as **codons**.

2. **tRNA (transfer RNA):** It is also formed in the nucleus from DNA. The function of tRNA is to match a specific amino acid to a specific codon of mRNA. Each tRNA can pick up a particular amino acid. In other words, before the formation of a peptide linkage, amino acid is activated and attached to one end of a specific tRNA molecule.
3. **rRNA (ribosomal RNA):** Like mRNA and tRNA, the rRNA is also produced in the nucleus from DNA. It is rich in guanine and cytosine in comparison to mRNA and tRNA. rRNA plays an important role in the formation of protein at the ribosome.

N.B.

The synthesis of a protein in ribosome is also produced in the nucleus from DNA.

The differences between DNA and RNA are given in Table 17.1.

TABLE 17.1

Differences between DNA and RNA

DNA	RNA
Present within nucleus	Present within cytoplasm
Consists of two stands of polynucleotides	Consists of a single strand of polynucleotides
Contains deoxyribose sugar	Contains ribose sugar
Nitrogenous bases are adenine, thymine, cytosine and guanine	Nitrogenous bases are adenine, uracil, cytosine and guanine
Replicates and transcribes	Does not replicate and transcribe
Stores genetic information	Helps in expression of genetic information

Chromosomes

The chromosomes (German: *chromosome* = a readily staining body) are deeply stained minute rod-like structures in the nucleus of the cell formed by condensation of chromatin during cell division. They contain DNA encoding genetic information inherited from the parents. The individual chromosomes are best defined (visible) under the microscope only during the metaphase stage of cell division.

Each chromosome presents a primary constriction called **centromere** or **kinetochore**. During cell division (prophase), each chromosome splits longitudinally into two **chromatids** except at the centromere. The centromere divides each chromatid into two arms and is associated with the movement of chromosomes during cell division. The free ends of chromatids are known as **telomeres**. The chromatids of some chromosomes present a secondary constriction near one end. The segment of chromatid distal to secondary constriction is called a **satellite body** (Fig. 17.4). Such chromosomes are sometimes called **SAT chromosomes**.

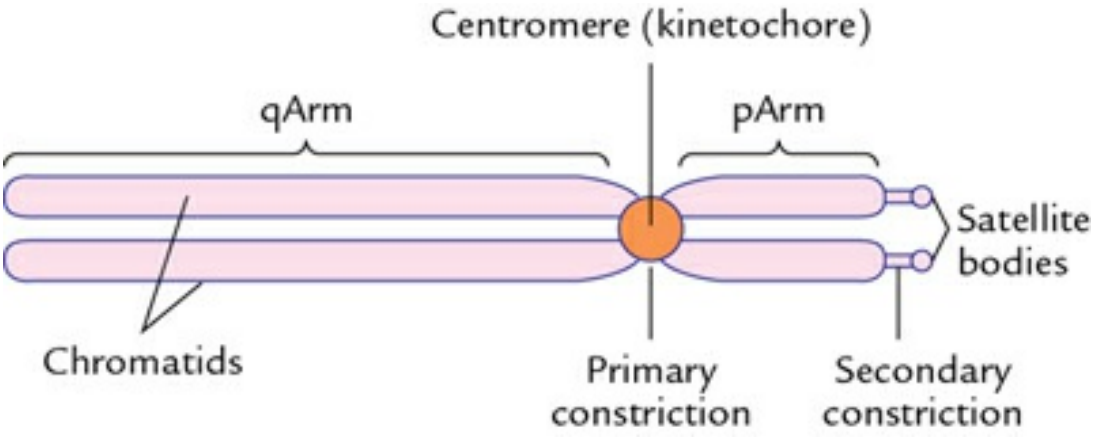


FIG. 17.4 ■ Morphological structure of a chromosome.

Chemical structure

The chromosome consists of DNA, a small amount of RNA, proteins (histone and non-histone) and metallic ions. DNA is the key constituent of the chromosome. It is the most essential and stable molecule. It exists as a highly coiled structure. In an active state, it is lightly stained and most extended and is called **euchromatic**, whereas in an inactive state, it is dark-staining and remains highly coiled and is called **heterochromatic**.

The **histones** are basic proteins that are aggregated as spheroidal particles. The DNA strand is coiled around each particle to form **a nucleosome**.

The non-histone proteins are acidic and form many enzymes.

Morphological types

Depending upon the location of the centromere, the chromosomes are classified into four types (Fig. 17.5):

1. **Metacentric:** Centromere is located in the middle of the chromosome.
2. **Submetacentric:** Centromere is located close to the middle of the chromosome.
3. **Acrocentric:** Centromere is located close to the end of the chromosome.
4. **Telocentric:** Centromere is located at the end of the chromosome.

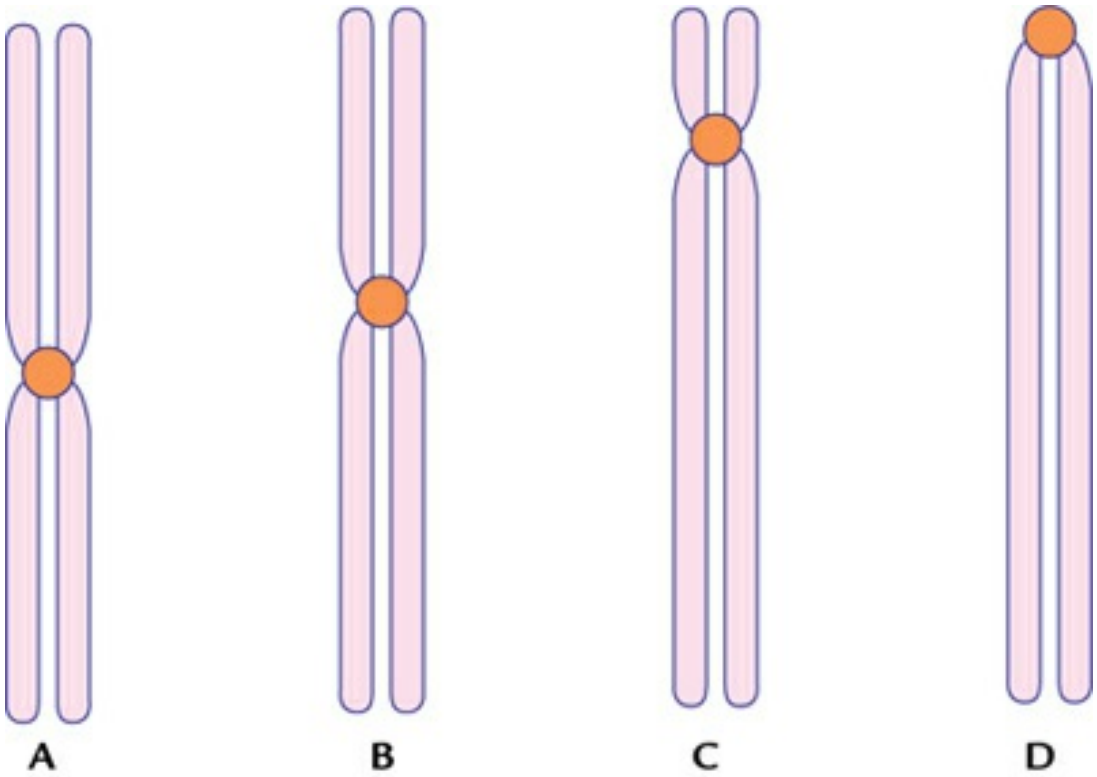


FIG. 17.5 ■ Morphological types of chromosomes: (A) metacentric; (B) submetacentric; (C) acrocentric and (D) telocentric.

Number of chromosomes

The number of chromosomes is constant in a species. In humans, this number is 46 in somatic cells* and 23 in germ cells. In somatic cells, they are arranged into 23 pairs, whereas in germ cells, they are not arranged in pairs. A cell with 23 pairs of chromosomes is called a **diploid** cell and a cell with 23 chromosomes is called a **haploid cell**.

In each pair of chromosomes, one is inherited from the mother and one from the father. The chromosomes belonging to the same pair are called **homologous chromosomes**. The complete set of chromosomes from a cell is called its **karyotype**.

Two of the 46 chromosomes are called **sex chromosomes** and the remaining 44 chromosomes are called **autosomes**.

A normal female has two **X** chromosomes (XX) in each somatic cell, whereas a normal male has one **X** and one **Y** chromosome (XY) in each somatic cell. For convenience, the autosomes are numbered in pairs from 1 to 22.

Clinical Correlation

Abnormalities in sex chromosome number are the most easily transmitted chromosomal abnormalities.

The presence of a Y chromosome makes a person male, and the absence of a Y chromosome makes a person female, regardless of the number of X chromosomes. Therefore, persons with chromosomal complement XO, XX, XXX or XXXX are females, and persons with chromosomal complement XY, XXY, XXXY or XYY are males.

A YO condition is lethal because genes on the X chromosome are necessary for survival.

Karyotyping

It is a process of arranging the chromosomes of a cell in order to study the complete chromosomal complement of an individual. According to the Denver system of classification (1960), the chromosomes, including sex chromosomes, are arranged into seven groups depending upon their: (1) size, (2) position of centromere, (3) length-ratio between their arms and (4) presence of satellite bodies on their arms. These groups are referred to by the capital letters A to G.

Method

First, an enlarged photomicrograph of a **chromosome spread** is taken from a stained slide (Fig. 17.6). Then individual chromosomes are cut out from the photograph, the homologous chromosomes are paired and arranged in a sequence. The longest chromosomes are placed at the beginning and the shortest at the end. This arrangement of chromosomes is called **karyotype** (Fig. 17.7). The karyotype provides chromosomal constitution of a cell or an individual.

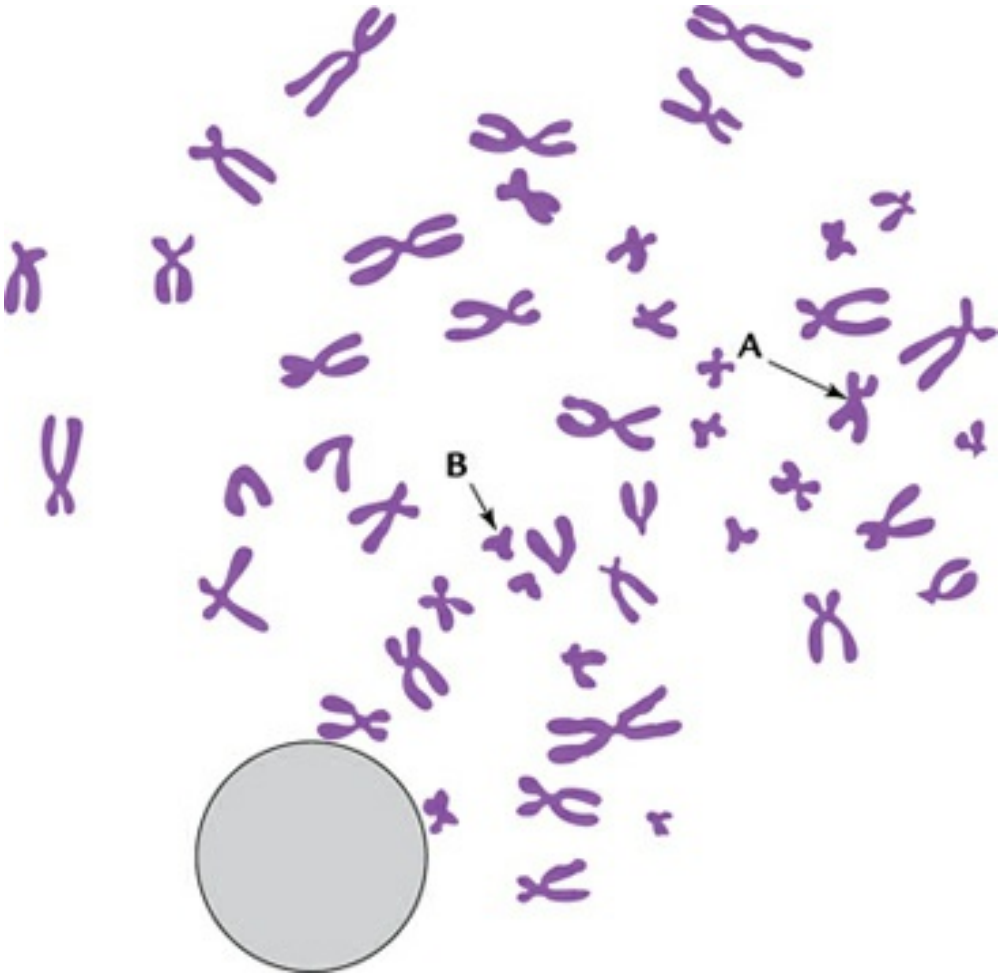


FIG. 17.6 ■ Schematic photomicrograph of chromosome spread (at metaphase stage of cell division of male human leucocytes). The two sex chromosomes are marked by arrows: (A) X chromosome and (B) Y chromosome.

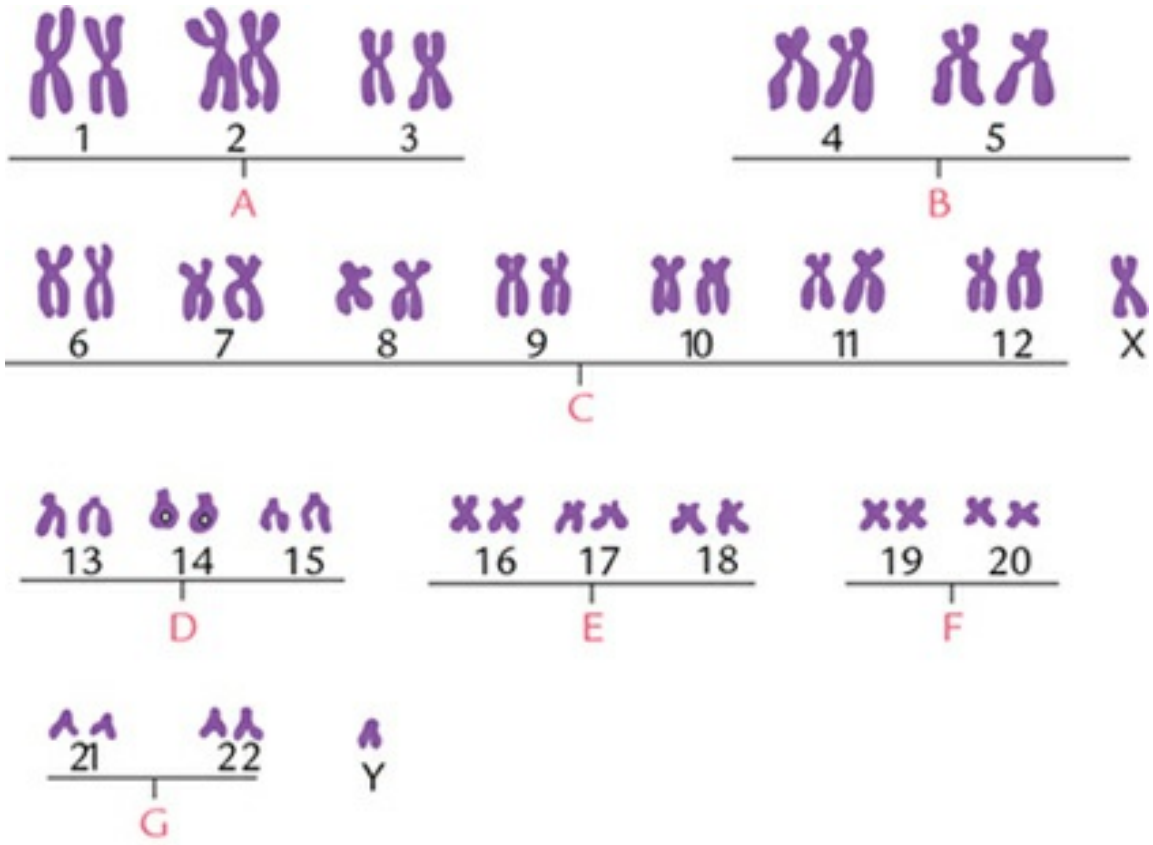


FIG. 17.7 ■ Karyotype of a normal male.

The features of chromosomes in different groups are presented in Table 17.2.

TABLE 17.2

Characteristic features of pairs of chromosomes in karyotype

Group	Pairs of chromosomes	Features
A	1, 2 and 3	Long and metacentric
B	4 and 5	Fairly long and submetacentric
C	6–12 + X chromosome	Medium sized and submetacentric
D	13–15	Medium-sized and acrocentric with a *satellite body* attached to the free end of the short arm of each chromosome
E	16–18	Fairly short and submetacentric
F	19 and 20	Short and metacentric
G	21 and 22 + Y	Very short and acrocentric with *satellite*

	chromosome	*bodies* on their short arms

The precise identification of individual chromosomes is now made possible by noting the patterns of bands on chromosomes by special staining techniques such as Q-banding, G-banding, R-banding and C-banding (Fig. 17.8).

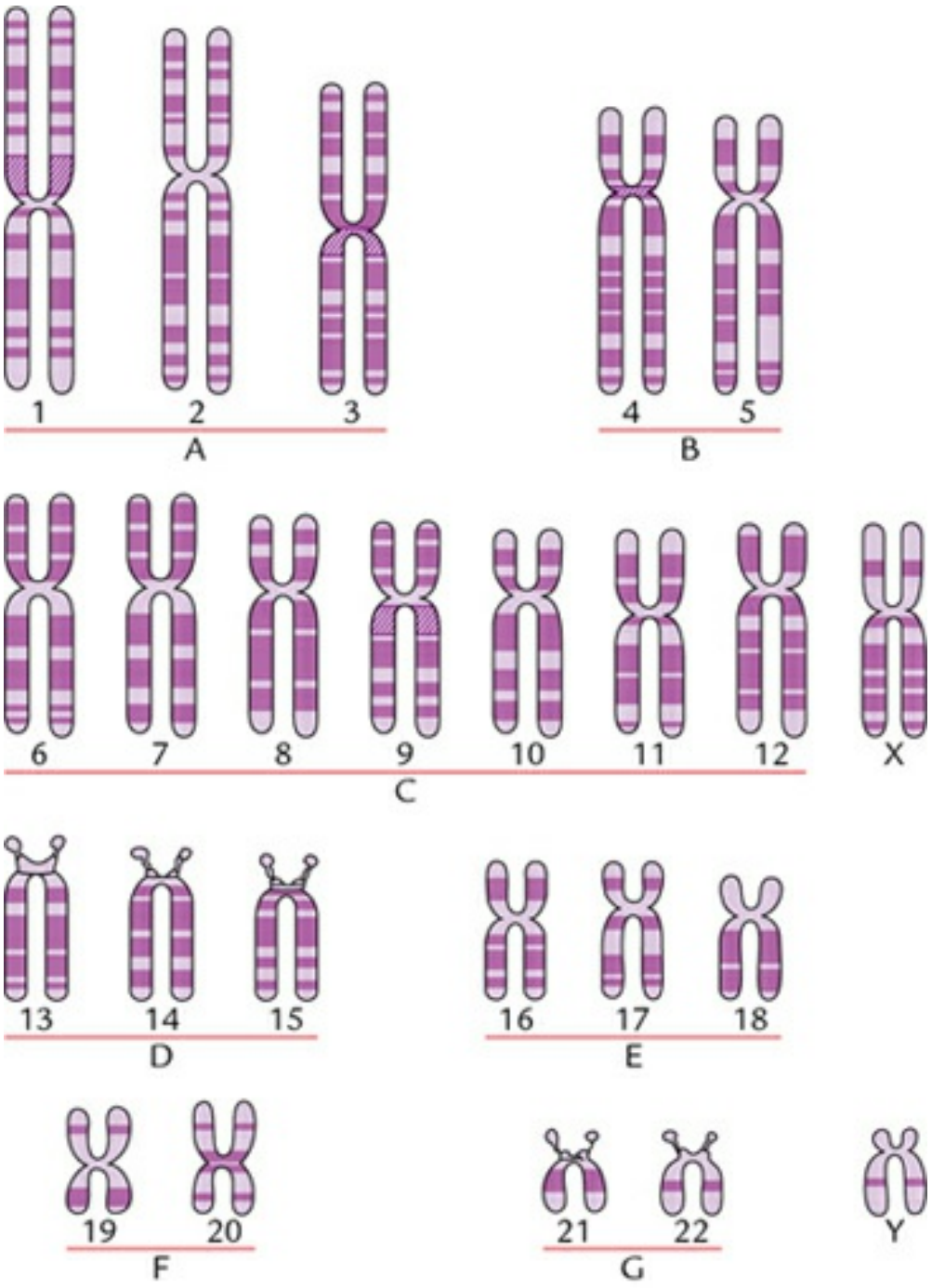


FIG. 17.8 ■ G- banding pattern of chromosomes.

Clinical Correlation

Significance of karyotyping:

The karyotyping is of clinical significance for, one can identify the structural and numerical variations in chromosomes, and with chromosomal banding patterns, one can note certain abnormalities of chromosome structure such as *deletion* and *translocation* of specific regions of chromosomes.

Sex chromatin (Barr body)

It is a darkly stained condensed clump of chromatin located subjacent to the nuclear membrane of somatic cells of normal (XX) females. It represents inactivated X chromosome.** During the interphase (resting phase) of the cell cycle, the chromosomes become uncoiled and thinned out; consequently, they cannot be identified. The nucleus thus contains a network of **chromatin threads**. However, in some places, the chromosome remains coiled and these are visualized as **chromatin granules**. The uncoiled segments of chromosomes, the **euchromatin**, are genetically active. The coiled segments of chromosomes, the **heterochromatin**, are genetically inactive, i.e. inert. During cell division, each chromosome becomes thicker, shorter and tightly coiled along its entire length. As a result, individual chromosomes are visualized and identified.

During interphase, in females, one out of two X chromosomes becomes highly coiled (genetically inactive) and the other remains uncoiled (genetically active). The coiled, genetically inactive X chromosome is seen as a heterochromatic body called **sex chromatin** (Fig. 17.9). It is also called **Barr body** after the name of a Canadian geneticist Murray Barr. It was first noticed by Barr and Bertram (in 1949) in the nucleus of the nerve cell of a female cat.

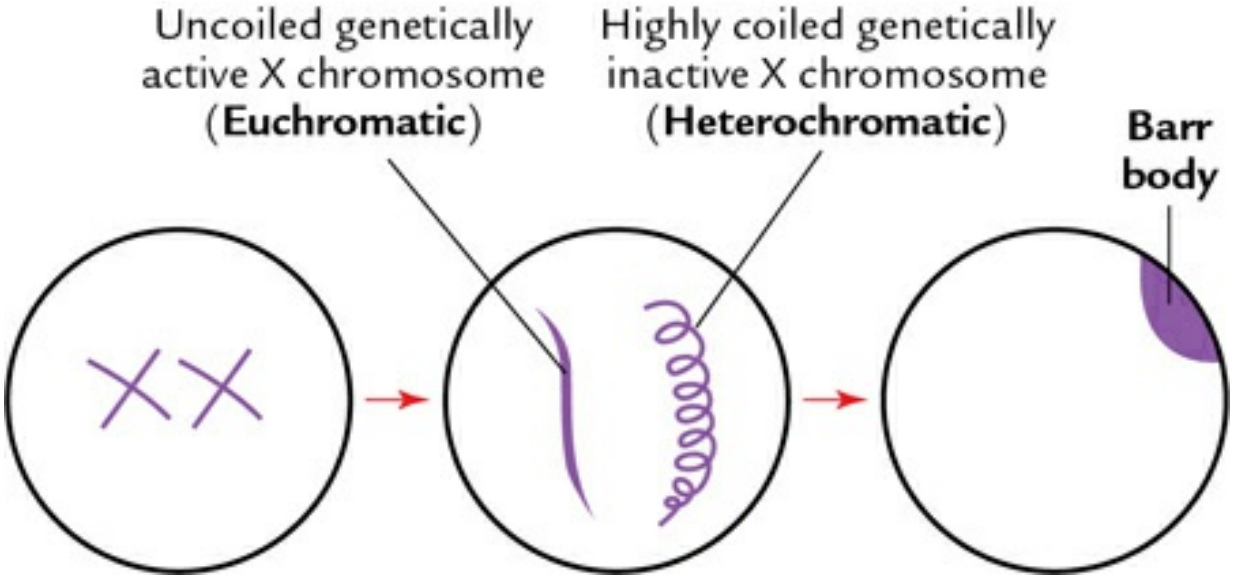


FIG. 17.9 ■ Formation of sex chromatin in a female.

The Barr body is generally located on the inner surface of the nuclear membrane as a dark basophilic body of chromatin in most of the cells of the body. It is generally ovoid or planoconvex. However, in neurons, it appears as a small dark body opposite to the nucleolus and in neutrophils, it appears as a knob of 1.5 μm in diameter known as a drumstick (Fig. 17.10).

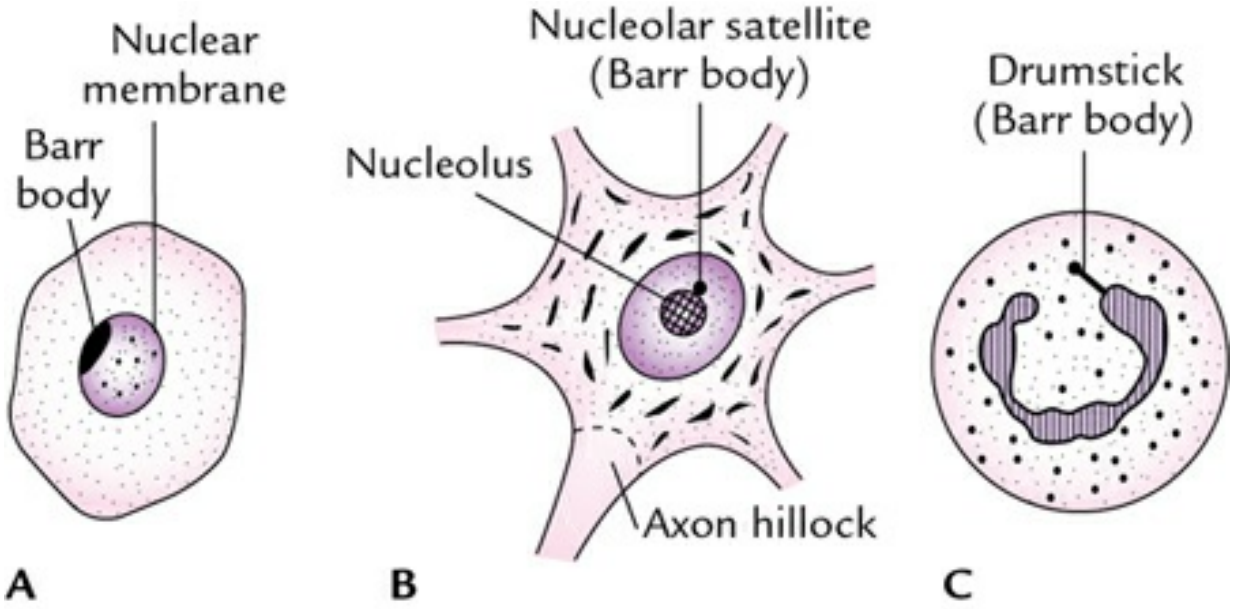


FIG. 17.10 ■ Location of Barr body as seen in (A) buccal smear; (B) neuron and (C) neutrophil.

N.B.

Structurally, sex chromatin is an extra X chromosome that is heterochromatic and genetically inactive.

Lyon's hypothesis

According to this hypothesis (formulated by Lyon), the number of Barr bodies in a cell is equal to the total number of X chromosomes minus one. It is also known as the '**n − 1 rule**', where **n** represents the number of X chromosomes in the cell. The number of Barr bodies per cell in different conditions is given in Table 17.3.

TABLE 17.3

Individual's sex chromosomal constitution and number of Barr bodies per cell

Individual	Sex chromosomal constitution	Number of Barr bodies
Normal male	XY	Nil
Turner's syndrome	XO	Nil
Normal female	XX	One
Klinefelter's syndrome	XXY	One
Triple X syndrome (super female)	XXX	Two

N.B.

During interphase, the Y chromosome in males exhibits within the nucleus of a cell an intensely fluorescent mass called '**F-body**' when stained with fluorochrome dye and examined under the fluorescent microscope.

Chromosomal abnormalities

The study of chromosomal abnormalities is of great clinical importance because they produce a number of genetic disorders causing various clinical conditions.

Classification

The chromosomal abnormalities may be classified in a number of ways:

1. On the basis of type of abnormality:
   (a) *Numerical*, involving changes in the number of chromosomes, e.g. polyploidy, aneuploidy
   (b) *Structural*, involving a change in the structure of chromosomes, e.g. deletion, translocation
2. On the basis of the types of chromosomes involved:
   (a) *Involving autosomes*, e.g. Down's syndrome
   (b) *Involving sex chromosomes*, e.g. Turner's syndrome, Klinefelter's syndrome.

Numerical abnormalities

The numerical abnormalities of chromosomes occur due to the failure of meiotic division to occur or due to abnormal meiotic division during the formation of gametes. In normal meiotic division during gametogenesis, both primary spermatocytes and primary oocytes produce four daughter cells, each with 23 chromosomes, and when haploid sperm fertilizes the haploid ovum, the diploid zygote is produced (Fig. 17.11).

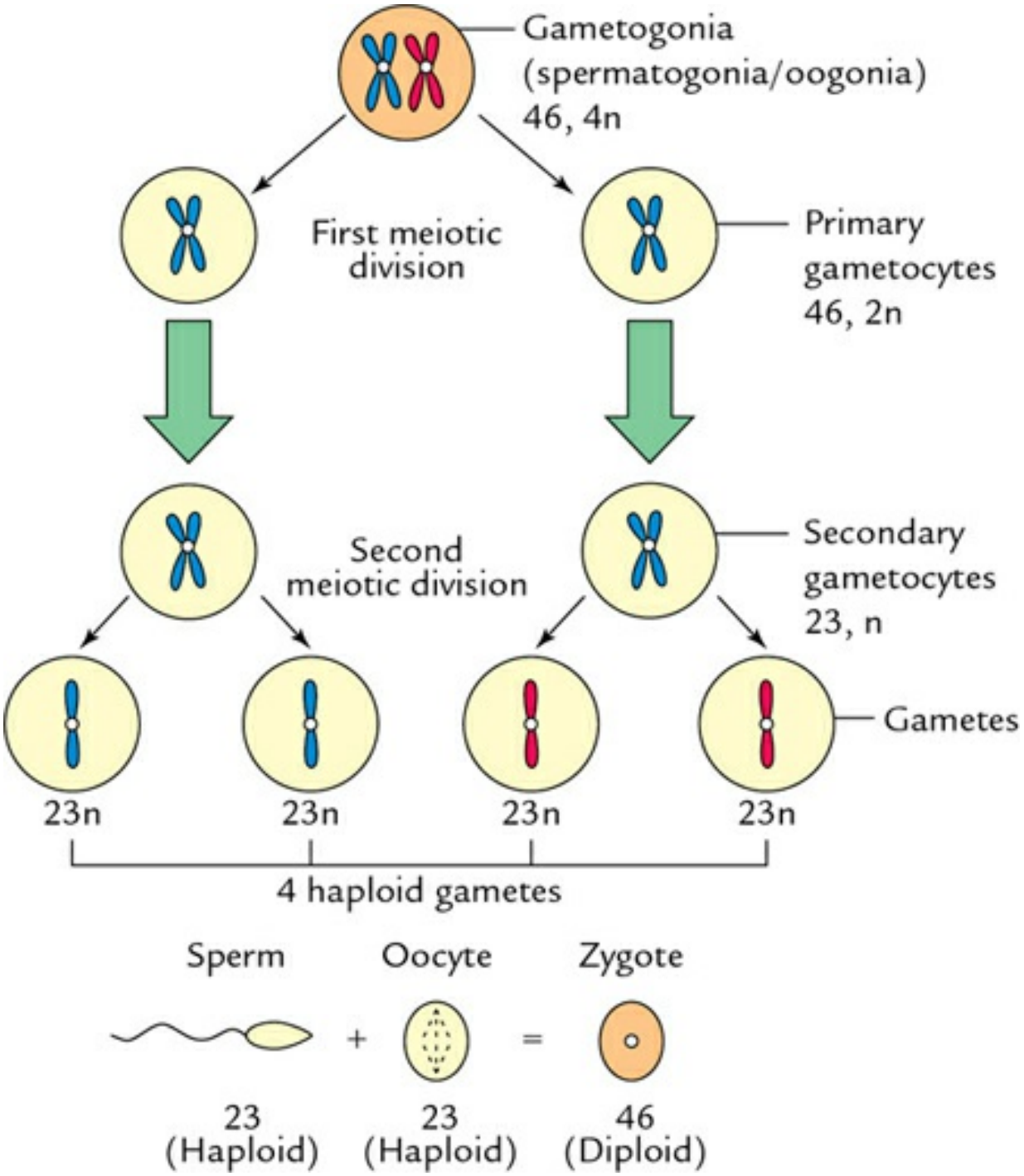


FIG. 17.11 ■ Normal meiotic division producing gametes with 23 chromosomes.

Sometimes separation of two chromosomes does not occur (non-disjunction) either during the first meiotic division (Fig. 17.12A) or during the second meiotic division (Fig. 17.12B) and then both the members of a pair move into one cell.

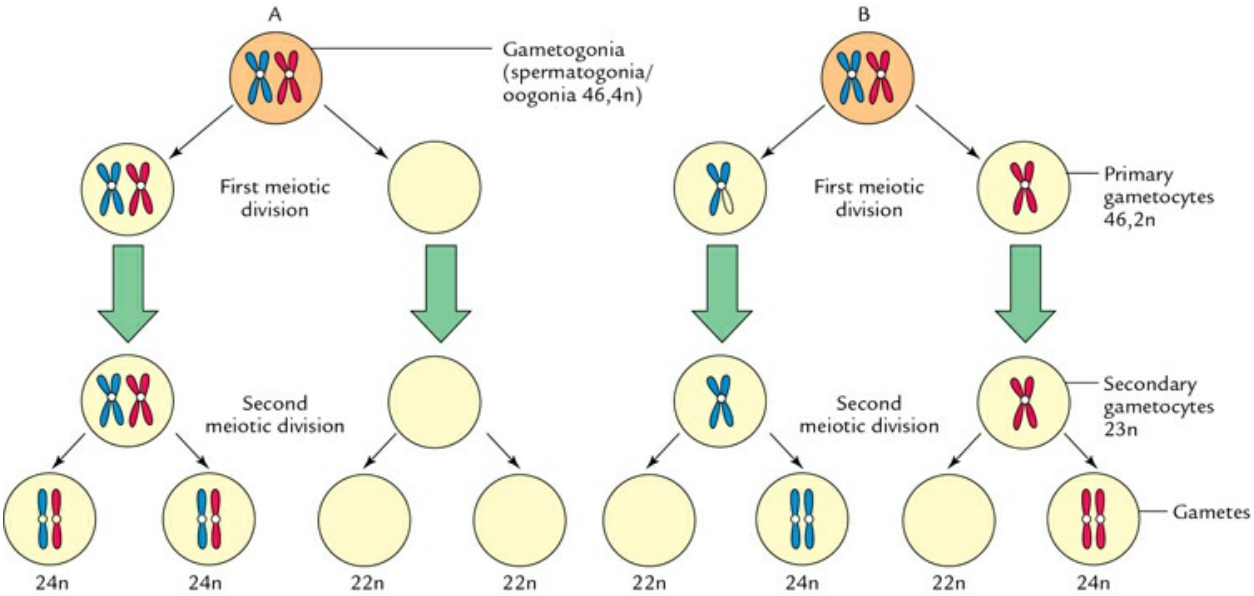


FIG. 17.12 ■ Non-disjunction occurring during meiosis: (A) non-disjunction in meiosis I producing gametes with 24 and 22 chromosomes and (B) non-disjunction occurring during meiosis II producing gametes with 24 and 22 chromosomes.

As a result of the non-disjunction of the chromosome (Fig. 17.13), one gamete receives 24 chromosomes and the other 22. Consequently, at fertilization, when a gamete (e.g. sperm) having 23 chromosomes fuses with a gamete (e.g. ovum) having 24 or 22 chromosomes, the result will be an individual with either 47 chromosomes (**trisomy**) or 45 chromosomes (**monosomy**).

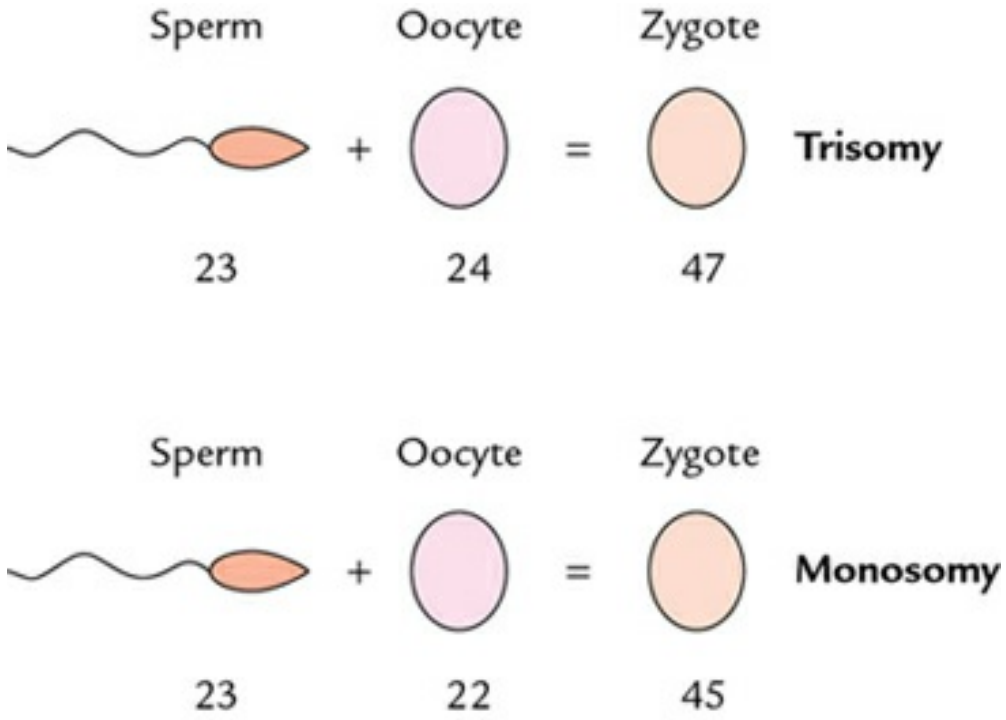


FIG. 17.13 ■ Non-disjunction during oogenesis. Note that if an abnormal oocyte with 24 chromosomes is fertilized by a normal sperm with 23 chromosomes, a zygote with 47 chromosomes is produced (i.e. trisomy). If an abnormal oocyte with 22 chromosomes is fertilized by a normal sperm with 23 chromosomes, a zygote with 45 chromosomes is produced (i.e. monosomy).

The numerical abnormalities include the following conditions:

1. **Polyploidy:** It is a condition in which chromosome number is increased in multiple haploid (23) sets of chromosomes, of course, in addition to the diploid number. In other words, polyploidy is the condition of extra haploid set/sets of chromosomes (i.e. 23) to the normal diploid set of chromosomes (i.e. 46); examples are:
   (a) *Triploidy*: A condition in which the cells contain 69 chromosomes (23 × 3). It occurs either due to failure of meiosis in germ cells, e.g. fertilization of the diploid ovum by a haploid sperm or fertilization of the haploid ovum by two haploid sperms (dispermy).

N.B.

Triploidy results in spontaneous abortion of the conceptus or brief survival of live-born infants after birth.

   (b) *Tetraploidy*: A condition in which the cells contain 92 chromosomes (23 × 4). It occurs due to the failure of the first

cleavage division.

N.B.

Tetraploidy results in spontaneous abortion of the conceptus.

2. **Aneuploidy:** It is a condition in which chromosome number is altered by one, i.e. there is the addition of one chromosome (**trisomy**) or loss of one chromosome (**monosomy**). It occurs due to non-disjunction during meiosis (Figs 17.10–17.12).

N.B.

Trisomy usually results in spontaneous abortion of the conceptus; however, trisomy 13 (Patau's syndrome), *trisomy 18* (Edward's syndrome), *trisomy 21* (Down's syndrome) and trisomy XXY (Klinefelter's syndrome) are found in a live-born population.

Monosomy also usually results in spontaneous abortion of the conceptus; however, monosomy of the X chromosome (45: XO), i.e. Turner's syndrome is found in a live-born population.

Structural abnormalities

These abnormalities involve a change in the structure of the chromosome. The types of structural abnormalities include deletions, microdeletions, translocation, fragile sites, isochromosomes, inversions and breakage.

The abnormalities in structure cause the following conditions:

1. **Deletions:** In this condition, there is a loss of a segment of a chromosome. The clinical conditions caused due to deletions include Wolf–Hirschhorn syndrome (due to deletion in the short arm of chromosome 4), Cri-du-chat or Cat's cry syndrome (due to deletion in the short arm of chromosome 5).

N.B.

Sometimes chromosome is deleted at both ends, and then the two broken ends adhere/unite to form a ring called *ring chromosome*, commonly seen due to breakpoints of chromosome 14.

2. **Microdeletions:** In this condition, there is a loss of a segment of a chromosome that can be detected only by a high-resolution banding. The clinical conditions caused by microdeletions include:
   (a) *Prader–Willi syndrome*: Due to microdeletion in the long arm of chromosome 15 derived from the father.
   (b) *Angelman's syndrome* or *Happy puppet syndrome*: Due to microdeletion in the long arm of chromosome 15 derived from the mother.
   (c) *DiGeorge syndrome*: Due to microdeletion in the long arm of chromosome 2.
   (d) *Miller–Dieker syndrome*: Due to microdeletion in the short arm of chromosome 17.
3. **Translocation:** In this condition, there is a breakage and exchange of segments between chromosomes. The examples include:
   (a) *Robertsonian translocation*: This is a special type of translocation in which breaks occur at the centromeres, e.g. translocation between long arms of chromosomes 13 and 14 (**most common translocation found in humans**) and chromosomes 21 and 22. The short arms of these chromosomes involved in Robertsonian translocations are generally lost.
   (b) Reciprocal translocation between chromosome 15 and chromosome 17: This leads to acute promyelocytic leukaemia.
   (c) Reciprocal translocation between chromosome 9 and chromosome 22 (Philadelphia chromosome): This leads to chronic myeloid leukaemia.
4. **Fragile sites:** In this condition, there are gaps or breaks in the chromosome. The clinical conditions caused due to this condition include **Fragile X syndrome** (*Martin–Bell syndrome*).
5. **Isochromosomes:** In this condition, the centromere divides transversely instead of longitudinally. As a result, two arms of a chromosome are separated forming two isochromosomes.
6. **Inversions:** In this condition, a part of the chromosome is detached and later unites with the same chromosome in an inverted position. As a result, there is a reversal of the order of DNA between two breaks in the chromosome. It can be **pericentric** if inversions occur on the sides of the centromere or **paracentric** if inversions occur on the same side of the centromere.
7. **Breakage:** In this condition, there occurs a break in chromosomes due

to ultraviolet radiation, and ionizing radiation.

The clinical conditions caused by breaks in chromosomes include:

(a) *Xeroderma pigmentosum*: Affected individuals are hypersensitive to sunlight (ultraviolet radiation).
(b) *Ataxia-telangiectasia*: Affected individuals are hypersensitive to ionizing radiation.
(c) *Fanconi's anaemia*: Affected individuals are hypersensitive to DNA cross-linking agents.
(d) *Bloom's syndrome*: Affected individuals hypersensitive to a wide variety of DNA-damaging agents.
(e) *Hereditary non-polyposis colorectal cancer*: Accounts for 15% of all cases of colorectal cancer.

Symbols used in genetics

These are as under:

- p = Short arm of chromosome
- q = Long arm of chromosome
- t = Translocation
- i = Isochromosome
- inv = Inversion
- r = Ring chromosome.

Further, when + or − signs are placed before a symbol, it stands for the addition or missing of a complete chromosome. On the other hand, when + or − sign is placed after a symbol, it indicates an increase or decrease in the length of the chromosome.

Genes

The term *gene* refers to a combination of DNA subunits that together constitute a unit of inheritance. The term '*gene*' was first coined by the Danish botanist Wilhelm Johannsen (1909). It contains the information needed to synthesize a particular protein/enzyme. There are about 50,000 to 100,000 genes in the human cell.

Structure

The gene consists of a transcription unit flanked by regulatory sequences (Fig. 17.14).

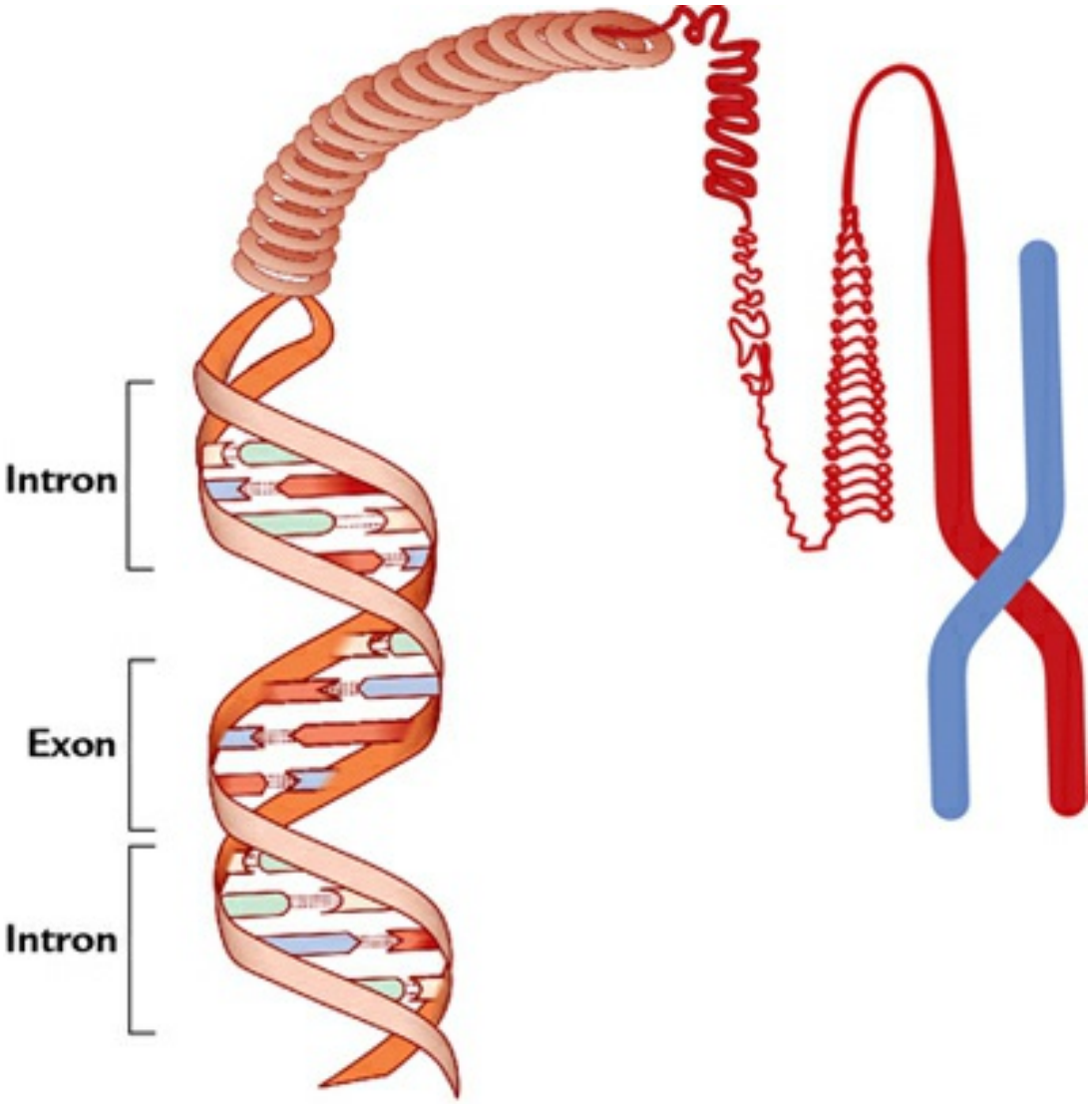


FIG. 17.14 ■ Structure of a gene.

The transcription unit is made up of an alternating pattern of ***exons*** (functional parts) and ***introns*** (non-functional parts). The exon is a segment of the gene that codes for mRNA (code for a particular protein). An intron is a segment of the gene that when transcribed into RNA is spliced out during the maturation process and does not code for a particular protein. The introns and exons may vary in length. Every gene requires a promoter to begin transcription. A promoter consists of DNA sequences that allow RNA

polymerase to bind and initiate the polymerization of ribonucleotides.

Types

The types of genes include:

1. *Structural genes*, which code for a specific amino acid sequence in a protein.
2. *Operation genes*, which allow transcription.
3. *Regulator genes*, which inhibit protein synthesis.
4. *Dominant genes*, which are able to express their traits.
5. *Recessive genes*, which are able to express only in the homozygous state.
6. *Sex-linked genes*, which are abnormal genes located on X or Y chromosomes.
7. *Jumping genes* (transposons), which can jump to and fro within a single chromosome or an adjacent one.

Functions of genes

1. Maintain the genetic specificity of an individual.
2. Play a key role in the transmission of traits from the parents to the offspring.
3. Synthesize various proteins and enzymes of the cell.

N.B.

Genes synthesize protein through transcription from DNA to RNA, and translation from RNA to protein.

Location of genes

Each gene occupies a specific **locus** on a chromosome. Both chromosomes of a given pair contain similar genes. The two chromosomes of a pair are homologous and genes occupying the same locus on homologous chromosomes are called **alleles**. If the two allelic genes are identical, the person is **homozygous** for the trait specified by that gene locus. If the two

alleles are different, the person is **heterozygous** for that trait.

During reproduction, both males and females contribute 23 chromosomes each to the zygote. Therefore, for any given pair of alleles controlling a given trait, the female contributes one allele and the male contributes one allele.

An exception occurs with X and Y chromosomes as there are no alleles on the Y chromosome for most of the loci on the X chromosome.

The paired chromosomes are called **homologous chromosomes** (Fig. 17.15). In females, the two sex chromosomes (XX) are identical in length; hence they are homologous. In males, the two sex chromosomes (XY) are unequal in length. The X chromosome is longer than the short chromosome; hence they have homologous and non-homologous parts (Fig. 17.16).

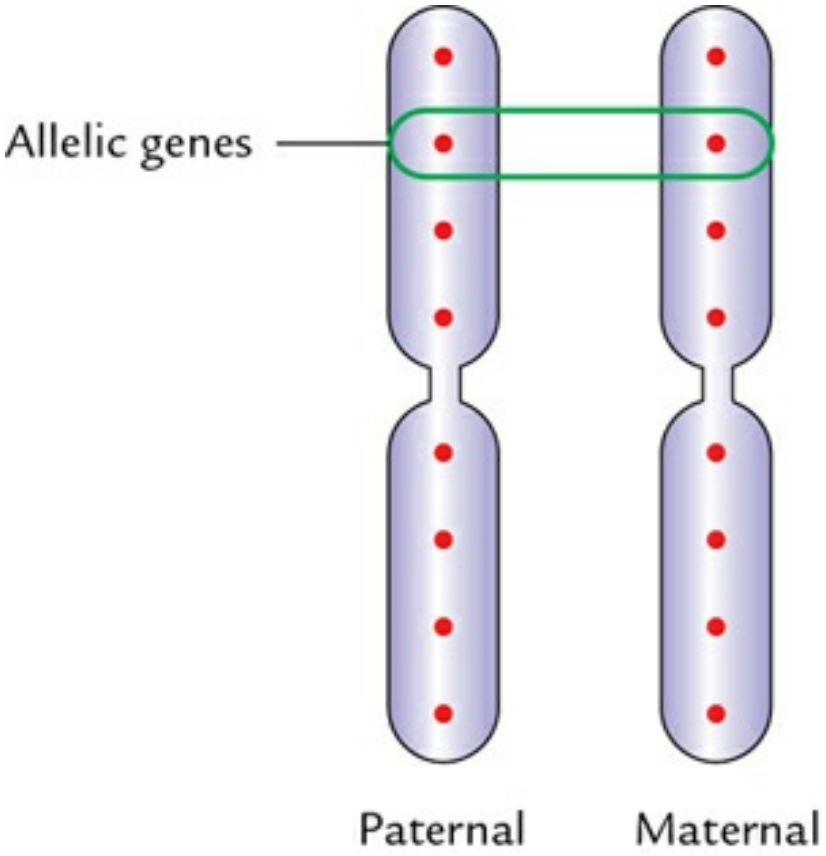


FIG. 17.15 ■ Homologous chromosomes with allelic genes.

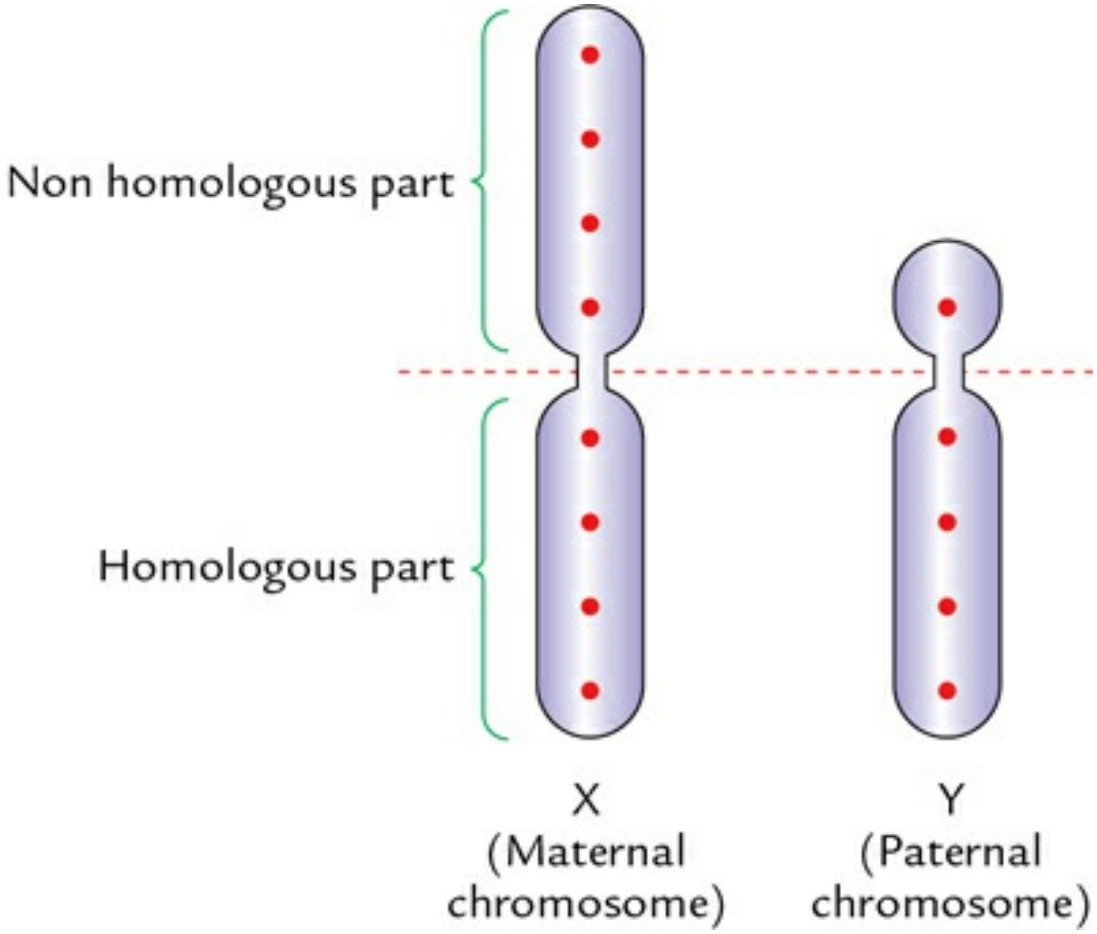


FIG. 17.16 ■ Male sex chromosomes (XY) with homologous and non-homologous parts.

Dominant and recessive genes

When a gene produces its effect, whether it is present either upon one or upon both chromosomes of a pair of the chromosome, it is called a **dominant gene**. If it produces its effect only when it is present on both chromosomes, it is called a **recessive gene**. Thus diseases are inherited through both dominant and recessive genes called dominant inheritance and recessive inheritance, respectively.

Inheritance

Inheritance is the process of transmission of characters/traits from generation to generation. Reproduction is an essential requisite for an inheritance to take place. The inheritance of traits from parents to offspring takes place through genes that carry all information about all types of traits.

The genes are located in both autosomes and sex chromosomes. The inheritance occurring through genes of autosomes is called autosomal inheritance, whereas inheritance occurring through genes on sex chromosomes is called sex-linked inheritance.

Autosomal inheritance

Each chromosome of a homologous pair contains genes for the same traits. For example, the ability to roll one's tongue is coded for on a single gene. Since one chromosome of each pair is inherited from the father and one from the mother, an individual has two genes controlling the ability to roll the tongue. Such paired genes are **alleles**.

The corresponding alleles contain genes concerned with the same trait, but they need not be identical. As discussed earlier, an individual may have two identical forms of a gene (*homozygous*) or two different forms of the gene (*heterozygous*).

Thus one copy of the tongue-rolling gene may code for the ability to roll the tongue, whereas the corresponding gene on the other chromosome may code for the inability to roll the tongue. Note that this example involves only two forms of the same gene. Some traits like eye colour are controlled by more than one gene.

In a homozygous individual, both the alleles are either dominant or recessive, but heterozygous individuals have one dominant and one recessive gene.

Punnett square

The probability of occurrence of a given genetic combination for certain traits can be predicted by Punnett square (Fig. 17.17).

- TT = Tongue-roller homozygous
- Tt = Tongue-roller heterozygous
- Tt = Tongue-roller heterozygous
- tt = Non-roller homozygous.

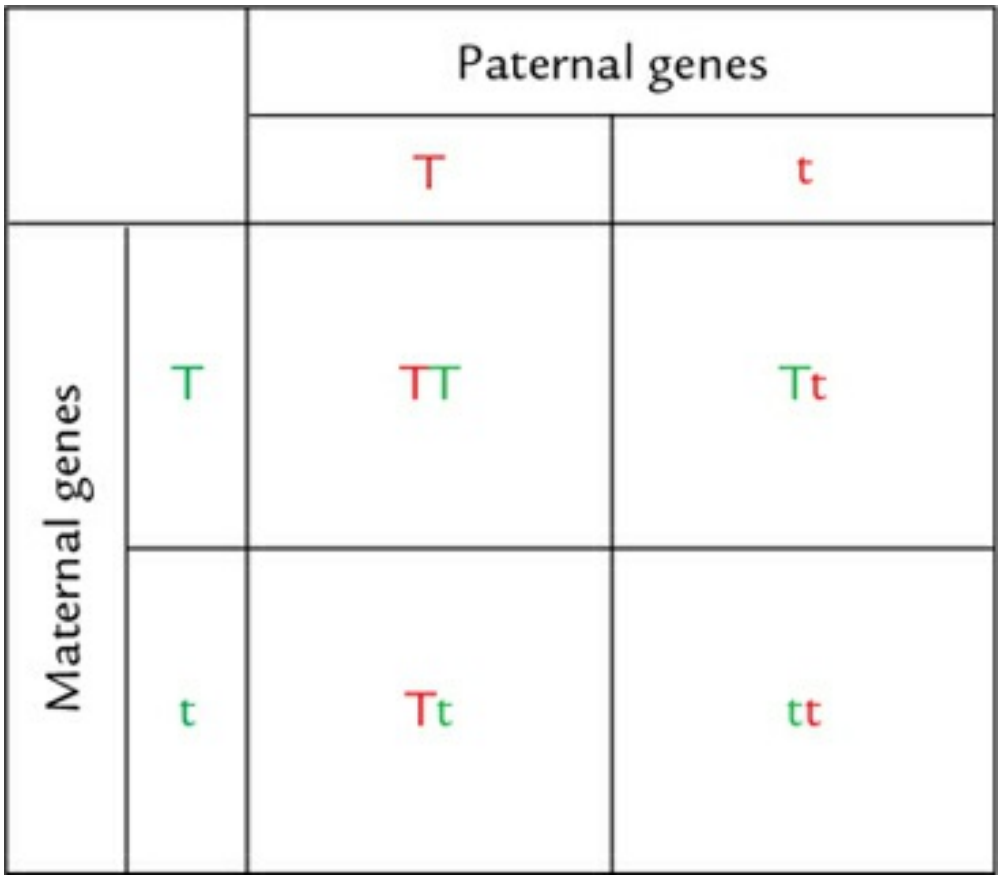
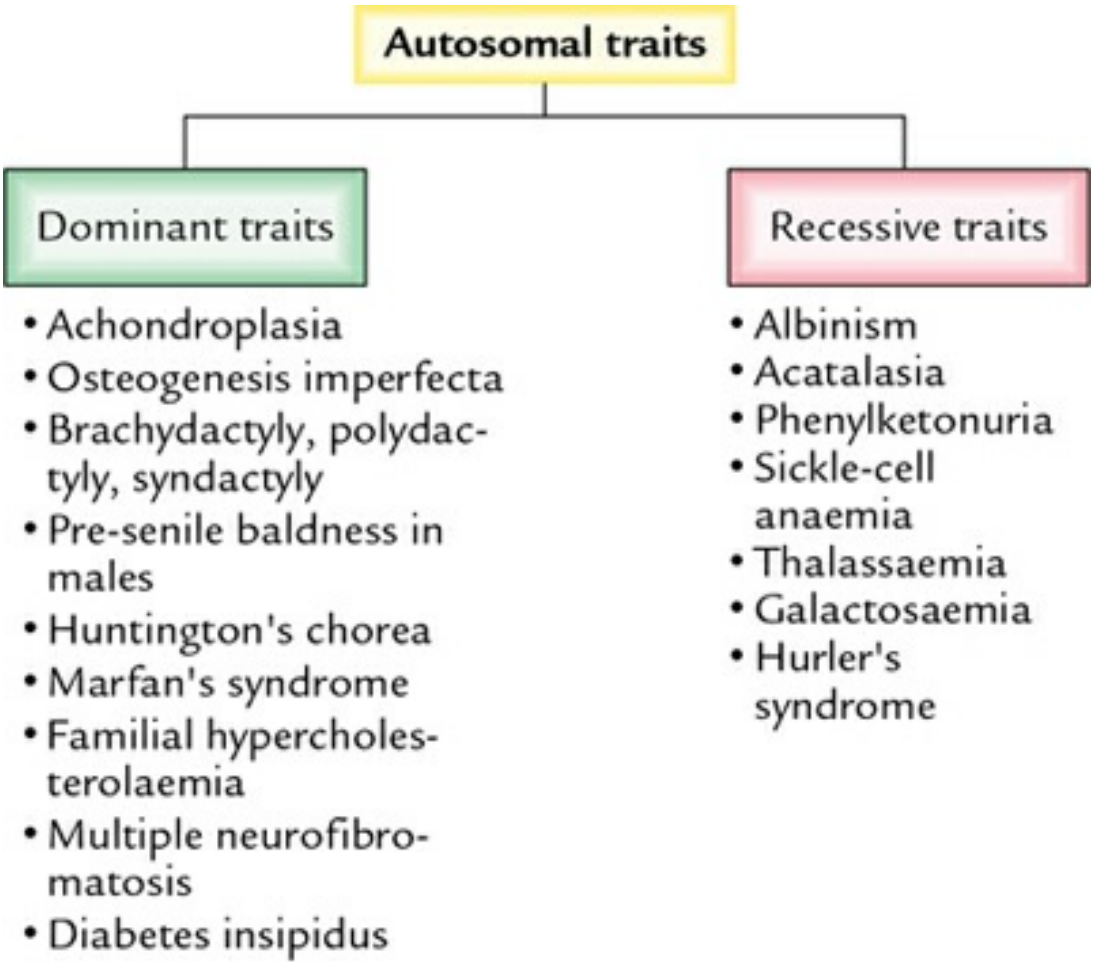


FIG. 17.17 ■ Punnett square showing probabilities of the genetic combination of the tongue-rolling gene.

Some examples of autosomal dominant traits are shown in Flowchart 17.1.



FLOWCHART 17.1 ■ Autosomal traits.

Sex-linked inheritance

The *Y* chromosome is shorter than the *X* chromosome. Therefore, traits coded on the non-homologous part of the X chromosome have no corresponding traits on the Y chromosome. These genes on sex chromosomes are called **sex-linked,** those on the X chromosome are X-linked and those on the Y chromosome are Y-linked.

X-linked inheritance

X-linked genes are exclusive to the X chromosome. For example, the gene that codes for normal **colour vision** is carried on the X chromosome only. It is the dominant form of the gene. There is a rare faulty recessive form of this gene that codes for **red-green blindness**. If a female inherits a faulty gene,

she is likely to have a normal gene on her other chromosome providing normal colour vision. A female carrying the faulty gene (colour-blind gene), even though she is not colour blind may pass the faulty gene onto her children and thus she is called a **carrier**. If the gene is faulty in the male, he will be colour blind because he has only one X chromosome and so will have only one copy of the gene.

N.B.

The ability to discern red-green colour depends entirely on the X chromosome.

If the normal gene is represented by 'C' and the faulty gene is represented by 'c', the genotype possibilities are as shown in Fig. 17.18.

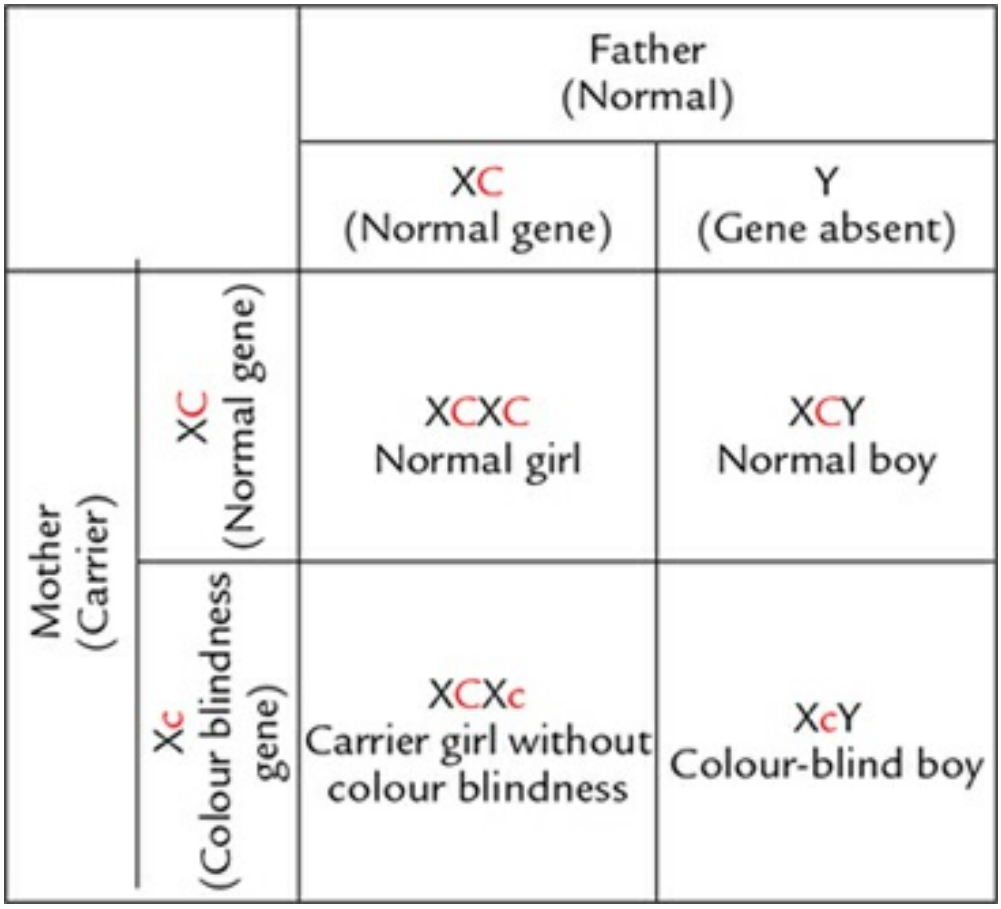


FIG. 17.18 ■ Punnett square showing sex-linked inheritance.

N.B.

For a female to be colour blind for red-green colour, she has to have a recessive allele (colour-blind gene) on both of her X chromosomes (XcXc). This is possible only if her mother is a carrier (XCXc) and her father is colour blind (XcY).

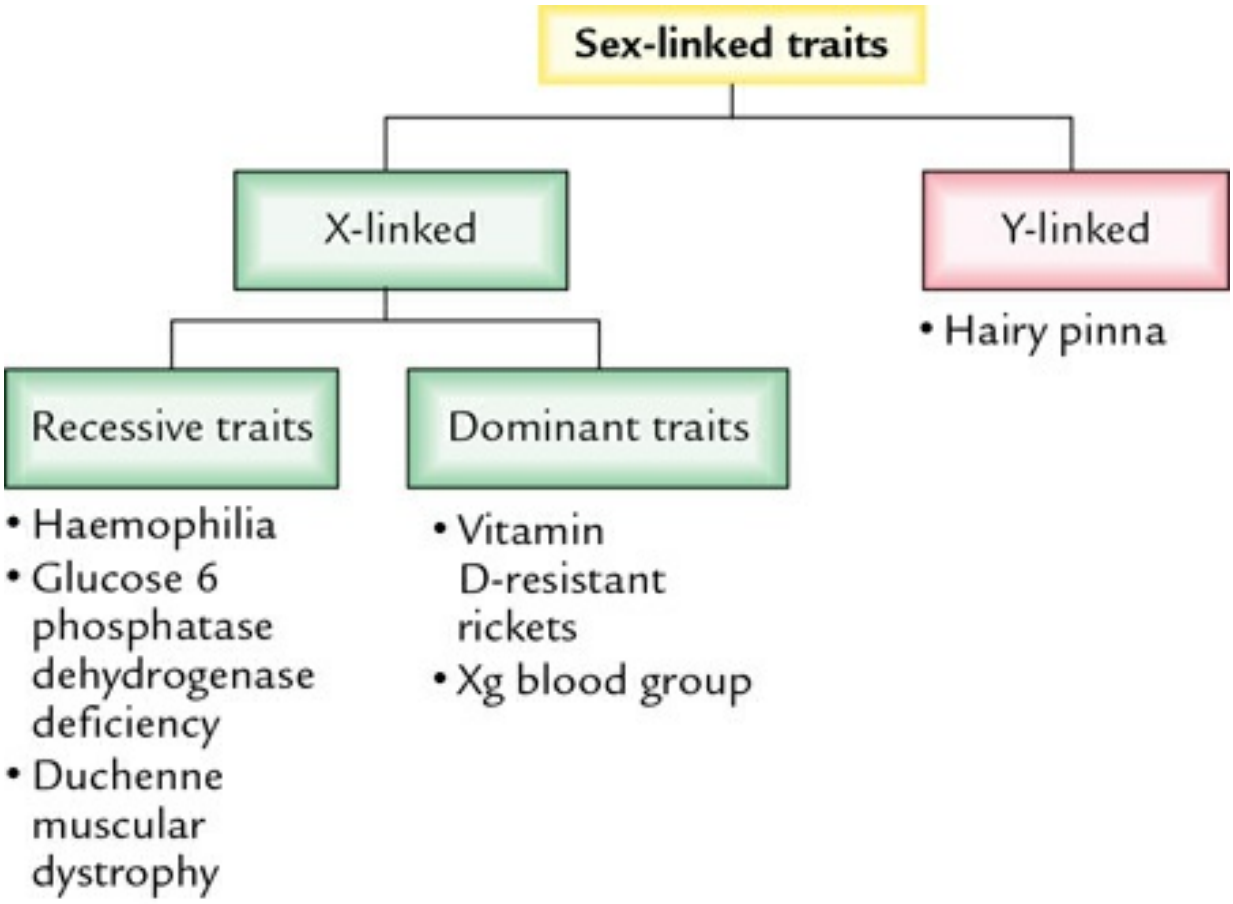
Clinical Correlation

Haemophilia: It is a clinical condition associated with repeated episodes of severe and prolonged bleeding at any site with little trauma. It is a sex-linked condition caused by a recessive allele responsible for faulty clotting. If H represents normal clotting and h represents abnormal clotting, then males with XHY will be normal and males with XhY will be haemophilic. The females with XhXh will also be haemophilic.

Y-linked inheritance (holandric inheritance)

Since males have only one Y chromosome, the gene is necessarily unpaired. Therefore if present, it will be expressed and the question of dominance and recessiveness does not arise. Further, the gene will be passed from the affected male to all his sons, e.g. characteristic growth of hair on the pinna of the ear. This is the only Y-linked gene inheritance and hence for all practical purposes, sex-linked means X-linked.

The sex-linked traits are given in Flowchart 17.2.



FLOWCHART 17.2 ■ Sex-linked traits.

Mitochondrial inheritance

The body receives all its mitochondrial DNA (mtDNA) only from the mother because during fertilization, the mitochondria of sperm do not pass into the ovum. Consequently, diseases that occur due to mutations in the mtDNA are inherited entirely through the mother. The leading examples of diseases caused due to mutations in the mtDNA are:

1. **Leber's hereditary optic neuropathy:** A condition characterized by sudden onset of blindness in adults.
2. **Pearson marrow-pancreas syndrome:** A condition characterized by a loss of bone marrow cells during childhood. It is frequently fatal.

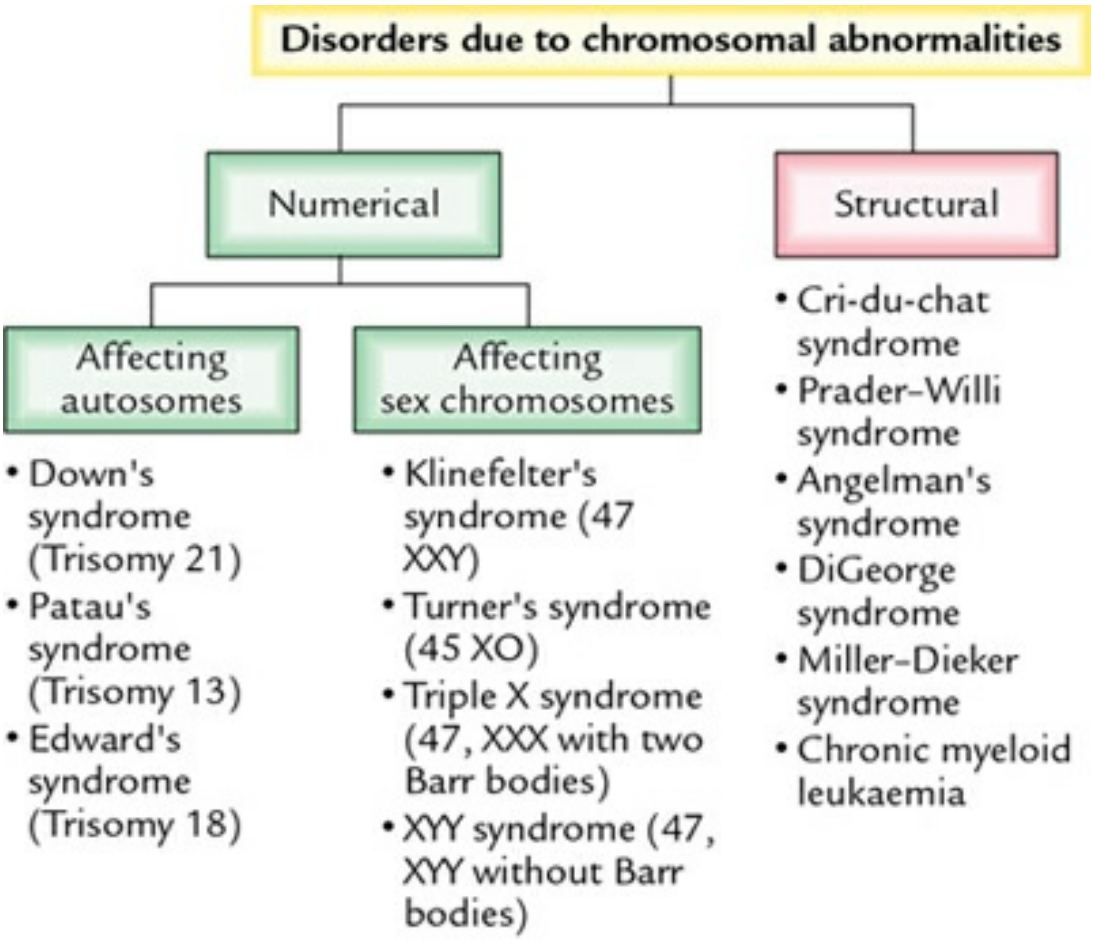
Genetic basis of diseases

A large number of human diseases occur due to genetic disorders. The disorders include numerical and structural abnormalities of chromosomes

and gene mutation.

Disorders due to chromosomal abnormalities

Disorders due to chromosomal abnormalities can be numerical or structural (Flowchart 17.3). The common disorders are discussed in detail in the following text.



FLOWCHART 17.3 ■ Disorders due to chromosomal abnormalities.

Numerical chromosomal abnormalities affecting autosomes

Down's syndrome (mongolism) or trisomy 21

In this disorder, there are three copies of chromosome 21 (*trisomy 21*), i.e.

there is an extra chromosome 21. The karyotype of the patient is 47, XX, + 21.

Trisomy 21 is of two types:

1. **Triplo-21 (non-familial mongolism):** It is common and the affected babies possess 47 chromosomes including two X chromosomes. It occurs during meiosis due to the non-disjunction of the 21st pair of chromosomes.
2. **Translocation mongolism (familial mongolism):** In this, an individual possesses 46 chromosomes. In this condition, the extra chromosome becomes attached to one of the other autosomes.

Down's syndrome occurs in one out of every 700 births (1/700).

The majority of the mongoloid babies have 47 chromosomes with trisomy 21, but about 3% have normal 46 chromosomes with translocation of two 21 chromosomes.

Characteristic clinical features (Fig. 17.19):

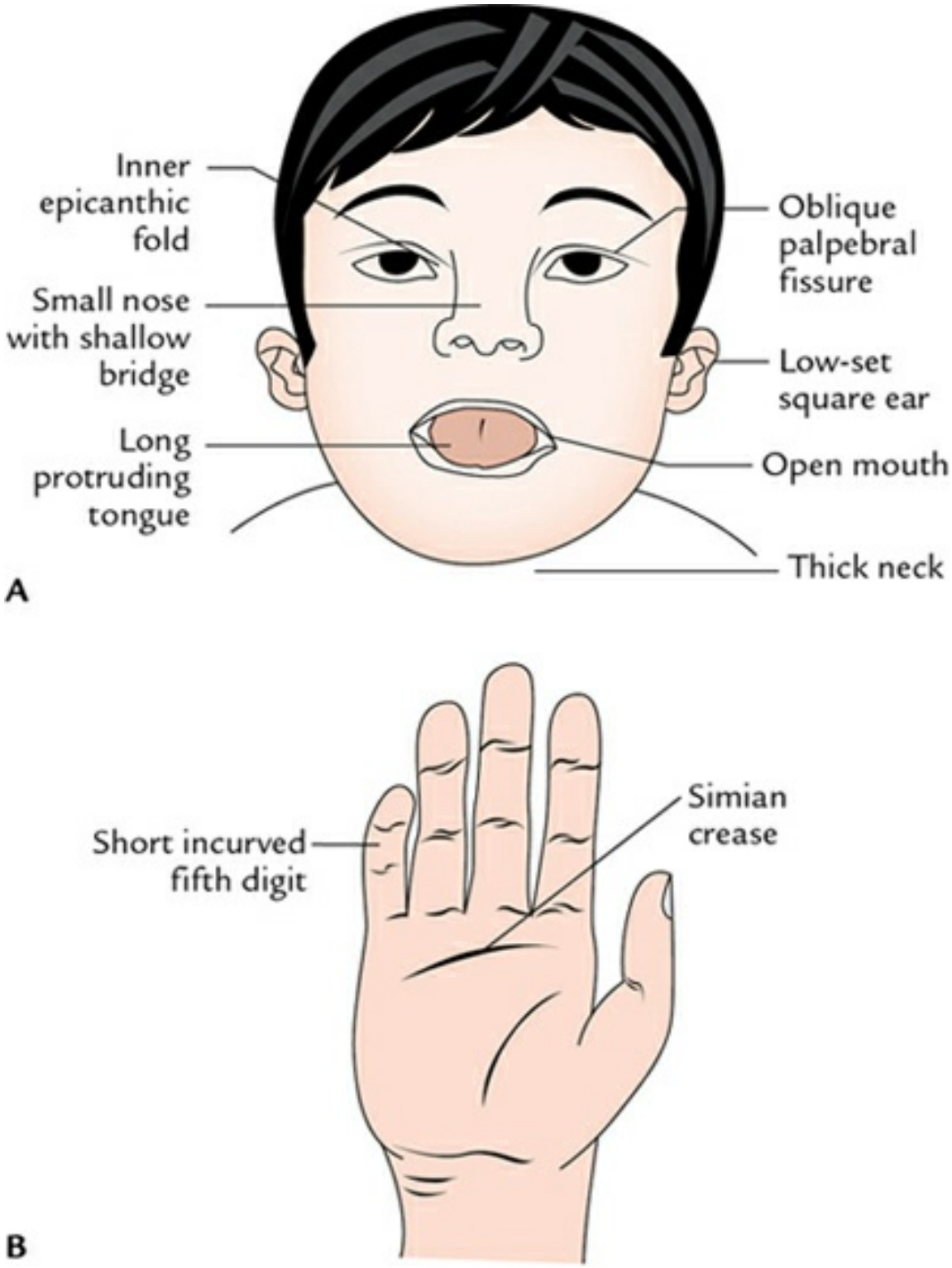


FIG. 17.19 ■ Down's syndrome: (A) facial features of an infant with Down's syndrome and (B) simian crease.

The affected individuals present the following features:

1. Round face with oblique palpebral fissures and inner epicanthic folds, i.e. mongoloid facies, hence the name mongolism

2. Small nose with shallow bridge, low-set square ears
3. Short and broad hands with a single transverse crease in the palm (*simian crease*) across the bases of four fingers
4. Open mouth with long protruding tongue
5. Mental retardation (I.Q.: 25 to 50)
6. Short stature with hyper flexibility of joints.

N.B.

- Down's syndrome is the best known and one of the most common chromosomal abnormalities in humans. It was first described by L. Down in 1886.
- Down's syndrome is the most common numerical chromosomal abnormality.
- The probability of Down's syndrome increases with the advancing age of the mother.
- Children with Down's syndrome are easy to manage as they love music. They usually die young.
- Down's syndrome is associated with low *α-fetoprotein* levels in amniotic fluid or maternal serum.
- Children with Down's syndrome are susceptible to infection and often have associated congenital heart abnormalities.

Patau's syndrome

In this disorder, there are three copies of chromosome 13 (*trisomy 13*).

Characteristic clinical features:

The affected children present the following features:

1. Profound mental retardation
2. Cleft-lip and cleft-palate
3. Omphalocele
4. Polydactyly.

N.B.

Infants with Patau's syndrome usually die soon after birth.

Edward's syndrome

In this disorder, there are three copies of chromosome 18 (*trisomy 18*).

Characteristic clinical features:

The affected children present the following features:

1. Elongated head with prominent occiput and low-set ears
2. Small facies with micrognathia
3. Overlapping of fingers
4. Rocker-bottom heels
5. Congenital heart defects.

N.B.

Infants with Edward's syndrome usually die within a few weeks after birth.

Structural chromosomal abnormalities affecting autosomes

Cri-du-chat syndrome (Cat cry syndrome)

This condition is caused by a deletion in the short arm of chromosome 5 so that part of chromosome 5 is missing.

Characteristic clinical features:

The affected children present the following features:

1. Round face
2. Characteristic cat-like cry (i.e. meowing cry) of a child
3. Hypertelorism
4. Congenital heart defects
5. Microcephaly
6. Mental retardation.

Prader–Willi syndrome

This condition occurs due to microdeletion in the long arm of chromosome 15 derived from the father (i.e. *paternal imprinting*).

Characteristic clinical features:

The affected children present the following features:

1. Hyperphagia (insatiable appetite) and obesity
2. Short stature with small hands and feet
3. Hypotonia
4. Hypogonadism
5. Mild to moderate mental retardation
6. Behavioural problems such as rage, violence etc.

Angelman's syndrome (Happy puppet syndrome)

It occurs due to microdeletion in the long arm of chromosome 15 derived from the mother (i.e. *maternal imprinting*). Angelman syndrome is the counterpart of Prader–Willi syndrome.

Characteristic clinical features:

The affected children present the following features:

1. Happy disposition with inappropriate laughter
2. Severe mental retardation (I.Q.: 5–10)
3. Ataxic gait (stiff, jerky, unsteady)
4. Seizures.

DiGeorge syndrome

It occurs due to microdeletion in the long arm of chromosome 2.

Characteristic clinical features:

The affected individuals present the following features:

1. Immunodeficiency, due to the absence of the thymus
2. Hypocalcaemia, due to the absence of parathyroid
3. Hypertelorism
4. Low-set prominent ears with micrognathia.

Miller–Dieker syndrome

It is caused by microdeletion in the short arm of chromosome 17.

Characteristic clinical features:

The affected children present the following features:

1. Lissencephaly (smooth brain, i.e. no gyri)
2. Microcephaly with high and furrowing forehead.

N.B.

Infants suffering from Miller–Dieker syndrome die at an early age. This syndrome should not be mistakenly diagnosed in the case of premature infants whose brains have not yet developed an adult pattern of gyri (gyri begin to appear normally at about 28 weeks after birth).

Chronic myeloid leukaemia

It is caused by a reciprocal translocation between chromosome 9 and chromosome 22. This is referred to as the **Philadelphia chromosome**. It is found in blood or bone marrow cells.

As a result of translocation, the **abl gene** on chromosome 9 fuses with **bcr gene** on chromosome 22, thus forming **abl/bcr oncogene** which transforms, haematopoietic precursor cells.

Characteristic clinical features:

Increased number of granulocytes in all stages of maturation and many mature neutrophils.

N.B.

Patients with chronic myeloid leukaemia with negative Philadelphia chromosomes have a poor response to chemotherapy. It seems likely that the presence of the Philadelphia chromosome is the result rather than the cause of the disease.

Chromosomal abnormalities affecting sex chromosomes

Klinefelter's syndrome

It is a trisomic condition found only in males. It is caused by the non-

disjunction of the XX chromosome during gametogenesis. As a result, the chromosomal complement in somatic cells is XXY. The individual is phenotypically a male but is sex-chromatin (Barr body) positive due to the presence of an extra X chromosome. The karyotype of the individual is 47, XXY.

Characteristic clinical features:

Individuals affected with Klinefelter's syndrome (Fig. 17.20) present the following features:

1. Affected individual is phenotypically a male with eunuchoid habitus.
2. Hypogonadism and associated azoospermia and sterility.
3. Gynaecomastia.
4. Axillary and pubic hair absent, chest hair reduced.
5. Mental retardation.
6. Length of legs and arms are usually longer than normal.
7. Increased gonadotropin levels.

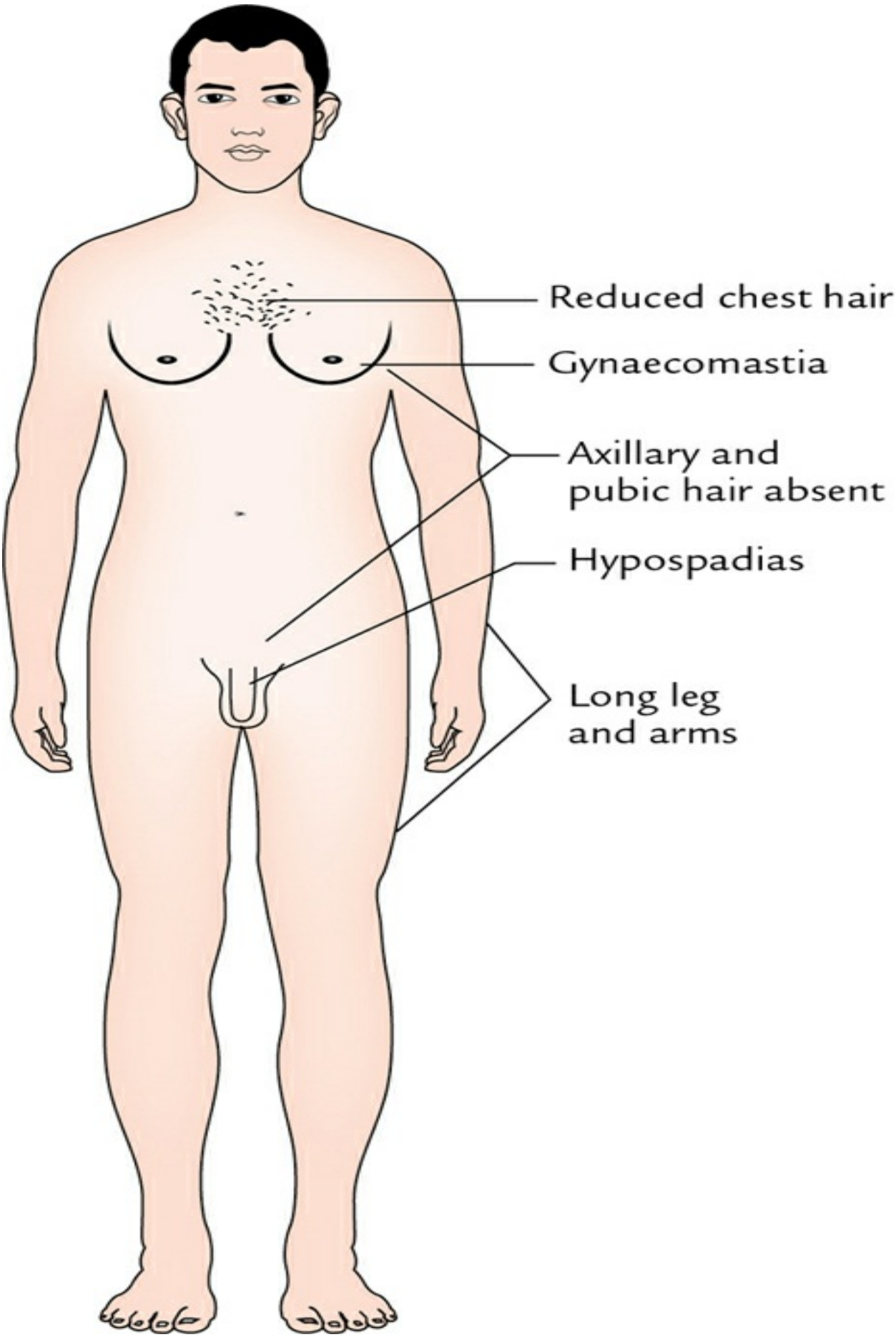

Reduced chest hair
Gynaecomastia
Axillary and
pubic hair absent
Hypospadias
Long leg
and arms

FIG. 17.20 ■ An individual with Klinefelter's syndrome (47, XXY karyotype; individual is tall, thin, shy and nervous).

N.B.

The incidence of Klinefelter's syndrome is about 1:500 male births and it increases with advancing maternal age.

Turner's syndrome

It is a monosomic condition found only in females. It occurs due to the loss of one X chromosome following non-disjunction of the X chromosome during meiosis. As a result, the chromosomal complement in somatic cells is 45, XO. The karyotype of an individual is 45, X.

Characteristic clinical features:

The affected individuals present the following features (Fig. 17.21):

1. Affected individual is phenotypically a female.
2. Short stature, webbing of the neck (due to delayed maturation of lymphatics)
3. Shield chest with pinpoint nipples
4. Bilateral cubital valgus
5. Low-set ears
6. Infantile external genitalia
7. Gonadal dysgenesis associated with amenorrhoea
8. Coarctation of the aorta.

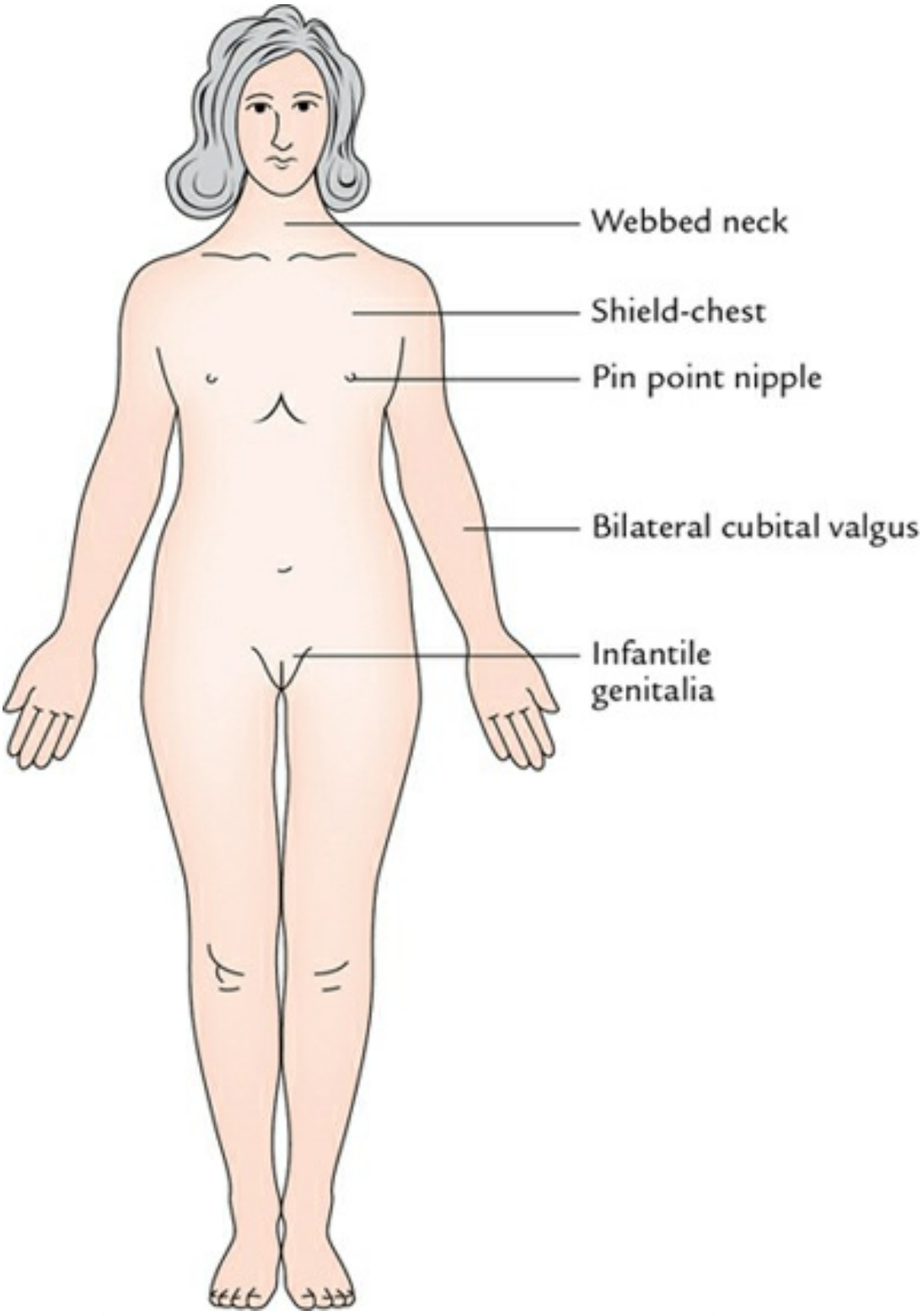


FIG. 17.21 ■ An individual with Turner's syndrome (45 XO karyotype).

N.B.

The incidence of Turner's syndrome is 2:3000 female births. This syndrome is the common cause of *primary amenorrhoea*. In 75% of Turner's patients,

the X chromosome is maternal in origin. Turner's syndrome is the only viable monosomy in human beings.

The key differences between Klinefelter's and Turner's syndromes are presented in Table 17.4.

TABLE 17.4

Differences between Klinefelter's and Turner's syndromes

Klinefelter's syndrome	Turner's syndrome
Trisomic condition found only in males	Monosomic condition found only in females
Chromosomal complement in somatic cells is: 47 XXY	Chromosomal complement in somatic cells is: 45 XO
Affected individuals are phenotypically males	Affected individuals are phenotypically females
Long stature	Short stature

Super female or triple X syndrome

It occurs due to the fertilization of an XX-containing oocyte by an X-containing sperm (gymnosperm). The karyotype shows 47 chromosomes. The individual is phenotypically a female with two Barr bodies, hence referred to as '**super female**'. The chromosome complement in the somatic cell is 47 XXX.

Characteristic clinical features:

The affected individuals present the following features:

1. Female phenotype
2. Some degree of mental retardation
3. Scanty menses
4. Infantile personality.

Single gene inherited diseases

Autosomal dominant inheritance

The diseases caused by autosomal dominant inheritance need only one defective copy of the gene from either parent, e.g. Huntington's disease (HD).

Huntington's disease (HD)

HD is a fatal neurodegenerative disorder caused by autosomal dominant mutation. The HD-gene is located on the short arm of chromosome 4. The inheritance of mutant HD-gene causes cell death of neurons in the caudate nucleus and putamen which leads to a disease called **Huntington's chorea**. Death follows about 5–10 years after the symptoms make their first appearance.

Characteristic clinical features:

The affected individuals present the following features:

1. Involuntary chorea (dance-like) movements of limbs
2. Mood disturbances
3. Swift grimaces and sudden movements of the head
4. Progressive loss of mental activity.

Autosomal recessive inheritance

A disease that occurs due to autosomal recessive inheritance affects only those individuals who receive two copies of the defective gene, one from each parent, e.g. **cystic fibrosis** (CF).

Cystic fibrosis (CF)

It is caused by autosomal recessive mutation. The CF gene is located on the long arm of chromosome 7.

It causes the production of abnormally thick secretion of mucus by epithelial cells lining the respiratory and gastrointestinal tracts, particularly in the first one.

Characteristic clinical features:

The affected individuals present the following features:

1. Obstruction of respiratory airways
2. Recurrent respiratory infections.

X-linked recessive inheritance

In X-linked recessive inheritance, the disease is usually observed only in males because males have only one X chromosome.

The females may also be affected, but rarely. In females, one X chromosome is inactivated to form a Barr body. The choice of whether the maternally derived or paternally derived X chromosome is deactivated is a random and permanent event. If the X chromosome with the normal gene is deactivated, the female has one X chromosome with the abnormal gene and will, therefore, be affected by the disease.

Examples of X-linked recessive inherited diseases are Duchenne muscular dystrophy (DMD), haemophilia and red-green colour blindness.

Duchenne muscular dystrophy

It is a hereditary disease of skeletal muscle which usually affects males. The DMD is caused by X-linked recessive mutation. The DMD gene is located on the short arm of chromosome X. The DMD gene encodes for a protein called dystrophin which anchors the actin (cytoskeleton) of skeletal muscle cells to the extracellular matrix. Thus, mutation of the DMD gene destroys the ability of dystrophin to anchor actin to the extracellular matrix. Consequently, the skeletal muscles become progressively weak from early childhood, and by the time the individual reaches adolescence, he/she becomes completely immobile.

Characteristic clinical features:

The affected individuals present the following features:

1. Progressive muscle weakness and wasting
2. Premature death due to cardiac and respiratory failure.

Haemophilia

The haemophilia results due to deficiency or dysfunction of a clotting factor VIII. It occurs due to mutation of the X-linked recessive gene located on one X chromosome, which is responsible for clotting factor VIII.

Characteristic clinical features:

The affected individuals present the following features:

1. Excessive bleeding, particularly from gums, but virtually no tissue is exempted.
2. When bleeding follows trauma, it is characteristically prolonged.
3. Bleeding tendency may range from mild to severe.
4. Excessive bleeding is unusual until the baby is about 6 months old.

N.B.

The treatment of haemophilia involves an injection of missing clotting factors taken from donated blood.

Red and green colour blindness (Fig. 17.22)

The red and green colour blindness due to presence of a rare form of a *recessive gene* that codes for red and green colour blindness. It passed down on X-chromosome. It mostly occurs in men.

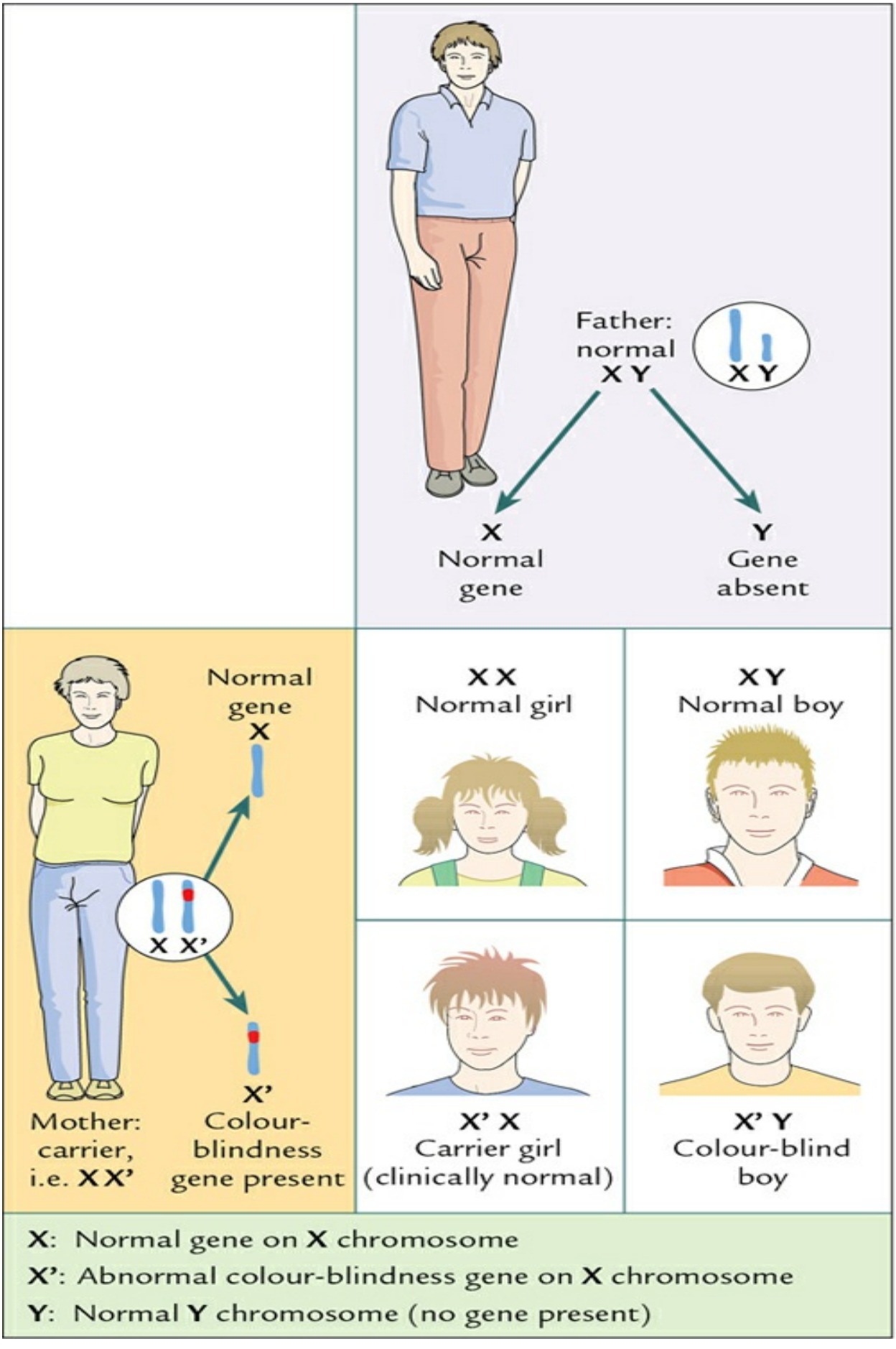

Father:
normal
X Y
X Y
X
Normal
gene
Y
Gene
absent
Normal
gene
X
X X'
X'
Mother:
carrier,
i.e. X X'
Colour-
blindness
gene present
X X
Normal girl
X Y
Normal boy
X' X
Carrier girl
(clinically normal)
X' Y
Colour-blind
boy
X: Normal gene on X chromosome
X': Abnormal colour-blindness gene on X chromosome
Y: Normal Y chromosome (no gene present)

FIG. 17.22 ■ Red and green colour blindness. (Source: Ross and Wilson Anatomy and Physiology in Health and Illness: Anne Waugh and Allison Grant, Figure 17.11, page 445, 12th Edition, Churchill Livingstone, Elsevier, 2014.)

The red-green colour blindness is described in detail on page 230.

Pedigree chart (Fig. 17.23) AN 74.2

The preparation of a pedigree chart is a procedure through which gene mapping is done.

- It is dependent on the study of segregation of *marker genes* in families with genetic disorders.
- The pedigree chart is a useful document that helps in determining mode of inheritance of a particular genetic disorder, which is an essential requisite in *genetic counseling*. By preparing pedigree chart, one can explain the inheritance patterns and predict risks for various family members to have offspring with genetic diseases (recurrence risks).

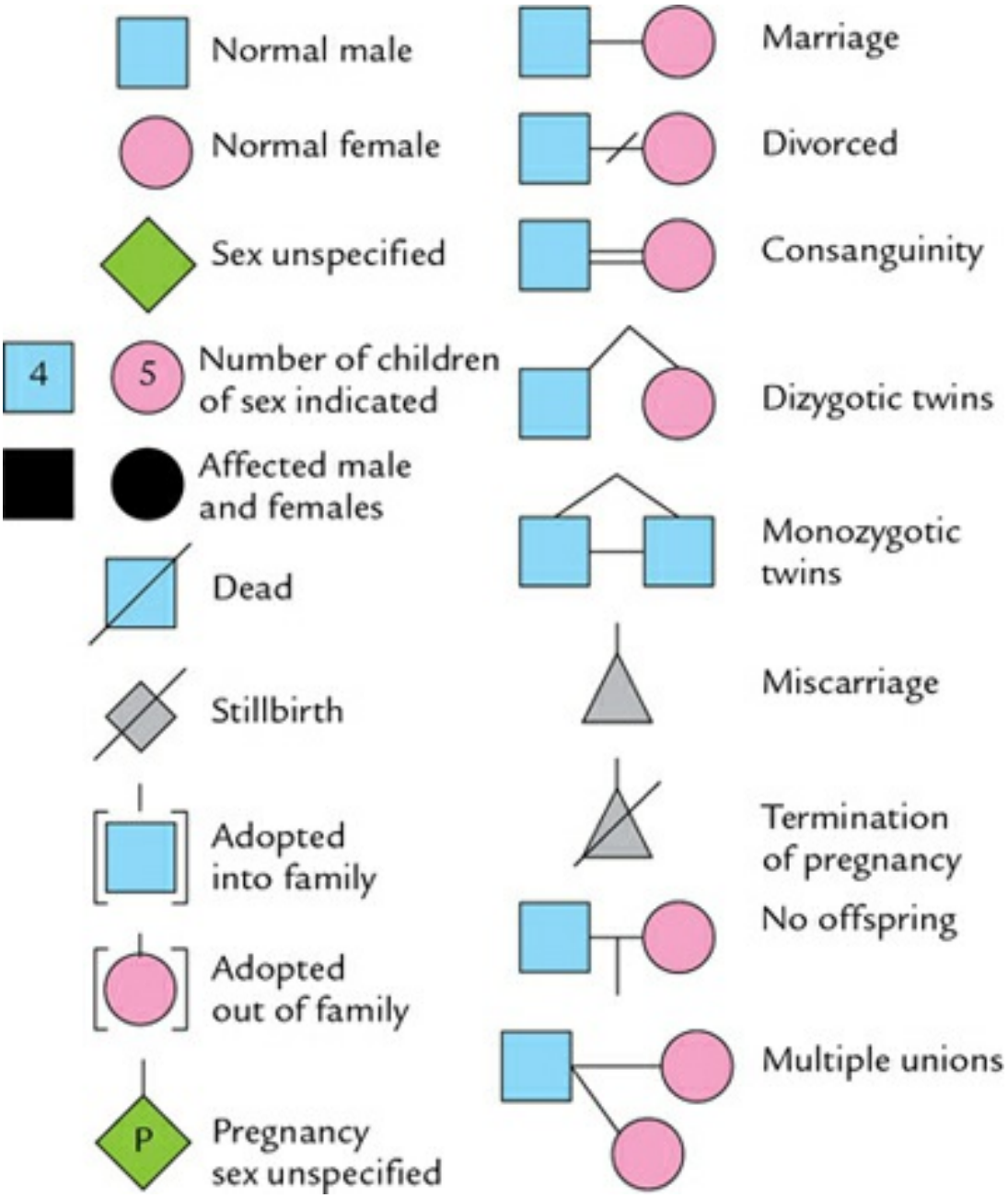


FIG. 17.23 ■ Symbols used in pedigree chart.

Methodology of preparing a pedigree chart

A graphic representation of a generation of a family is made by using various symbols. The symbols represent relationships, clinical findings, etc.

The steps of making pedigree chart are as follows:

- Extract information
- Use standard symbols with key for interpretation
- Identify information and use other family members for documentation

of information
- Ask details about adoption, abortion, stillbirth, etc.
- Ask about history of consanguinity

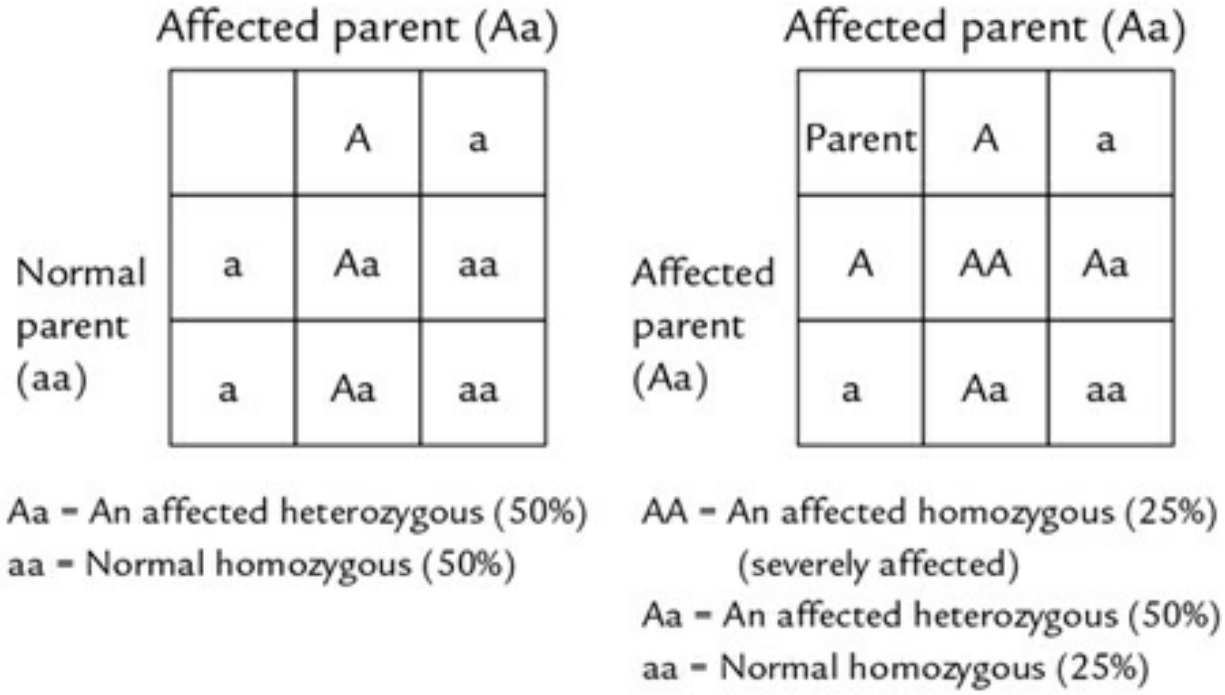
The standard symbols used for making pedigree chart are given in Figure 17.23.

Autosomal inheritance AN 74.4

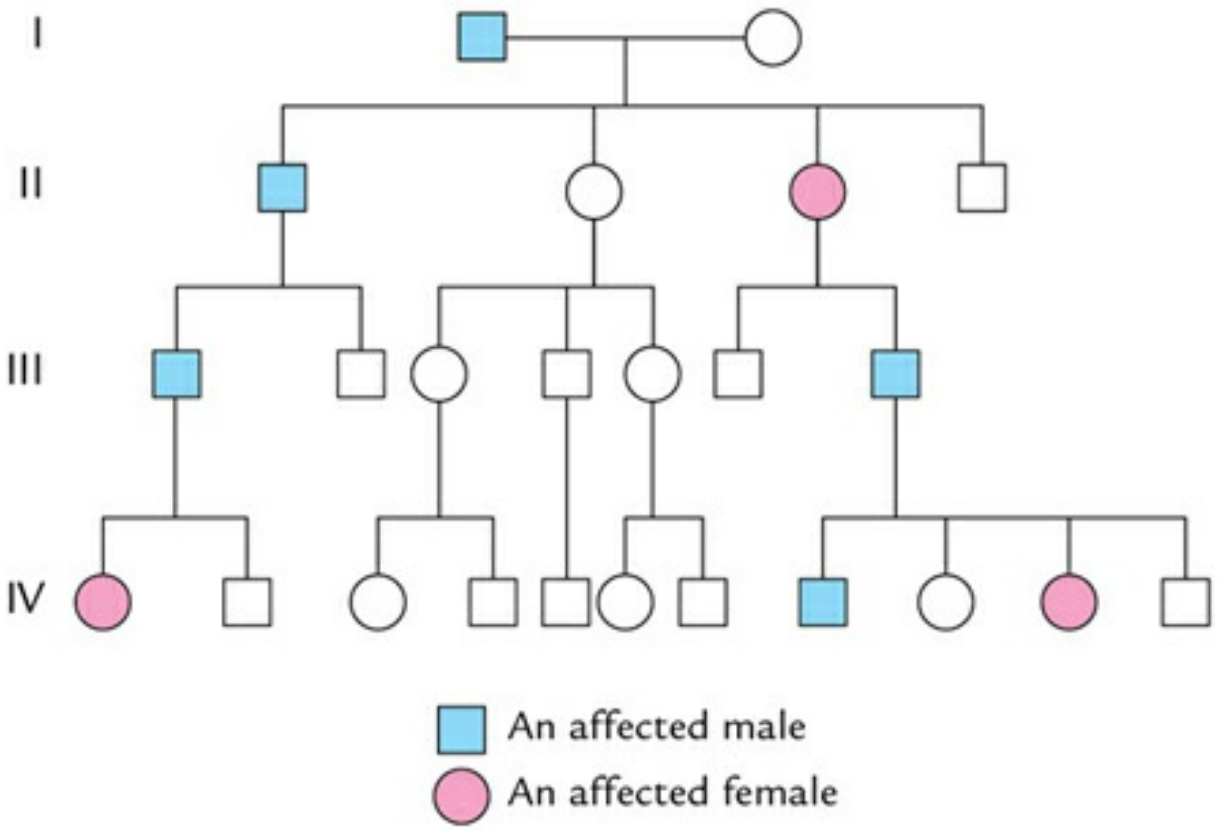
Autosomal dominant inheritance (Fig. 17.24)

When one parent is affected (i.e., have an abnormal dominant allele), then 50% children are affected. The pedigrees involving autosomal dominant disease exhibit vertical pattern of inheritance from one generation to the other. The examples of disorders caused by autosomal inheritance are as follows:

- Marfan syndrome
- Achondroplasia
- Brachydactyly
- Neurofibromatosis
- Osteogenesis imperfecta
- Huntington's disease.



A. Percentage of genetic risk in an autosomal dominant disorder.



B. Pedigree of an autosomal dominant disorder.

FIG. 17.24 ■ Autosomal dominant disorder.

N.B.

The unaffected members of family do not transmit the trait further.

Autosomal recessive inheritance (Fig. 17.25)

In this, the disease is transmitted by a couple, both of whom are carriers of an abnormal gene, but they themselves are not affected, i.e., only siblings are affected but parents are normal. This inheritance shows horizontal pattern where many individuals in a single generation are affected. The risk of children affected is 25% in carrier couple. The parents are usually close relatives (cousins). The examples of autosomal recessive disorders are as follows:

- Cystic fibrosis
- Inborn errors of metabolism
- Haemoglobinopathies, e.g., sickle cell anaemia and thalassemia.

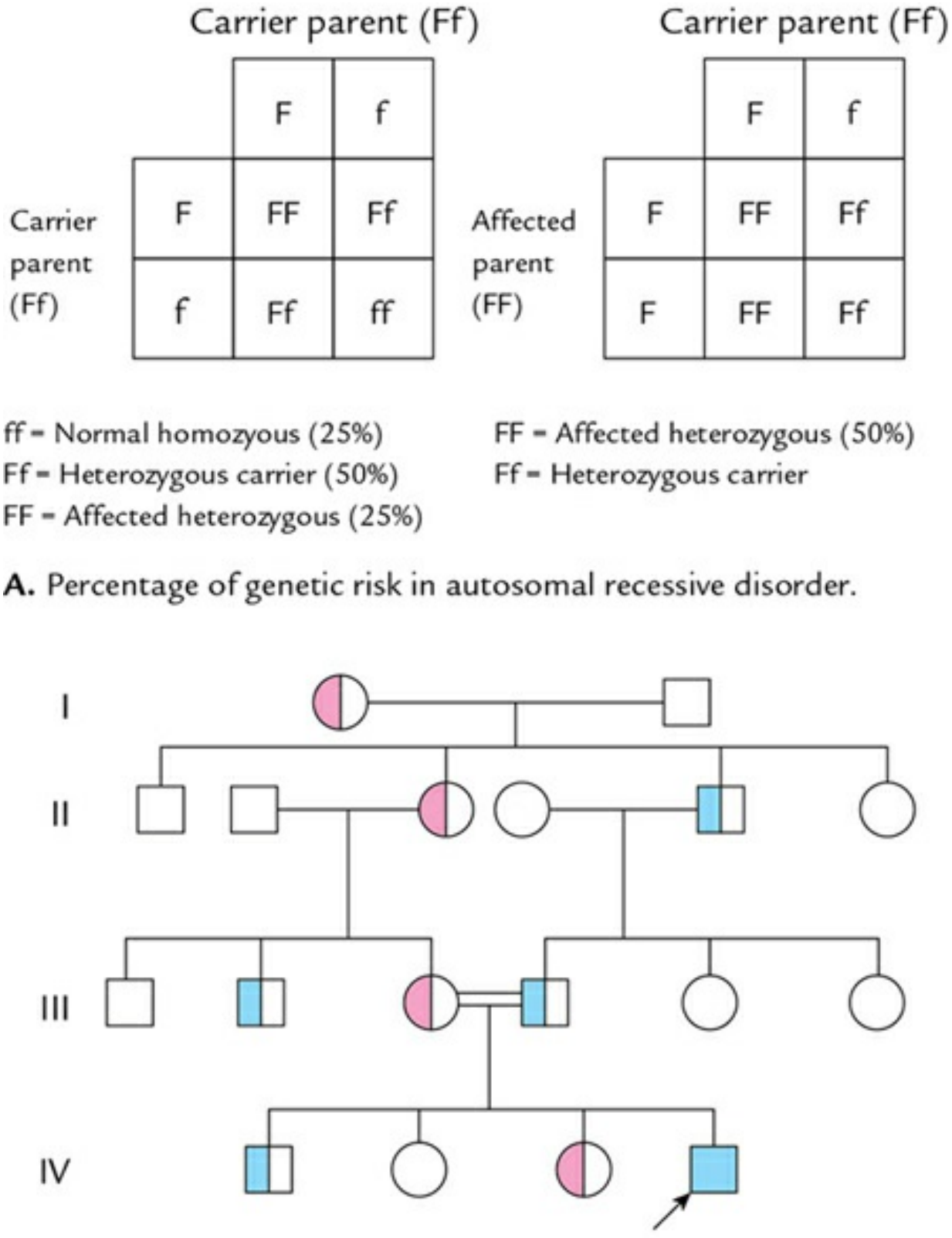


FIG. 17.25 ■ Autosomal recessive disorder.

N.B.

The presence of consanguinity alerts parents to the possibility of an autosomal recessive disorder in children.

Sex-linked inheritance

The **Y** chromosome is shorter than **X** chromosome. Therefore, traits coded on the nonhomologous part of X chromosome have no corresponding traits on the Y chromosome. These genes on sex chromosomes are called **sex linked,** those on X chromosome are X linked, and those on Y chromosome are Y linked.

The genes that are carried by sex chromosomes are called **sex-linked genes.**

Since men inherit only one **"Y"** chromosome, they inherit only Y-linked inheritance. The question of dominant and recessive inheritance does not arise.

On the contrary, women inherit two XX chromosomes; hence, they have both X-linked dominant inheritance as well as X-linked recessive inheritance.

X-linked inheritance

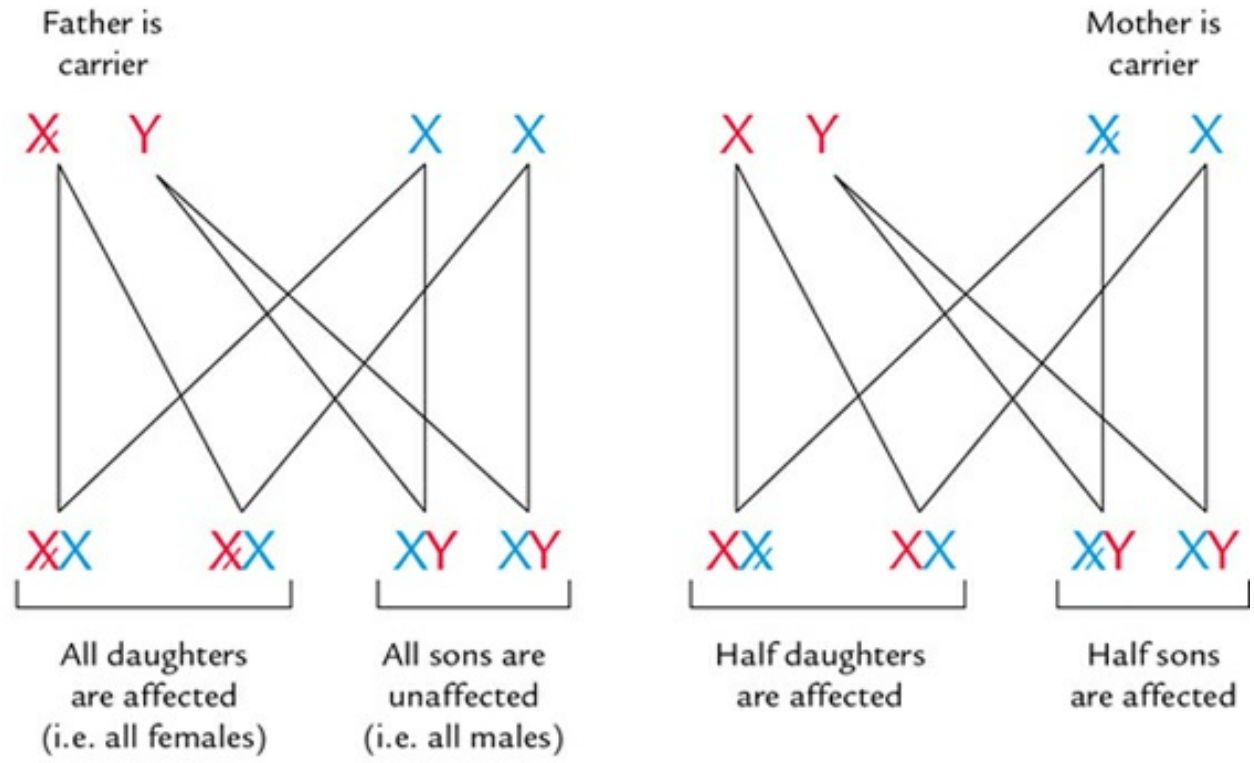
X-linked genes are exclusive to X chromosome. For example, the gene that codes for normal **color vision** is carried only on the X chromosome. It is the dominant form of gene. There is a **rare, faulty, recessive form of this gene** that codes **for red–green blindness**. If female inherits a faulty gene, she is likely to have a normal gene on her other chromosome that provides normal color vision. A female carrying the faulty gene (color blindness gene), even though she is not a color blind, may pass the faulty gene onto her children and thus she is called a **carrier**. If the gene is faulty in male, he will be color blind because he has only one X chromosome and so will have only one copy of the gene.

N.B.

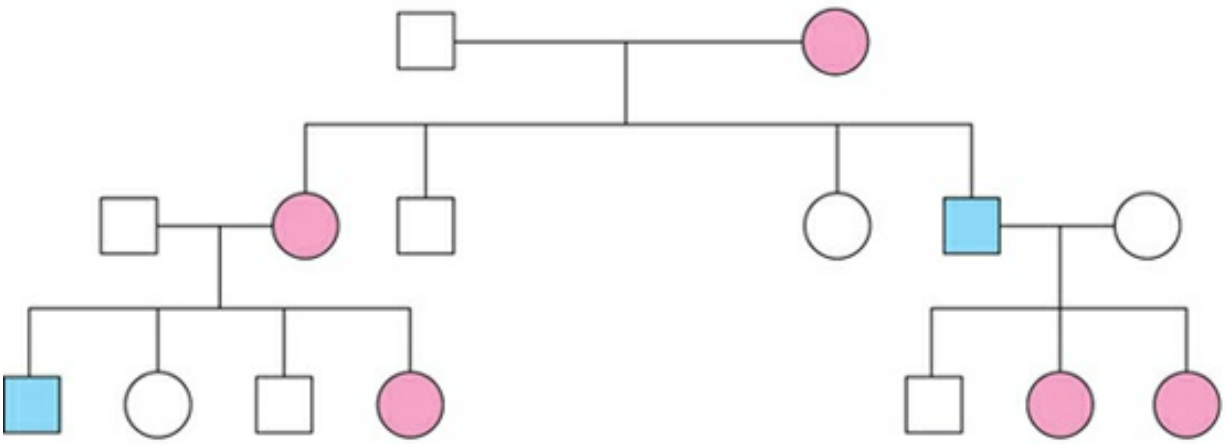
The ability to discern red–green color depends entirely on X chromosome.

X-linked dominant inheritance (Fig. 17.26)

- ***It is less common than sex-linked recessive disorder.***
- It occurs more frequently in females than males (2:1).
- The affected male transmits the trait to all his daughters and none to his sons.
- The affected females if homozygous, they will transmit the trait to all of her children.



A. Percentage of risk affecting sons and daughters.



B. Pedigree of X-linked dominant disorder.

FIG. 17.26 ■ X-linked dominant inheritance.

The affected females, if heterozygous, they will transmit the trait to half of her children.

For examples:

- Vitamin D–resistant rickets
- Hypophosphatemia
- Xg blood group.

X-linked recessive inheritance (Fig. 17.27)

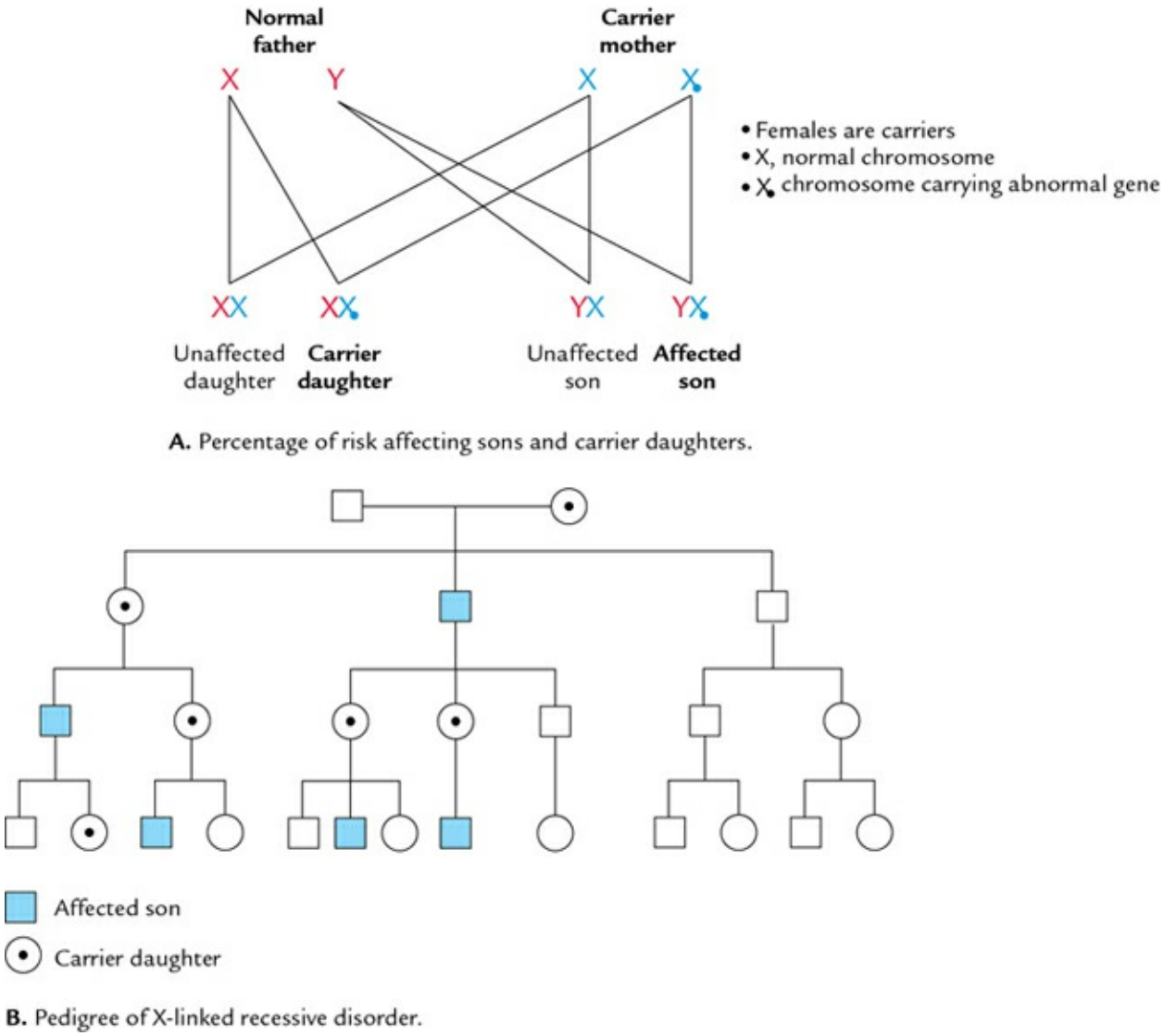


FIG. 17.27 ■ X-linked recessive inheritance.

The females are carriers. Their one X chromosome contains abnormal

gene. The gene on other X chromosome is normal.

- The trait is transmitted by male through daughters to half of their sons.
- No male-to-male transmission occurs because father contributes only Y chromosome to his sons.

For examples:

- Hemophilia
- Color blindness (red-green color blindness)
- Diabetes mellitus
- Duchenne muscular dystrophy (DMD)

N.B.

- The trait usually affects males.
- For a female to be color blind for red and green color, she has to have a recessive allele (color blind gene) on both of her X chromosomes (XcXc). This is possible only if her mother is a carrier (XCXc) and her father is a color blind (XcY).
- Capital 'C' = Normal gene
- Small 'c' = Faulty gene

Y-linked inheritance (holandric inheritance)

Since males have only one Y chromosome, the gene is necessarily unpaired. Therefore, if present, it will be expressed and the question of dominance and recessiveness does not arise. Further the gene will be passed on from affected male to all his sons, e.g., characteristic growth of hair on the pinna of ear. This is the only Y-linked gene inheritance and hence **for all practical purposes, sex linked means X linked.**

Multifactorial inheritance AN 74.3

The multifactorial inheritance occurs as a result of interaction of genes and environmental factors. Some examples of congenital disorders caused by multifactorial inheritance are as follows:

- Neural tube defects
- Cleft lip
- Cleft palate
- Club foot
- Congenital dislocation of hip
- Congenital heart defects

N.B.

Nongenetic factors that contribute to multifactorial inheritance include:

- Drugs, e.g., thalidomide and anticonvulsants.
- Infections, e.g., rubella virus.
- Ionizing radiations, e.g., X-rays and radioactive substances.

Mutation

The mutation is a permanent change in genomic sequence.

It can be caused by the alteration of a single base units in DNA, or the deletion, insertion, or rearrangement of larger sections of genes or chromosomes. These changes are irreversible and heritable.

Mutagens

Substances causing mutation are called mutagens.

For examples:

1. Radiation by UV light or X-rays
2. Chemicals
3. Viruses
4. Jumping genes (transposons) in a DNA sequence

The mutation can occur at the level of gene (**gene mutation**) or at the

level of chromosome (**chromosomal mutation**).

About 70% mutations are harmful. The rest have either no effects or may even have some beneficial effects.

Types of mutation

The eukaryotes have two primary cells types:

(a) Somatic cells
(b) Germ cells.

The mutation can occur in the somatic cells or in the germ cells.

(a) **Somatic mutations**

As the name indicates, these occur in somatic cells, hence not passed into the subsequent generation. Furthermore, majority of these mutations are phenotypically silent but some are expressed in the individual containing the mutation.

(b) **Germline mutations**

- As the name indicates, these occur in germ cells.
- Only some gametes arising from germ cells will carry mutant gene. Then it can be passed into the subsequent generation by sexual means.

Usually, the germ cell mutations are not expressed in the individual carrying the mutation.

The differences between somatic and germline mutations are given in Table 17.5.

 **TABLE 17.5**

Differences between somatic and germline mutations

Somatic Mutation	Germline Mutation
Occurs in somatic cells, hence not transmitted to the children	Occurs in germ cells, hence transmitted to children
Can cause cancer	Can cause certain types of cancer, e.g.: – Retinoblastoma (eye tumour) – Wilms tumour

	(malignancy of kidney)
People are mosaics	People are not mosaics

N.B.

Mutation of gene or genes leads to genetic disorders.

Genetic counseling

Introduction

The genetic counseling is a process by which parents and their relatives who are at the risk of inherited disorders are advised about the following three things:

(a) **Nature and consequences of genetic disorder.**
(b) **Chances of transmitting the genetic disorder.**
(c) **How to prevent, avoid, or improve the outcome of the disorder.**

Indications of genetic counseling

The indications of genetic counseling are as follows:

- When one or both parents are **known carriers of certain trait to cause genetic disorder**.
- When children are born with birth defect, e.g., **spina bifida** and **cleft lip/palate**
- When children are born with **intellectual disability of unknown cause,** e.g., learning disabilities or autism.
- When children are born with **metabolic disorder,** e.g., **phenylketonuria (PKU) and galactosaemia**.
- In adult onset of genetic condition, e.g., **Huntington disease or hereditary cancers**.

Goals of genetic counseling

These are as follows:

1. To increase the understanding of genetic disorders.
2. To discuss the management options of genetic disorders.
3. To explain the risks and benefits of prenatal tests for genetic disorders.

Who should go for genetic counseling?

1. People having family history of genetic disorders.
2. Females older than 35 years planning to have a child.
3. When there is increased nuchal translucency measuring 3 mm or more detected by ultrasound scanning at 12 weeks and 5 days.

N.B.

Nuchal translucency is produced due to fluid collecting behind the neck.

Benefits of prenatal counseling to parents

- Can calculate the likelihood of baby to be born with genetic disorder, e.g., **Down syndrome, cystic fibrosis,** and **sickle cell anaemia.**
- Can have better peace of mind.
- Can plan appropriate testing.
- Can plan early intervention.
- Can help in decision-making.

Steps followed in genetic counseling

1. Accurate diagnosis of disorder.

2. Survey of relatives with similar conditions.
3. Management – it includes early detection and interaction.
4. Follow-up to prevent occurrence in next generation.

Golden Facts to Remember

• **Father of Genetics**	Gregor Johann Mendel (discovered fundamental laws of inheritance in 1865)
• **Correct structure of DNA was first deduced by**	James Watson and Francis Crick (1953)
• **Structural unit of DNA**	Gene
• **The term 'gene' was first coined by**	Johannsen (1909)
• **Unit of inheritance**	Gene
• **Number of genes in the human genome**	50,000–100,000
• **Most important intermediary molecule for gene expression**	RNA
• **Best known and most common chromosomal abnormality**	Down's syndrome (trisomy 21)
• **Only viable monosomy in human beings**	Turner's syndrome (45, XO)
• **Most common translocation in chromosomes of human beings**	Robertsonian translocation
• **Commonest hereditary bleeding disorder**	Haemophilia
• **Commonest X-linked gene disorder**	Red-green colour blindness
• **Most important process required for inheritance**	Reproduction
• **Most X-linked disorders are recessive conditions except**	Vitamin D-resistant rickets which is an X-linked dominant condition

• **Only known condition which is Y-linked**	Hairy pinna in male
• **In all living organisms, genetic information is stored in DNA except**	In some viruses (RNA viruses) in which the genetic information is stored in RNA
• **All cells in the body contain 46 chromosomes except**	Gametes (sex cells) which contain 23 chromosomes

Multiple choice questions

1. **Each nucleotide consists of all of the following subunits *except:***
   (a) A molecule of deoxyribose sugar
   (b) A molecule of the ribose sugar
   (c) A molecule of nitrogenous base
   (d) A molecule of phosphate
2. **All of the following nitrogenous bases are present in a DNA molecule *except:***
   (a) Adenine
   (b) Thymine
   (c) Uracil
   (d) Guanine
3. **Select the *incorrect statement* about the chromosomes:**
   (a) Each chromosome presents a primary constriction called the centromere
   (b) Number of chromosomes is not constant in a species
   (c) Each somatic cell contains 23 pairs of chromosomes
   (d) Females have two X chromosomes (XX) in each somatic cell
4. **Select the *incorrect statement* about the Barr body:**
   (a) Structurally, it represents an X chromosome that is genetically inactive
   (b) Generally, it is located on the outer surface of the nuclear membrane
   (c) The number of Barr bodies in a cell is equal to the total number of X chromosomes minus one
   (d) In neurons, it appears as a small dark body opposite the nucleolus

5. **Select the *correct statement* about the karyotyping:**
   (a) Chromosomes are arranged in seven groups, referred to by the letters A to G
   (b) Chromosomes of groups A and F are submetacentric
   (c) Chromosomes of group D and group G are metacentric
   (d) X chromosome belongs to group G and Y chromosome belongs to group C
6. **Clinical conditions caused by trisomy include all of the following *except:***
   (a) Patau's syndrome
   (b) Down's syndrome
   (c) Klinefelter's syndrome
   (d) Cri-du-chat syndrome
7. **Clinical features of Down's syndrome include all *except:***
   (a) Oblique palpebral fissures with epicanthic folds
   (b) Presence of simian crease
   (c) Long protruding tongue
   (d) Long legs and arms
8. **Select the *incorrect statement* about the Klinefelter's syndrome:**
   (a) It is a trisomic condition found only in females
   (b) The affected individual is sex-chromatin positive
   (c) The affected individual has an increased level of gonadotrophin
   (d) Lengths of legs and arms are usually longer than normal
9. **Which of the following clinical condition is caused by monosomy?**
   (a) Klinefelter's syndrome
   (b) Turner's syndrome
   (c) Down's syndrome
   (d) Cri-du-chat syndrome
10. **Select the *incorrect statement* about the X-linked recessive inheritance:**
   (a) It usually affects the males
   (b) It usually affects the females
   (c) It may affect the females rarely
   (d) Females act as a carrier

Answers

1. *b,* **2.** *c,* **3.** *b,* **4.** *b,* **5.** *a,* **6.** *d,* **7.** *d,* **8.** *a,* **9.** *b,* **10.** *b*

*All the cells of the body are somatic cells except the germ cells.

**In a female embryo at a particular stage of embryogenesis (usually at the blastocyst stage), one of the two X chromosomes is inactivated on a random basis.

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FOURTH EDITION

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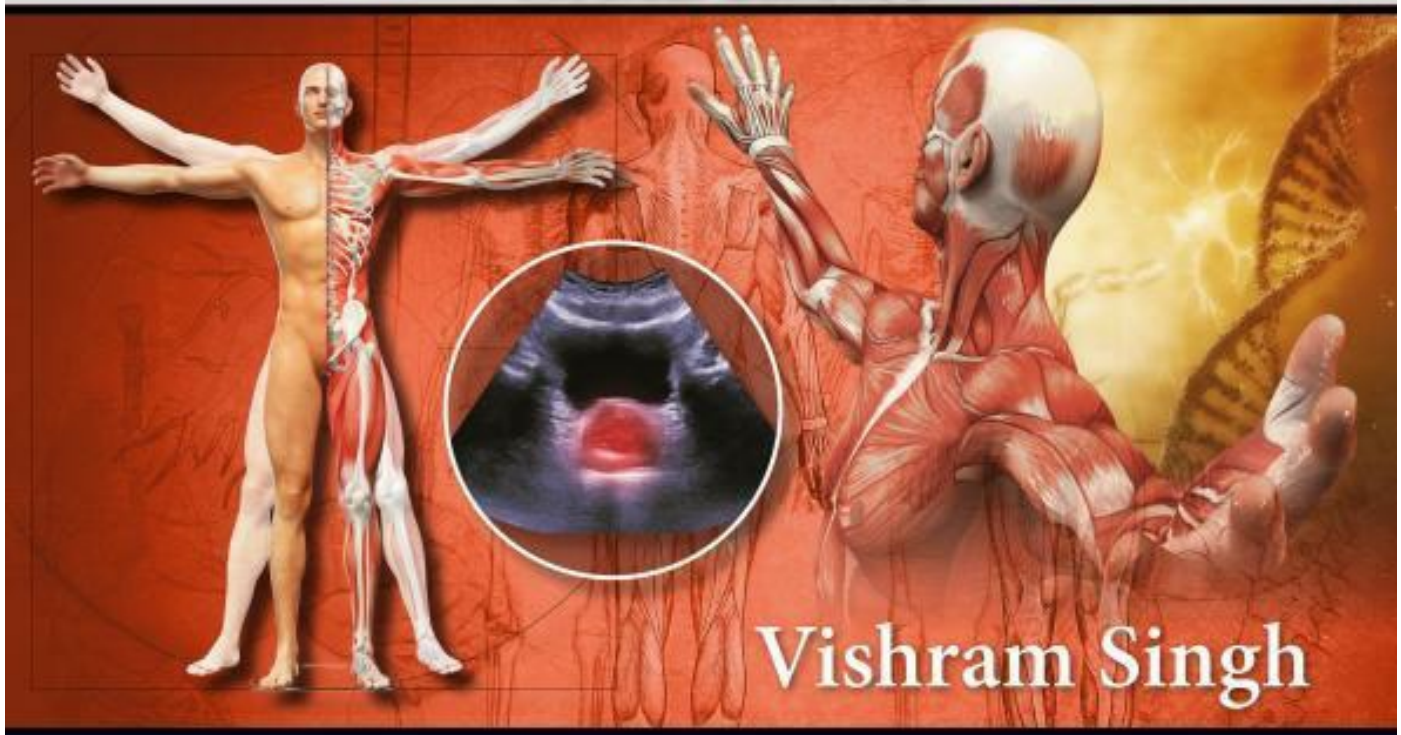

Vishram Singh

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