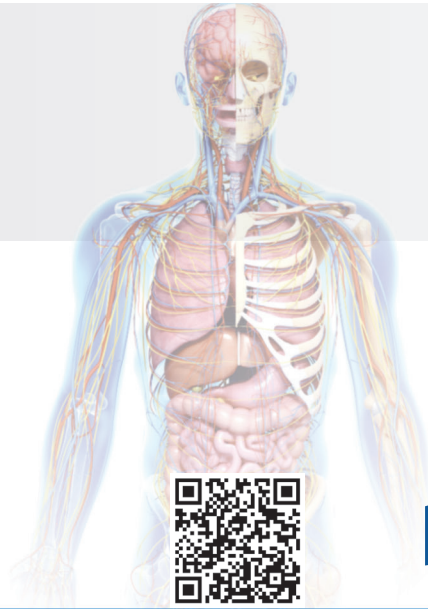


General Anatomy

1. Introduction to Anatomy
2. Anatomical Terminology
3. Cell and Tissues
4. Skeleton
5. Joints
6. Muscular System
7. Cardiovascular System
8. Lymphatic System
9. Nervous System
10. Skin and Fasciae
11. Principles of Radiology
12. Introduction to Cadaver Dissection





Introduction to Anatomy

INTRODUCTION

- *Human anatomy* is a branch of science that deals with the study of structure and organization of human body.
- A *cadaver* is a deceased body of a human being that is used for educational, medical, or scientific purposes. Human cadavers are preserved using formalin solution.
- '*Anatomy*' term is derived from the Greek word '*anatome*.' [*ana* = through and *temnein* = to dissect]. It was coined by Aristotle (2300 years back).
- *Dissection* is the process of carefully cutting and separating the various parts or structures of human body to study the anatomical structures and organization.

SUBDIVISIONS OF ANATOMY

- Anatomy is divided into various types based on the method of study.
 1. *Gross anatomy*: It is also called *cadaveric* or *topographical anatomy*. It is a study of human cadavers by dissection. It is divided into two types:
 - A. *Regional anatomy* – a study of the human body in parts.
For example, the human body is studied in the following six regions as follows (Fig. 1.1):
 1. Head and neck
 2. Brain
 3. Thorax
 4. Abdomen and pelvis
 5. Upper limb
 6. Lower limb
 - B. *Systemic anatomy* – a study of human body as structures forming a particular system. For example,
 - Integumentary system
 - Skeletal system
 - Arthrology (study of joints)
 - Muscular system
 - Nervous system

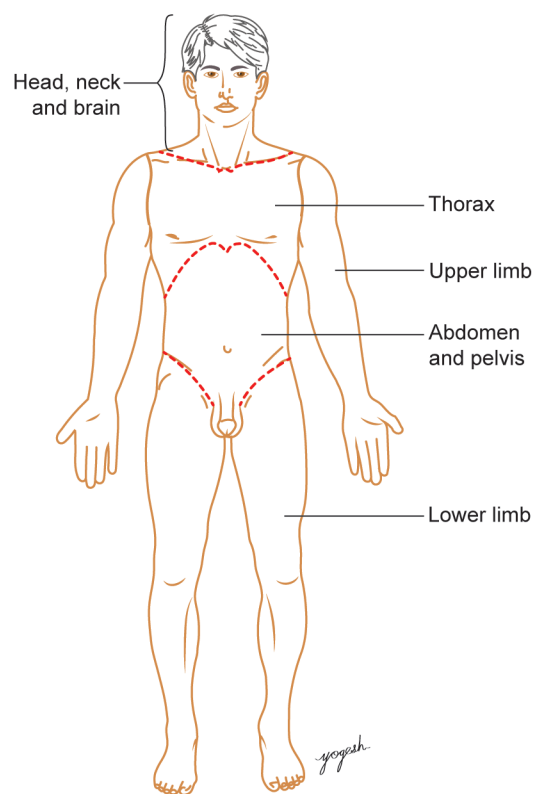


Fig. 1.1: Regions of the body

- Cardiovascular system
 - Lymphatic system
 - Endocrine system
 - Digestive system
 - Respiratory system
 - Reproductive system
 - Urinary system.
2. *Microscopic anatomy (histology)* is the study of structure using microscope.
 3. *Surface anatomy* is the study of the relationship of the deeper structures of the body in relation to the skin surface. For example, palpation of radial artery.
 4. *Living anatomy* is the study by inspection, palpation, percussion, auscultation, and with the

- help of bronchoscope, gastroscope, cystoscope, and other imaging techniques.
5. *Clinical or applied anatomy* is applying anatomical knowledge for diagnosing and treating various diseases and surgeries.
 6. *Radiological anatomy* is the study of bones and other structures using radiography, ultrasound, computerized tomographic (CT) scan, and magnetic resonance imaging (MRI).
 7. *Experimental anatomy* is the study of factors that influence and determine the form, structure, and function of the different parts of the body.
 8. *Embryology or developmental anatomy* is a study of developmental changes in an individual or embryo.
 9. *Genetics* deals with the study of heredity and variations based on genes, DNA, and chromosomes.
 10. *Comparative anatomy* is the study of changes in the form, structure, and function of different animals and human body.
 11. *Physical anthropology* is the study of external features and measurements of different races and groups of people.

HISTORY OF ANATOMY

The history of anatomy is long and developed with struggle by breaking blind beliefs of people. Some of the contributors are as follows:

- *Hippocrates of Cos* (460–377 BC) was a famous Greek physician regarded as the 'Father of medicine'.
- *Herophilus* (about 325 BC) was a teacher of anatomy at Alexandria (Egypt). He performed the first dissection of human body and is regarded as the 'Father of Anatomy'.
- *Claudius Galen* (130–201 AD) was referred to as 'Prince of physician'. He has written many anatomy descriptions.
- *Mundino del Luzei* (1276–1326) was an Italian physician and anatomist. He is regarded as the 'restorer of anatomy' and is known for his work titled 'Anathomia.'
- *Leonardo da Vinci* (1452–1519) was Italian genius artist and anatomist. He is regarded as the 'Founder of modern anatomy' and also known for artistic work Mona Lisa.
- *Andreas Vesalius* (1514–1564) was a German anatomist who worked at University of Padua in Italy. He is regarded as a 'reformer of anatomy' or 'Father of modern anatomy' and has written a book, 'De Humani Corporis Fabrica'. He considered the human body as God's most beautiful creation.
- *William Harvey* (1578–1657) was an English anatomist who is known for functional orientation of anatomy and work on blood circulation.

- *Antonie van Leeuwenhoek* (1632–1723) discovered a microscope that later helped develop microanatomy.
- *Marcello Malpighi* (1628–1634) was an Italian anatomist and regarded as the 'Father of histology'.
- *William Hunter* (1718–1783) was a London anatomist, and he introduced modern embalming techniques.
- *John Hunter* (1728–1793) was a famous surgeon. He developed Hunterian Museum and is known for Hunters/adductors canal.
- **Some major contributions**
 - Wilhelm Conrad Röntgen (1845–1923) discovered X-rays.
 - Gregor Johann Mendel (1822–1884): 'Father of genetics'.
 - 1901: Theodor Kocher – thyroid surgery, Nobel awardee.
 - 1909: Camillo Golgi and Santiago Cajal – Nobel prize for work on nervous system.
 - 1914: Sir Frederick Grant Banting and Charles H – Nobel prize for insulin discovery
 - 1921: Dr Robert H Devison – formalin-based embalming
 - 1934: Sir Henry Hallett Dale and Otto Loewi – Nobel prize for discovery of chemical transmission of nerve impulse and neurotransmitters.
 - 1939: Ernst Ruska and Max Knoll – developed electron microscope
 - 1948: James Watson and Francis Crick – discovered 3-D structure of DNA
 - 1962: James Till and Ernest McCulloch – discovered stem cells in bone marrow.
 - 1969: Roger Wolcott Sperry – Nobel prize for split-brain and cerebral hemisphere research
 - 1970: Godfrey Hounsfield and Allan Cormack developed CT scan
 - 1985: Kary Mullis – developed PCR techniques
 - 1995: Ian Wilmut – first successful cloning of mammal
 - 2003: Completion of human genome project
 - 2017: 3D Bioprinting of human organ
 - 2020: The COVID-19 pandemic hampered entire human life.

Some Interesting Facts

- The largest region of human body is abdomen.
- The largest bony cavity of body is cranial cavity. The longest bony canal of body is vertebral canal. The largest serous cavity of body is peritoneal cavity.
- The hardest tissue is enamel of tooth.
- Heart is the first organ of the body that start functioning.
- **Assignment for students:** Make a list of Indian scientists who have contributed significantly to medical science.

Anatomical Terminology

Competency:

AN1.1 Demonstrate normal anatomical position, various planes, relation, comparison, laterality, and movements in our body.

ANATOMICAL NOMENCLATURE

- *Claudius Galen* (130–201AD) was a Greek surgeon and philosopher. He wrote various books on medicine and anatomy and described multiple structures of human body.
- *Andreas Vesalius* (1514–1564) was a Flemish physician and anatomist. He has written a famous book, '*De Humani Corporis Fabrica*' in Latin.
- Due to these books, most anatomical terms are derived from Greek and Latin.
- *Basle Nomina Anatomica* (BNA) is a Latin-based anatomical nomenclature approved by the *German Anatomical Society* in 1895 at Basale.
- *Birmingham Revision* (BR) of BNA was done by the *Anatomical Society of Great Britain and Ireland* in 1933.
- *Nomina Anatomica* was adopted in 1955 by the *International Anatomical Nomenclature Committee* (IANC). It was later revised in 1961, 1966, 1977, 1983, and 1989.
- *Terminologica Anatomica* is a current international standard for human anatomical terminology. It was developed by the *Federative International Programme for Anatomical Terminology*, a Programme of *International Federation of Association of Anatomists* (IFAA).
- The *International Anatomical Nomenclature Committee* (IANC) is currently working on updating *Terminologica Anatomica*.
- The author of this book, Dr Yogesh Sontakke, is a member of the IFAA working group for *Terminologica Histologica* (committee for updating histological terms).



Some Interesting Facts

- Anatomy is like learning alphabet of the medical language. It is a precise science and foundation for entire system of medicine.
- Strong knowledge of anatomy and physiology is essential to become a good doctor.

POSITIONS OF BODY

Anatomical Position

- **Definition:** In anatomical position (Fig. 2.1): *Viva*
 1. The body is erect
 2. Eyes are directed forward and looking straight
 3. Upper limbs hanging by the side of the body
 4. Palms of hand facing forward and fingers pointing straight downward
 5. The lower limbs are parallel to each other
 6. Feet flat and close together and toes pointing forwards.
- **Need of anatomical position:**
In the medical field, all the body structures are described in the anatomical position. The descriptions

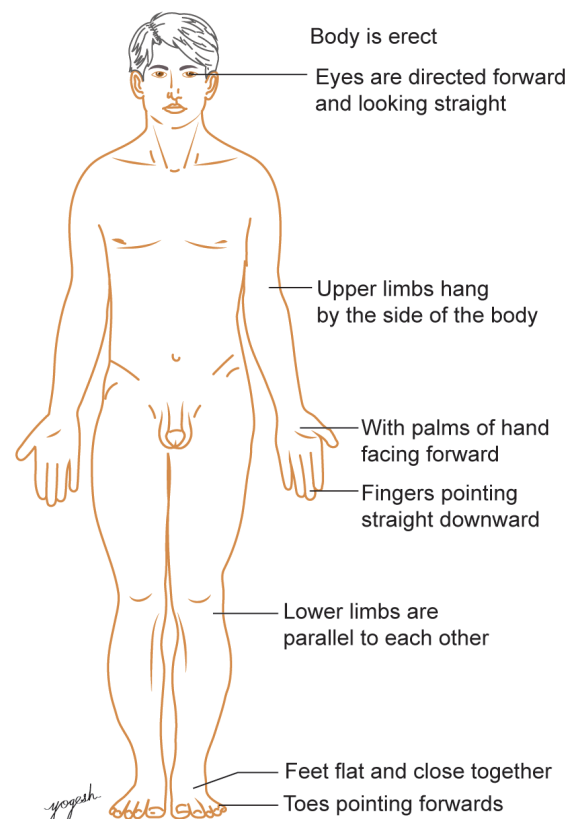


Fig. 2.1: Anatomical position

of all structures in anatomical position are essential for the following reasons:

1. Standardization of all description irrespective of position of patient or specimen, place, time, and so on.
2. Precision and to avoid confusion.
3. Clinical assessment and surgical planning using surface anatomy.
4. Radiological imaging and its comparison with living anatomy.
5. Communication with patient.

Supine position

- In supine position, a person lying on back, arms by the side, palms facing upward, and feet put together (Fig. 2.2).

Prone Position

- In prone position, a person lying on their belly, with face, chest, and abdomen facing downwards (Fig. 2.2).

Lithotomy Position

- In lithotomy position, a person lies on back with legs up and feet supported in stirrups; the hips and knees are semi-flexed, and thighs abducted. This position is mainly used for normal vaginal delivery and also for perineal examination, procedures, and surgeries (Fig. 2.3).

Fundamental Position

- The fundamental position is similar to the anatomical position, except the palms face medially to the body.

Right and Left Lateral Recumbent Position

- In lateral recumbent position person lies on the right or left side with the right or left side of the body touching the surface (Fig. 2.4).

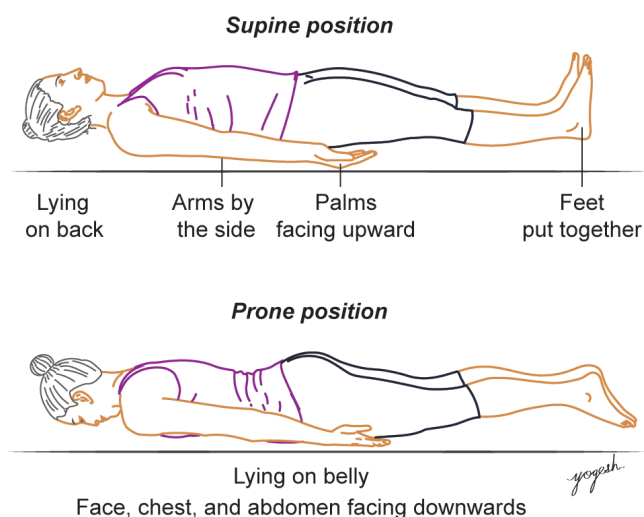


Fig. 2.2: Supine and prone position of body

Trendelenburg Position

- In this position, a person lies in supine position with feet higher than the head by 15–30° (Fig. 2.5). This position helps to increase the blood flow to brain in cases of hypotension and shock. It is also used for laparoscopic surgeries of the lower abdomen and pelvis.

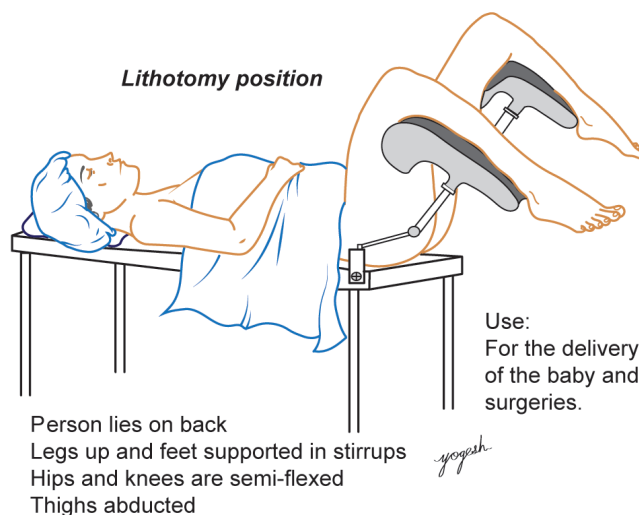


Fig. 2.3: Lithotomy position

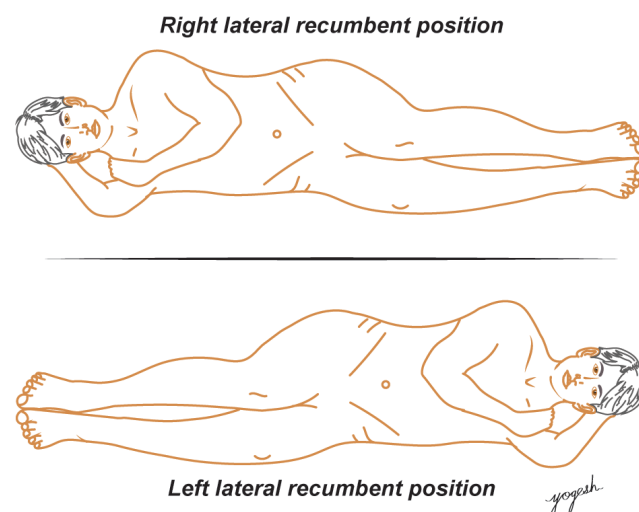


Fig. 2.4: Right and left lateral recumbent position

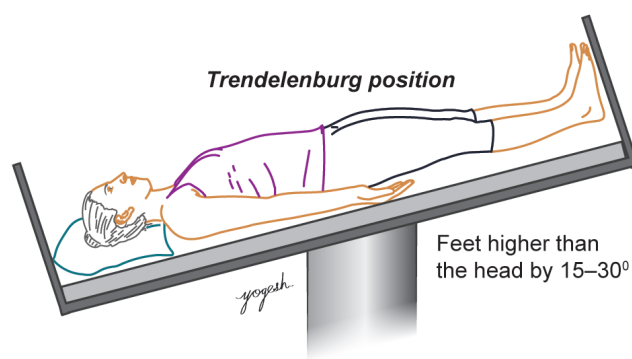


Fig. 2.5: Trendelenburg position

Fowler's Position

- In this position, a person is sitting straight up or leaning slightly backward. This position helps in improving breathing in non-ambulatory patients and increasing comfort during eating (Fig. 2.6).

Sims' Position

- In this position, a person lies on his/her left side with left hip and lower limb straight and right hip and knee semi-flexed. It is used for rectal examination (Fig. 2.7).

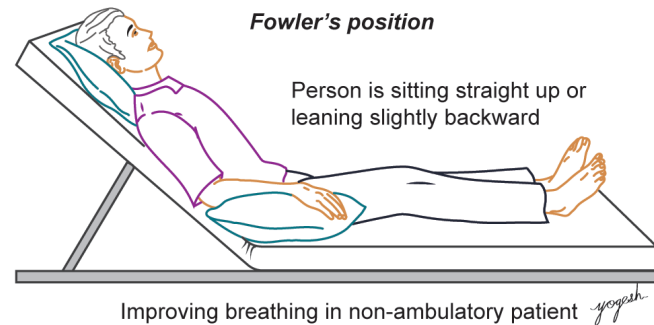


Fig. 2.6: Fowler's position

ANATOMICAL PLANES OF THE BODY

- Anatomical planes are useful for description of structural arrangements of human body and relationship of structures (Fig. 2.8).
 - Median or midsagittal plane:** It passes through the center of the body and divides it into two equal right and left halves. *Viva*
Note: Midsagittal plane may not divide internal structures into equal halves.
 - Sagittal plane:** Any plane parallel to the median plane is sagittal plane. *Viva*
 - Coronal or frontal plane:** It passes longitudinally at right angle to the sagittal plane. It divides the body into anterior and posterior portions. *Viva*

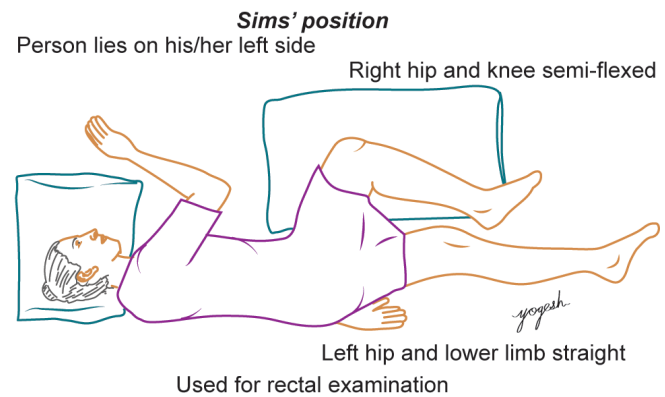


Fig. 2.7: Sims' position

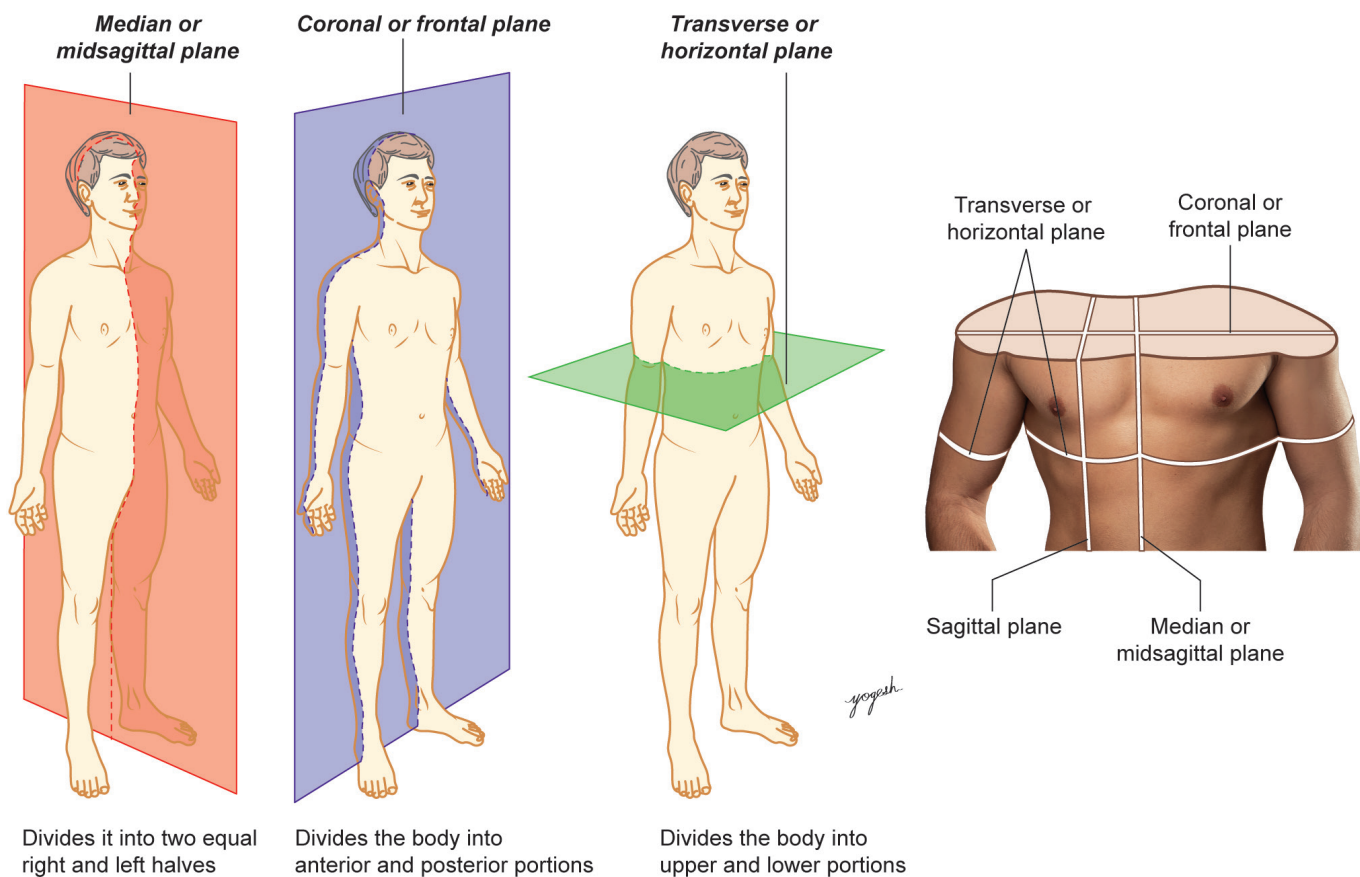


Fig. 2.8: Fundamental planes of body

Note: Sagittal planes are parallel to sagittal suture, whereas coronal planes are parallel to the coronal sutures.

4. *Transverse or horizontal plane:* It is a cross-sectional plane that passes parallel to the horizon and divides the body into upper and lower portions.
Note: Sagittal, coronal and transverse planes are perpendicular to each other.
5. *Oblique plane:* Any plane other than coronal, transverse, and sagittal/mid-sagittal is oblique plane.
6. *Cardinal plane:* It is a plane that passes through the center of gravity.
7. *Note:* The center of gravity is a point at which all cardinal planes intersect.

ANATOMICAL TERMS

Descriptive Terms

- These terms are used to describe structure or its relationship with other structures. These are as follows (Fig. 2.9A–D):

1. *Anterior:* Towards the front of the body
2. *Posterior:* Towards the back of the body
3. *Superior:* Towards the head
4. *Inferior:* Towards the feet
5. *Medial:* Towards the median plane of the body
6. *Lateral:* Away from the median plane of the body
7. *Median:* In the median plane or in between two structures
8. *Superficial:* Towards the surface of the body or skin
9. *Deep:* Away from the surface of the body or skin; within the body
10. *Central:* Towards the center of the body
11. *Peripheral:* Away from the center of the body
12. *External:* Close to the surface of the body, towards the skin
13. *Internal:* Close to the center of the body
14. *Ipsilateral:* On the same side of the body
15. *Contralateral:* On the opposite side of the body
16. *Invagination:* Inward or inside protrusion
17. *Evagination:* Outward or outside protrusion.

Terms for Limbs (Fig. 2.10)

1. *Proximal:* Near the trunk or close to the root of the limb.
2. *Distal:* Away from trunk or away from the root of the limb.
3. *Palmar:* Towards the palm of hand
4. *Dorsal:* Towards the dorsum of hand or foot
5. *Ulnar:* Towards the inner border of forearm
6. *Radial:* Towards the outer border of forearm
7. *Tibial:* Towards the medial side of leg
8. *Fibular:* Towards the outer side of leg
9. *Flexor surface:* Front of upper limb and back of lower limb.

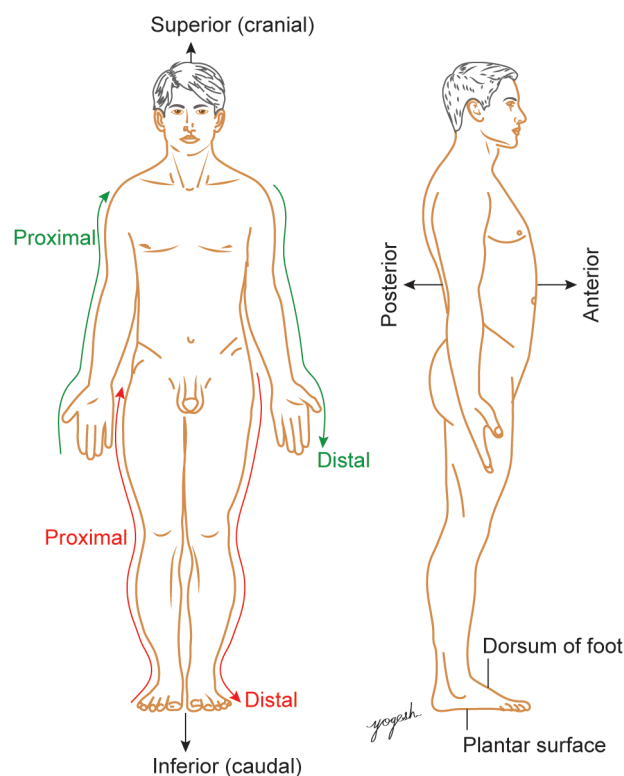


Fig. 2.9A: Descriptive anatomical terms

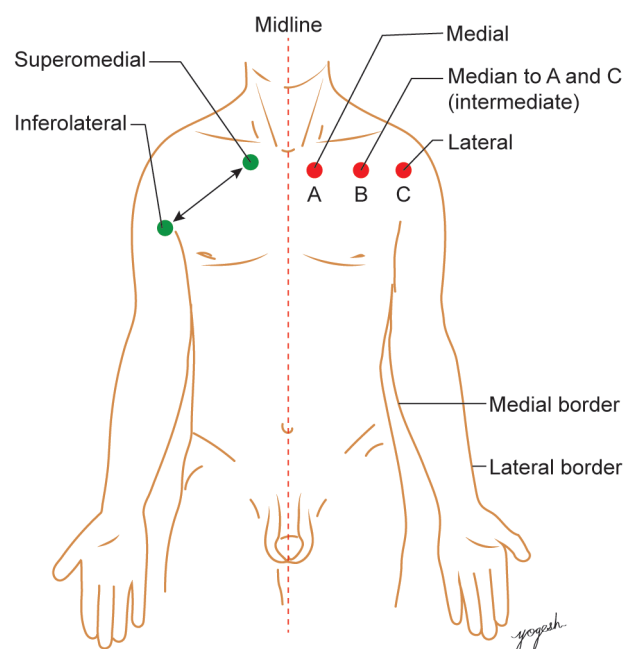


Fig. 2.9B: Descriptive anatomical terms

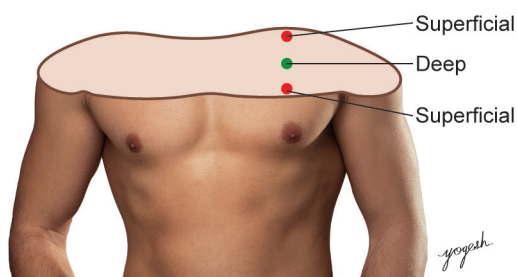


Fig. 2.9C: Descriptive anatomical terms

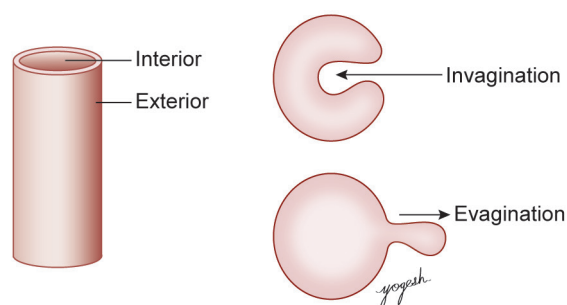


Fig. 2.9D: Descriptive anatomical terms

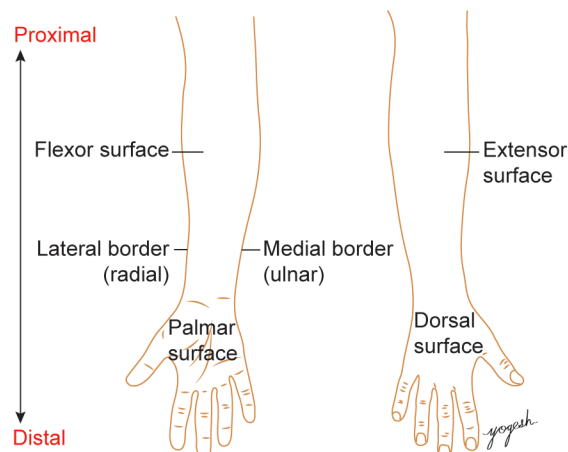


Fig. 2.10: Terms for upper limb

10. *Extensor surface*: Back of upper limb and front of lower limb
11. *Plantar surface*: Towards the sole of foot.

Terms of Embryonic Descriptions (Fig. 2.11)

1. *Ventral*: Towards the belly
2. *Dorsal*: Towards the back
3. *Cranial or rostral*: Towards the head
4. *Caudal*: Towards the tail
5. *Preaxial border*: Outer border of the upper limb and inner border of lower limb
6. *Postaxial border*: Inner border of the upper limb and outer border of lower limb.

Note: During embryonic development, limbs rotate opposite to each other, upper limbs rotate medially, and lower limb rotates laterally.

Terms for Muscles

1. *Origin*: Relatively fixed end of the muscle
2. *Insertion*: Relatively moveable end of the muscle
Note: Origin and insertion are relative terms. If insertion end of muscle is fixed, then origin end of muscle moves.
3. *Tendon*: Fibrous, non-contractile, cord or rope-like end of muscle
4. *Belly*: Fleshy and contractile part of muscle
5. *Aponeurosis*: Flattened tendon
6. *Raphe*: Stretchable fibrous band made up of interdigitating muscle fibers.

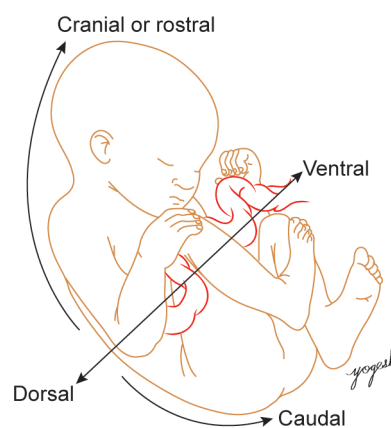


Fig. 2.11: Terms of embryonic descriptions

7. *Ligament*: Fibrous inelastic band connecting bones
8. *Prime movers*: Group of muscles that initiate and maintain particular movement
9. *Antagonist*: Group of muscles that oppose the action of prime movers
10. *Synergist*: Group of muscles that assist the action of prime movers
11. *Fixators*: A group of muscles that contract simultaneously and isometrically to fix the bone and facilitate the action of prime movers.

Terms Related to Movements (Figs 2.12–2.15)

1. *Flexion*: It approximates flexor surfaces of adjoining body parts to reduce the joint angle. It takes place in the sagittal plane around the transverse axis. For example, flexion at the elbow joint.
2. *Extension*: It approximates extensor surfaces of adjoining body parts to increase the joint angle. For example, extension at the elbow joint.
3. *Abduction*: It is the movement of the limb away from the midline in the coronal plane. For example, abduction at shoulder joint.
4. *Adduction*: It is a movement of the limb towards the midline of the body in the coronal plane. For example, adduction at shoulder joint.
5. *Rotation*: It is a movement of the body part around the long or vertical axis. It may be medial or lateral rotation.
6. *Medial rotation*: It is an inward rotation to make the anterior surface of the part to face medially.
7. *Lateral rotation*: It is an outward rotation to make the anterior surface of the body part to face laterally. For example: Medial and lateral rotation of arm.
8. *Circumduction*: It is a circular, cone-shaped movement of the body part with the combination of flexion, extension, abduction, and adduction. The joint forms the apex of the cone. Circumduction occurs only in multiaxial or biaxial joints. For example: Circumduction of shoulder and hip joints, circumduction of wrist joint, and ankle joint. The circumduction of shoulder joint is helpful for bowling in cricket.

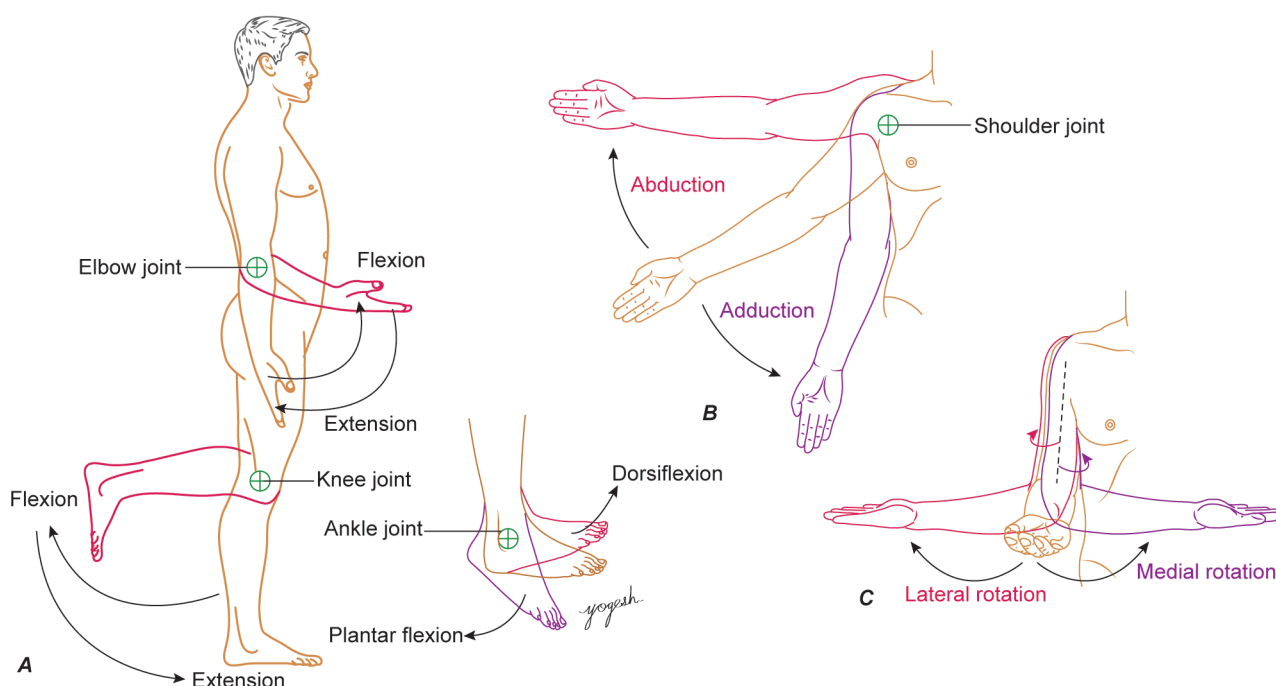


Fig. 2.12: Flexion, extension, adduction, abduction, medial and lateral rotation movements

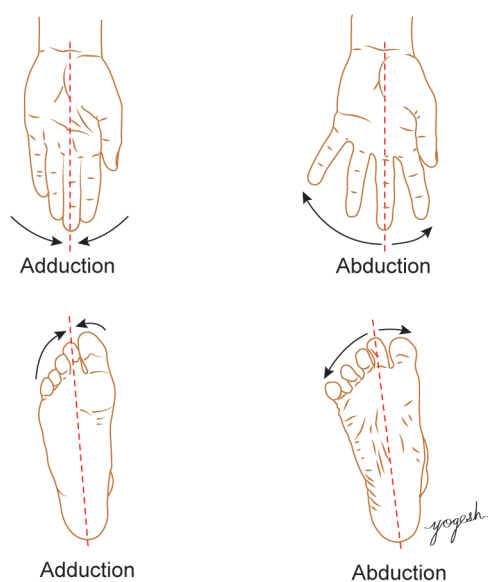


Fig. 2.13: Adduction and abduction of fingers and toes (red dotted line indicates axis of movements)

9. *Supination*: It is a rotation movement to make the front of the forearm and palm to face anteriorly (or superiorly in mid-flexed position of elbow).
10. *Pronation*: It is a rotation movement to make the palm to face posterior (or downward in mid-flexed position of elbow).
11. *Inversion*: It is a movement of the sole of foot in which the sole faces medially or inwards.
12. *Eversion*: It is a movement of the sole of foot in which the sole of foot faces laterally or outwards.
13. *Gliding movement*: It is movement of relatively flat surfaces against each other in multiple directions without significant angular or rotational movement.

For example, movements of intercarpal joints (plane synovial joints). *Note*: Angular movements change angle of joints. These include flexion, extension, adduction, abduction, and lateral flexion of trunk.

14. *Opposition of thumb*: It is a movement in which the tip of thumb touches any of fingers.
15. *Lateral flexion* is the movement of trunk sideways to the right or left.
16. *Elevation*: It is a movement lifts the body part upwards. For example, elevation of mandible to close the mouth.
17. *Depression*: It is a movement to lower down the body part. For example, depression of mandible to open the mouth.
18. *Protraction*: It is a forward thrusting movement of body part. For example, protraction of jaw, protraction of shoulder and arm.
19. *Retraction*: It is backward thrusting movements of the body part. For example: Retraction of jaw or mandible.

Some Interesting Facts

- In flexion at ankle joint, the dorsum of the foot is elevated. Hence, it is also called dorsiflexion.
- In extension at ankle joint, the plantar surface of the foot is pressed downward; hence it is also called plantar flexion.
- *Hyperextension* is the extension of the body part beyond its normal anatomical position. For example, bending head backward.
- In case of adduction and abduction of fingers, the midline passes through middle finger. Hence approximation of fingers towards middle finger is

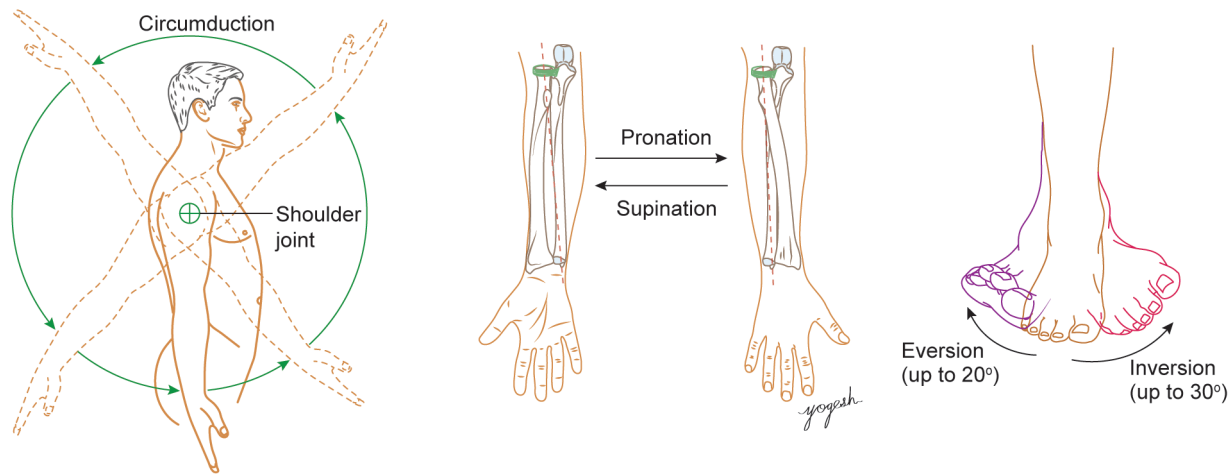


Fig. 2.14: Circumduction, supination, pronation of forearm, inversion, and eversion of foot

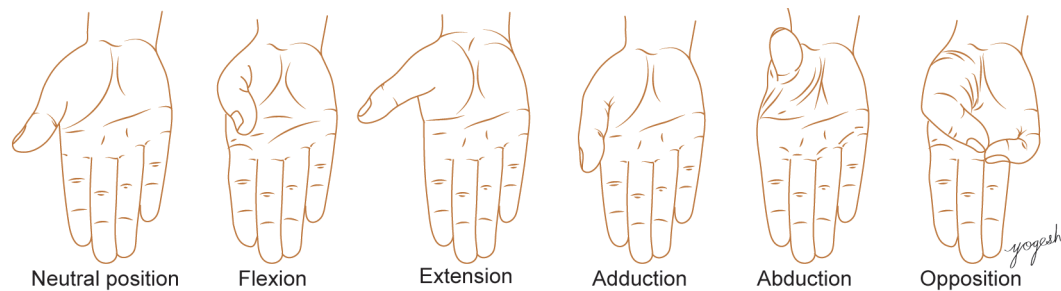


Fig. 2.15: Movements of first carpometacarpal joint (right)

adduction, and spreading out fingers away from middle finger is abduction.

- Supination and pronation are useful for picking up the food from plate and putting it in the mouth.
- Inversion and eversion of foot help in walking on uneven surfaces.
- Movements of the thumb occur in a perpendicular plane than other fingers.
- *Adjunct motion* is the voluntary independent rotation constituting a degree of freedom.
- *Conjunct motion* is obligatory coupled rotation which always accompany some other main movement.

Terms for Vessels

1. *Arteries* – carry blood away from heart
2. *Veins* – carry blood towards heart
3. *Venae comitantes* – veins accompanying an artery
4. *Capillaries* – small, microscopic vessels that form network.
5. *Anastomosis* – communication between adjacent vessels
6. *Sinusoids* – thin-walled vessels with large gaps in the wall.

Terms for Nerves

1. *Nerve* – cord-like structure that consists of bundles of nerve fibers.

2. *Plexus* – network of nerves
3. *Ganglion* – group of neuronal cell bodies outside the central nervous system.

Terms for Bones

1. *Line* – linear elevation (less prominent ridge), e.g. superior nuchal line
2. *Crest* – sharp ridge or border, e.g. iliac crest
3. *Ridge* – linear raised border, e.g. supracondylar ridges of humerus
4. *Tubercle* – slight, rounded elevation, e.g. greater and lesser tubercles of humerus
5. *Tuberosity* – prominent, rounded elevation or projection, e.g. ischial tuberosity
6. *Trochanter* – very large projection of bone, e.g. greater trochanter of femur
7. *Spine* – long, thin projection, e.g. spine of vertebrae
8. *Styloid process* – sharp, pointed bony projection
9. *Head* – rounded articular end of bone, e.g. head of humerus
10. *Condyle* – rounded knuckle-like projection, e.g. condyles of femur
11. *Epicondyle* – rough prominence above the condyle, e.g. epicondyles of humerus
12. *Facet* – small flat area for articulation, e.g. facet on vertebrae for ribs
13. *Groove* or *sulcus* – linear depressed area, e.g. radial groove of humerus

14. *Fossa* – larger hollow depressed area, e.g. radial fossa of humerus.
15. *Foramen* – hole in the bone for passage of nerves and vessels, e.g. foramen ovale of skull
16. *Canal* or *meatus* – tubular passage in the bone, e.g. carotid canal of skull
17. *Fissure* – gap between the adjacent bones, e.g. superior orbital fissure
18. *Sinus* – air-filled cavity in skull bones.

Terms in Clinical Anatomy

Suffixes

1. '____itis': Means inflammation, e.g. tonsillitis = inflammation of tonsils, appendicitis, arthritis.
2. '____ectomy': Means removal from body, e.g. appendectomy (removal of appendix), tonsillectomy.
3. '____otomy': Means to open and close hollow organ or region, e.g. laparotomy (opening and closing abdominal cavity), hysterotomy (opening and closing uterus), cystostomy.
4. '____ostomy': Means to open hollow organ and to leave it open, e.g. cystostomy (creating opening in urinary bladder).
Colostomy (creating opening in colon)
Tracheostomy (creating opening in trachea)
5. '____oma': Means a tumor, e.g. lipoma (tumor of adipose cells), osteoma (tumor of bone), hemangioma (tumor of blood vessels)

Clinical examination terms

- *Observation* – visual inspection
- *Palpation* – feeling with pressure
- *Percussion* – detecting resonating vibrations
- *Auscultation* – listening to organ sounds using a stethoscope
- *Reflex* – response testing.

Clinical terms

- *Symptoms*: Subjective complaints of the patient about the suffering or disease
- *Signs*: Objective (physical) findings of a physician on observing or examining the patient.
- *Diagnosis*: Identification or determination of
 - Cause of disease
 - Nature of disease
 - Clinical condition

- *Prognosis*: Forecasting probable course or outcome of the disease.
- *Therapy*: Mode of treatment
- *Pyrexia*: Fever
- *Paralysis*: Loss of voluntary movements of body parts
- *Hemiplegia*: Paralysis of half of the body
- *Paraplegia*: Paralysis of both lower limbs
- *Monoplegia*: Paralysis of any one limb
- *Quadriplegia*: Paralysis of all four limbs
- *Anesthesia*: Loss of sensation
- *Analgesia*: Loss of pain sensation
- *Coma*: Loss of consciousness from which person cannot be aroused
- *Lesion*: Abnormal or damaged area of the body
- *Inflammation*: Local reaction of the body part to injury. It includes swelling, pain, redness, raised temperature, and loss of function.
- *Edema*: Swelling due to accumulation of excess extracellular fluid
- *Ulcer*: Discontinuity in skin or mucous membrane
- *Ischemia*: Reduced blood supply to body part
- *Necrosis*: Death of tissue due to irreversible damage to it
- *Infarction*: Death of tissue due to loss of blood supply
- *Gangrene*: Necrosis with putrefaction by bacteria
- *Atrophy*: Decreased size of cells
- *Hypertrophy*: Increased size of cells
- *Hyperplasia*: Increased number and size of cells
- *Syndrome*: A disease with group of signs and symptoms together
- *Tumor*: A circumscribed, non-inflammatory abnormal growth
- *Benign*: Mild form of illness or non-spreading tumor
- *Malignant*: Severe form of disease or spreading tumor
- *Cancer*: Malignant tumor
- *Metastasis*: Spread of disease or cancer from one part to another
- *Thrombosis*: Intravascular coagulation of blood
- *Embolism*: Occlusion of a blood vessel by a circulating thrombus
- *Hemorrhage*: Abnormal and excessive bleeding. It can occur externally or internally.
- *Sinus*: A blind tract, open at one end.



Cell and Tissues

ORGANISATION OF THE HUMAN BODY

- The human body is complex, resembling a highly advanced machine. Understanding its structure is essential. Inside the body, there are different levels of structural organization.
- There are four main layers to the organisation of the body as follows:
 1. **Cellular level:** The fundamental building block of life is the cell. A multicellular organism, the human consists of between 60 and 100 trillion cells. Each of the various cell types found in the human body is specialized to carry out particular tasks. Specialized cells include bone cells, muscle cells, fat cells, blood cells, and nerve cells. The structure of each of these cell types varies depending on its functions.
 2. **Tissue level:** Tissue is an aggregation of group of cells organized to perform one or more specific functions. Epithelial tissue, connective tissue, muscular tissue, and nerve tissue are four basic tissues of the body.
 3. **Organ level:** An organ is a specialized, self-contained structure that performs a specific function or group of functions. Examples: Heart, stomach, kidney, and so on.
 4. **System level:** Each organ system composed of multiple organs working together to carry out related or similar functions. Human body comprises 11 primary systems, such as the integumentary, skeletal, muscular, nervous, endocrine, circulatory, lymphatic, respiratory, digestive, urinary, and reproductive systems.

TISSUES

- **Definition:** Tissue is an aggregation of group of cells organized to perform one or more specific functions.

Classification

- Four basic tissues of the body: The tissues of the body are grouped into four basic types as follows:

1. **Epithelial tissue (epithelium):** The surfaces of the body (inner and outer) and inner surface of tubular structures within the body are covered by a layer of cells that rests on the basement membrane. Such a covering layer is called epithelium. They also form secretory units of glands.
2. **Connective tissue:** It supports the other three basic tissues of the body. It consists of cells, connective tissue fibers and intercellular matrix. Specialized connective tissues include bone (with mineralized matrix), cartilage (with hydrated matrix), and blood (flowing connective tissue).
3. **Muscle tissue:** It has contractile cells. It is further classified into skeletal, cardiac, and smooth muscles.
4. **Nerve tissue:** It consists of cells that have the property of excitability and conduction. Nervous tissue receives information from external and internal environment, interpret the information, and convey it to other organs to control their functions. It consists of nerve cells and supporting neurological cells.

CELL

- Cell is basic structural and functional unit of all organisms. Human tissue consists of *eukaryotic cells* (Fig. 3.1).
- Cytoplasm consists of gel-like matrix called *cytosol/hyaloplasm*, cell organelles, cytoskeleton, and inclusions. Cytoskeleton consists of microtubules, intermediate, and actin filaments (Table 3.1).

Some Interesting Facts

- The largest cell in the body is ovum.
- Zygote is the least differentiated cell in the body.
- Neurons, myocytes of cardiac muscle are the most differentiated cells in the body.
- Longest period of cell cycle is G1 phase.
- Mitosis is the most common type of cell division.

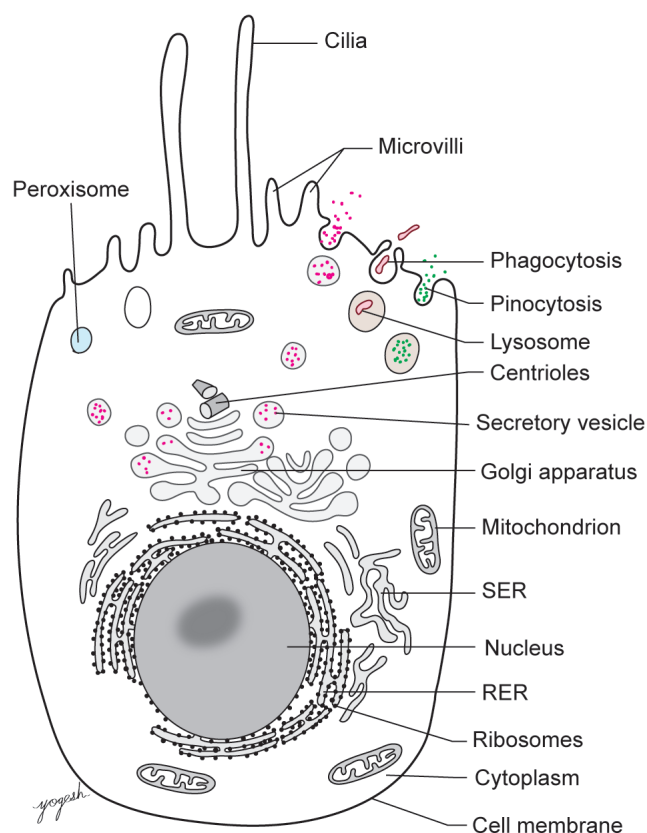


Fig. 3.1: The cell and cell organelles (practice figure)

TABLE 3.1: Cell organelles and functions

Cell organelles	Functions
Plasma membrane	Selective barrier, cell adhesion
rER	Synthesis and transfer of proteins to Golgi complex
sER	Lipid and steroid metabolism
Golgi apparatus	Posttranslational modification of proteins
Secretory vesicles	Transport and storage of secretory proteins
Mitochondria	Powerhouse of cell
Lysosomes	Disintegration of phagocytosed material
Peroxisomes	Oxidation of fatty acids, detoxification
Ribosomes	Protein synthesis

Plasma Membrane (Cell Membrane)

- Plasma membrane is a dynamic structure. It consists of an amphipathic lipid bilayer, integral membrane proteins, and peripheral proteins (Fig. 3.2).
- The plasma membrane consists of two electron-dense layers separated by middle electrolucent layer (Fig. 3.2).
- Thickness is ~8–10 nm.
- Plasma membrane has three types of lipids: Phospholipids, cholesterol, and glycolipids. *Phospholipid* molecules have polar hydrophilic end/head and nonpolar hydrophobic end/tail. The head consists of choline, phosphate, and glycerol. Nonpolar end consists of two fatty acid chains. Hydrophilic ends face toward extracellular and intracellular surfaces.
- Plasma membrane has two types of proteins: Integral membrane proteins and peripheral membrane proteins.
- *Integral proteins* are confined within the plasma membrane and cross the entire or partial thickness of the cell membrane, whereas *peripheral proteins* are confined only on the surfaces of plasma membrane.
- Integral proteins form pumps (Na^+ pump), channels (gap junctions), receptor proteins, linker proteins (anchor cytoskeleton), enzymes (ATPase), and structural proteins. Integral proteins can move within the lipid bilayer.
- Carbohydrates of plasma membrane form glycoproteins and glycolipids. They form *glycocalyx coat* on the outer surface of the plasma membrane. They help cell to interact with extracellular environment, cell recognition, cell adhesion, and metabolism.
- Glycocalyx also forms major histocompatibility complexes (MHC) and blood group antigens on RBCs.
- **Functions:**
 - *Selective barrier:* Plasma membrane limits the mobility of the substances across it.
 - *Protection:* Plasma membrane isolates the intracellular environment from extracellular environment.
 - *Cell shape/adhesion:* Plasma membrane anchors the cytoskeleton and provides attachment with adjacent

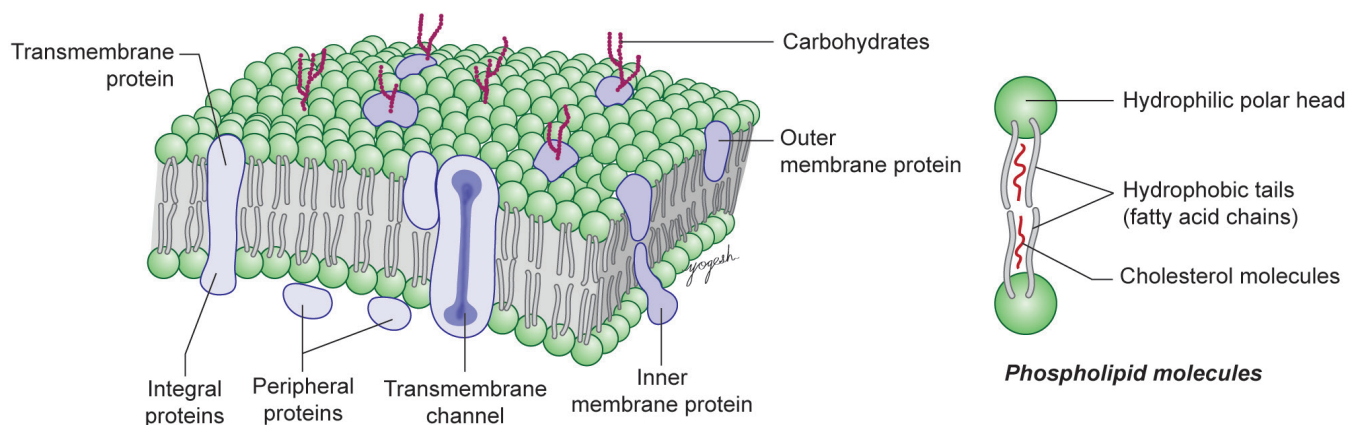


Fig. 3.2: Structure of cell membrane

cells and basement membrane to provide a particular shape to the cell.

- **Polarity:** Plasma membrane maintains ionic polarization and respond to stimuli by depolarizing.
- **Receptors:** Plasma membrane has receptors for specific molecules (hormones).
- **Transport:** Plasma membrane helps in transport across it by endocytosis, exocytosis, pinocytosis, and so on.

Cell Organelles

- Cytoplasm contains numerous structures that perform various functions. These are called cell organelles.

Endoplasmic Reticulum (ER)

- Endoplasmic reticulum is a network of interconnecting membranes that form cisternae (Fig. 3.3). There are two varieties of ER: Rough-surfaced ER (having coating of ribosomes) and smooth-surfaced ER (without ribosomes).

Rough-Surfaced Endoplasmic Reticulum (rER)

- On the surface of rough endoplasmic reticulum, ribosomes are attached on outer surface of rER by *ribosome docking proteins*. Mostly, rER is continuous with outer nuclear membrane.
- Newly synthesized protein enters the lumen/cisternae of rER and undergoes posttranslational modifications such as glycosylation, folding, and so on. Later, modified proteins are delivered to the Golgi apparatus.
- Clinical fact: In *emphysema*, there is an inability of rER to deliver the synthesized enzyme α -1 antitrypsin to Golgi apparatus that results in *α -1 antitrypsin deficiency*.
- **Functions:**
 - **Protein synthesis:** Site for translation (mRNA $\rightarrow$ proteins)
 - **Checkpoint:** rER destroys defective proteins.

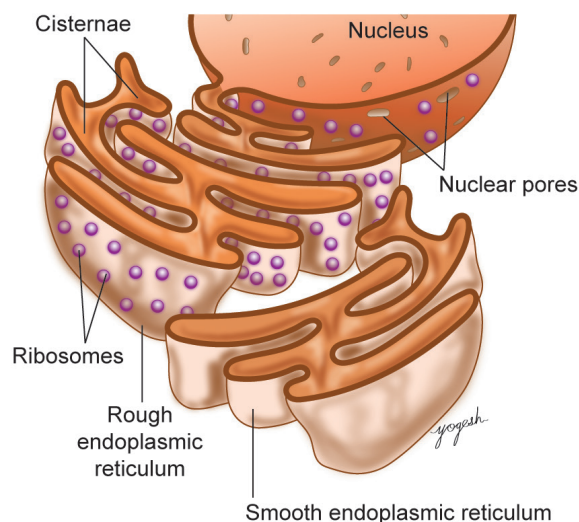


Fig. 3.3: Endoplasmic reticulum

Smooth-Surfaced Endoplasmic Reticulum (sER)

- Smooth-surfaced endoplasmic reticulum consists of short anastomosing tubules.
- **Functions:**
 - **Lipid metabolism:** sER is the main site for lipid synthesis. They are abundant in cells of liver, cells of adrenal cortex, and Leydig cells of testis.
 - **Sarcoplasmic reticulum:** In smooth and cardiac muscles, sER forms sarcoplasmic reticulum that acts as Ca^{++} ion reservoir.
 - **Detoxification:** sER is involved in detoxification of drugs and other chemicals.
 - Glycogen metabolism.

Golgi Complex

- It is made up of 3–20 flattened curved membranous cisternae (sacs) that forms a shallow cup-like structure. It has convex/forming face (*cis-face*) and concave/maturing face (*trans-face*) (Fig. 3.4). Its *cis-face* faces toward rER and nucleus, whereas *trans-face* faces toward cell membrane. Middle part of Golgi apparatus is called medial *Golgi network*.
- **Location:** Usually, Golgi apparatus is located toward secretory portion (apical portion) of the cell membrane.
- **Functions:**
 - **Posttranslational modification of proteins:** Freshly synthesized proteins are transferred from rER to the Golgi apparatus. These proteins are modified by the Golgi apparatus.
 - **Formation of secretory vesicles:** Modified proteins are wrapped around by the membrane of Golgi apparatus and get separated to form membrane-bound secretory vesicles or endosomes or lysosomes.

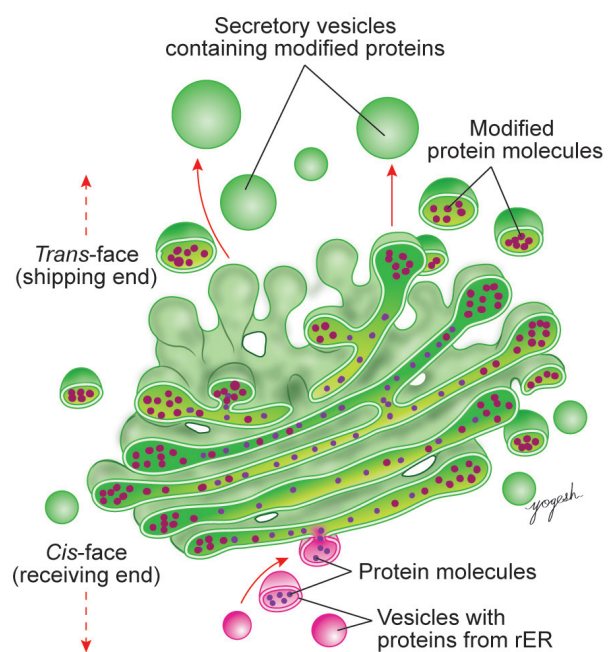


Fig. 3.4: Golgi apparatus

Mitochondria

- Mitochondria are *powerhouses* that generates energy (ATPs). Mitochondria are absent in RBCs and terminal keratinocytes of skin.
- Size: 0.5–2 μm , elliptical-shaped.
- It is bounded by bilaminar membrane with matrix (Fig. 3.5).
- *Outer mitochondrial membrane* is smooth and has voltage-dependent anion channels called *mitochondrial porins*. Inner mitochondrial membrane shows folding called *cristae* (for increasing surface area). Inner mitochondrial membrane is a site for oxidation reactions, respiratory electron transport chain, and ATP synthesis. It has tennis racket-shaped elementary (F1) particles. Heads of these particles carry out oxidative phosphorylation to generate ATP.
- *Mitochondrial matrix* contains enzymes of Krebs cycle and fatty acid β -oxidation.
- *Mitochondrial DNA* is a small circular double helix DNA that contains 37 genes. Mitochondrial DNA is inherited from mother (ooplasm of ovum), as cytoplasm of sperm does not contribute to zygote. Due to mitochondrial DNA, mitochondria are self-replicating.
- Life span: ~10 days.
- *Functions*:
 - Powerhouse of cell: Mitochondria produce ATP by aerobic respiration.
 - Self-replication: Mitochondrial DNA helps in certain protein synthesis and replication of mitochondria.
 - Apoptosis (programmed cell death): Mitochondria sense cellular stress and release cytochrome C from intermembranous space into the cytoplasm. This cytochrome C initiates programmed cell death (apoptosis).

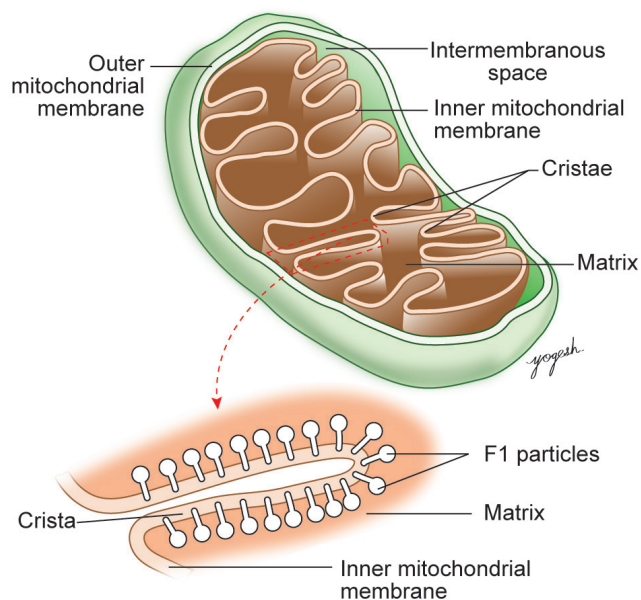


Fig. 3.5: Mitochondrion

Ribosomes

- Ribosomes are small cytoplasmic particles (15–20 nm). It consists of two subunits: Small (40S) and large (60S) (Fig. 3.6). Ribosome synthesis is controlled by nucleolus (site of rRNA synthesis).
- *Functions*:
 - Ribosomes synthesize proteins as follows:
 - Free ribosomes produce structural proteins of a cell
 - Membranous ribosomes (rER) produce secretory proteins.

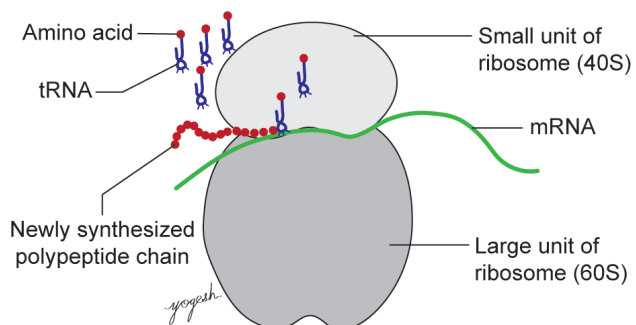


Fig. 3.6: Ribosome

Lysosomes

- Lysosomes are membranous spherical cytoplasmic vesicles (0.2–0.8 μm in diameter).
- Lysosomes are derived from Golgi apparatus as primary lysosomes (Fig. 3.7). Primary lysosome fuses with endocytic vesicle that contains material for digestion/destruction and forms secondary lysosome.

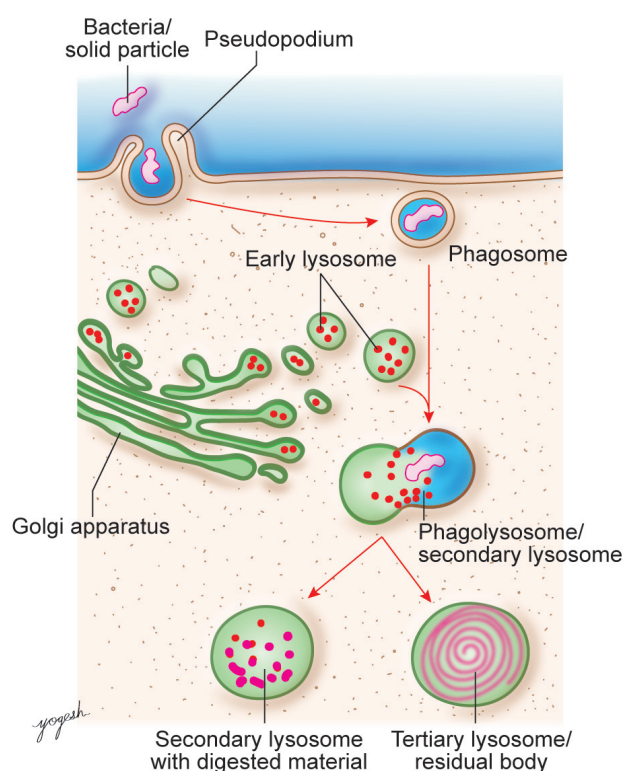


Fig. 3.7: Role of lysosome

- Lysosomes contain hydrolytic enzymes such as proteases, nucleases, glycosidases, lipases, and phospholipases.
- **Functions:**
 - Digestion of foreign material (*Heterophagy*): Lysosomes digest material (bacteria) that entered into the cell by endocytosis.
 - *Autophagy* (removal of old cell organelles): Lysosome removes worn-out organelles of cytosol.
 - *Autolysis*: In case of diseases/lack of oxygen supply to the cell, lysosomal enzymes destroy own cells (autolysis).
 - Inflammation: Neutrophil releases lysosomal enzymes in extracellular space that digest extracellular matrix and initiates acute inflammation.

Peroxisomes (Microbodies)

- Peroxisomes are membranous organelles that contain oxidative enzymes required for amino acid oxidation, and β -oxidation of fatty acids.
- Oxidation of these compounds generates hydrogen peroxide (H_2O_2) that is toxic for cells. This H_2O_2 is broken down by enzyme *catalase* of peroxisomes, and thus, the cell is protected.
- Peroxisomes help for detoxification in liver and kidney.

Endosomes

- Endosomes are derived from *endocytosis*.
- *Early endosomes*: On endocytosis, the membrane-bound organelle called early endosome is formed.
- *Late endosomes/lysosomes*: Golgi apparatus transfers hydrolytic enzymes and converts early endosomes to late endosomes or lysosomes.

Cytoskeleton

- Cytoskeleton is a supporting network of protein filaments in cytoplasm.
- Cytoskeleton helps in maintaining cellular architecture, cellular mobility and migration, movement of cilia, microvilli, tail of sperms, anchoring the cell on basal lamina, and form cell junctions.
- Components of cytoskeleton:
 - Microtubules
 - Microfilaments
 - Intermediate filaments.

Centrioles

- Centrioles are hollow cylindrical structures that are made up of nine microtubule triplets arranged in cylindrical pattern. There are two centrioles in a cell. They are arranged at right angle to each other.
- Centrioles are surrounded by *pericentriolar area*. Centrioles and pericentriolar area together called *centrosome* or *microtubule organizing region*.
- **Functions:**
 1. Centrosome initiates formation of microtubules.
 2. Centrosome forms mitotic spindle.

3. Centrosome provides basal bodies for cilia and flagella.
4. Centrioles self-replicate just before cell division.

Nucleus

- Nucleus is an oval or spherical membranous structure.
- Most of the cells contain single nucleus except
 - RBCs and platelets do not have nuclei
 - Striated muscle cells, osteoclasts, and syncytiotrophoblast are multinucleated
 - A few hepatocytes and transitional epithelial cells are binucleated.
- It consists of the following components: Chromatin, nucleolus, nuclear membrane, and nucleoplasm (Fig. 3.8).
- *Nuclear envelope*: Nuclear envelope is bilaminar membrane. *Perinuclear cisternal space* lies between two layers of nuclear envelope.
- *Nuclear pores* are intervals in nuclear membrane that transport RNAs and proteins between the nucleus and the cytoplasm.
- *Nucleoplasm* is a material enclosed by nuclear envelope besides chromatin and nucleoli. It contains various proteins, ions, and inclusions.
- *Chromatin*: Genetic material of the cell located in the nucleus is in the form of a long thread called *chromatin*. Chromatin consists of (Human genome project–2003):
 - 1.8 m long DNA
 - 1000 times longer than the nucleus diameter
 - 46 chromosomes
 - 2.85 billion base pairs of nucleotides
 - 23,000 protein-coding genes.
- Chromatin consists of DNA coiled around histone and nonhistone proteins (structural proteins). The presence of DNA and RNA (acids/negative charges) makes the chromatin basophilic (stained with hematoxylin).
- *Gene* is a union of genomic sequences encoding a coherent set of potentially overlapping functional products.

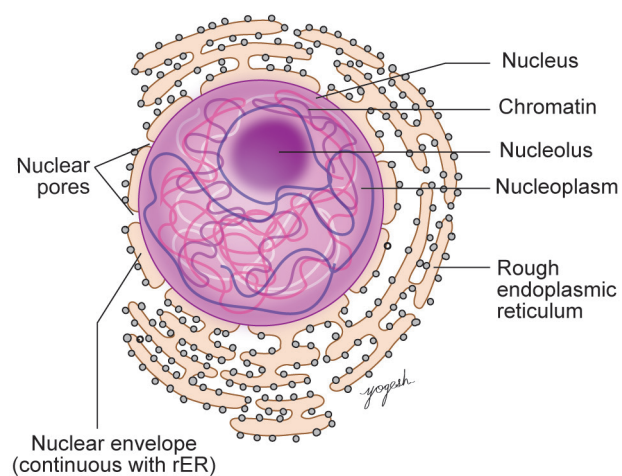


Fig. 3.8: Structure of nucleus

- **Histone proteins:** Histone proteins form an octamer having eight molecules of histone proteins. DNA wrapping around histone proteins produces *beads on a string* appearance. During cell division, chromatin condenses to form *chromosomes*.
- **Nucleolus:** Nucleolus is a spherical mass of heterochromatin. Each nucleus shows 1–2 nucleoli (maximum 5–6). It contains a protein nucleostemin that binds p53 protein and regulates cell cycle and cell differentiation.

Clinical Integration

- **Kartagener syndrome or primary ciliary dyskinesia:** It is a defect in the organization of microtubules that results in *defective ciliary movement* in the respiratory tract, defective sperm movement, and defective ciliary movement of fallopian tubes. It results in repeated respiratory infections, and male and female infertility. It may be due to mutation of DNAH5 and DNA11 genes. It is also associated with situs inversus.
- Colchicine, vinblastine, and vincristine prevent mitotic spindle formation and arrest cell division in mitosis. Colchicine is useful for chromosomal studies in cytogenetics.
- **Alzheimer's disease:** Defective formation of neurofilaments (intermediate filaments) causes Alzheimer's disease. It results in accumulation of neurofibrillary tangles in neurons.
- In alcoholic liver cirrhosis, keratin filaments accumulate in hepatocytes and form *Mallory bodies* (inclusions).
- **Duchenne muscular dystrophy:** It is a X-linked recessive disorder that affects only boys. It involves a defective gene for dystrophin protein. Dystrophin is essential in binding contractile assembly to sarcolemma in skeletal muscles.
- **Lysosomal storage diseases:** Many genetic disorders cause lysosomal storage disease because of deficiency of certain lysosomal enzymes. *Tay-Sachs disease* is an inherited lysosomal disorder due to hexosaminidase deficiency. It results in accumulation of gangliosides in neurons that cause seizures, muscle rigidity, and death (before 5 years of age).
- **Zellweger syndrome/cerebrohepatorenal syndrome:** It is an inherited nonfunctioning peroxisomal disorder and leads to early death.

APICAL CELL SURFACE MODIFICATIONS

- As per functional need, apical surface (luminal surface) of epithelial cells shows surface modifications such as microvilli, stereocilia, and cilia (Fig. 3.9).

Microvilli (Finger-like Projections)

- Microvilli are *apical cell surface modifications*. The main function of microvilli is to increase cell surface area for absorption or secretion (Fig. 3.9).
- **Locations:** Apical surface of epithelial cells in small intestine, gall bladder, and bile duct, proximal convoluted tubules of kidney.

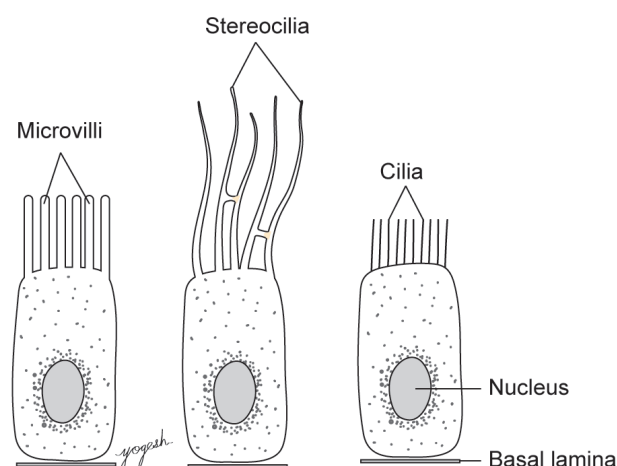


Fig. 3.9: Microvilli, stereocilia, and cilia (practice figure)

- **Dimensions:** Length: 1–2 μm and diameter: 0.5 μm .
- **Functions:**
 - Increases surface area by 15–30 folds for absorption or secretion.
 - Slight motility of microvilli helps them to come in contact with newer food molecules in gut.
 - Regularly arranged microvilli produce *striated border* over apical surface of absorptive cells of intestinal epithelium, whereas irregularly arranged long microvilli produce *brush border* (gallbladder and proximal convoluted tubule).

Stereocilia

- Stereocilia is a *long, thick microvillus* (5–10 μm). Stereocilia are nonmotile and increase cell surface area.
- Stereocilia are present on epithelium of receptor (hair) cells in internal ear and epithelial cells of epididymis.
- **Functions:**
 - In hair cells of internal ear: Here, stereocilia serve as a sensory mechanoreceptor. Vibration induces movement of stereocilia that generates signal.
 - In epididymis: Here, stereocilia increase the surface area for fluid absorption.

Cilia

- Cilia are apical cell membranous hair-like projections. Cilia are *motile*.
- **Dimensions:** 10 μm length, 0.25 μm diameter.
- **Locations:** Respiratory tract (pseudostratified columnar) epithelium, sperms (tail of sperm is flagellum or long cilium), fallopian tube.
- **Functions:**
 - In respiratory tract, ciliary movements help to remove the mucus from the epithelial surface.
 - For sperm, tail (flagellum/long cilium) helps in motility.
 - In fallopian tube, cilia help to bring gametes (ova/sperms) to site of fertilization and move fertilized egg toward the uterus.

PHASES OF CELL LIFE

- **G₁ phase:** It follows M phase. Events – cytoplasm increases in volume; damaged DNA gets repaired (Fig. 3.10).
- **S phase:** It follows G₁ phase. Events – DNA gets replicated to form two sister chromatids of each arm of the chromosome. Each cell contains 4n (double 2n) number of chromosomes.
- **G₂ phase:** It follows S phase. Event – it is a checkpoint before mitosis or meiosis for the confirmation of duplicated chromatin.
- **G₀ phase:** It is a nondividing phase of cell cycle.
- **M phase:** It is the cell division phase.

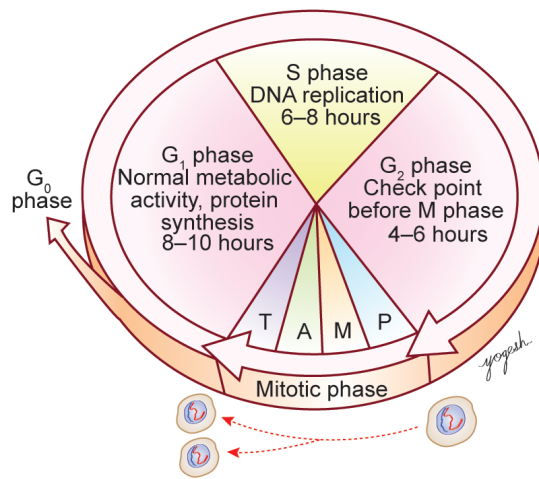


Fig. 3.10: Phases of cell division. Abbreviations: P: Prophase; M: Metaphase; A: Anaphase; T: Telophase

CELL DIVISION

- Cell division is a process of cell multiplication. It is of two types: Mitosis and meiosis.

Mitosis

- Mitosis is a cell division that maintains constant number of chromosomes in parent and offspring cells. Mitosis is always preceded by S phase where DNA duplicates.

Phases of Mitosis (Fig. 3.11)

- **Prophase:** Events – chromosomes condense and become visible; spindle fibres emerge from centrosomes, nuclear envelope breaks down, and centrosome moves toward the opposite pole.
- **Prometaphase:** Events – continued condensation of chromosomes, centromeres, and sister chromatids becomes visible, attachment of microtubules to the centromere.
- **Metaphase:** Events – chromosomes arranged at metaphase plate, attachment of each centromere to spindle fibers from the opposite pole.
- **Anaphase:** Events – centromeres split into two, chromatids are pulled toward the opposite poles.

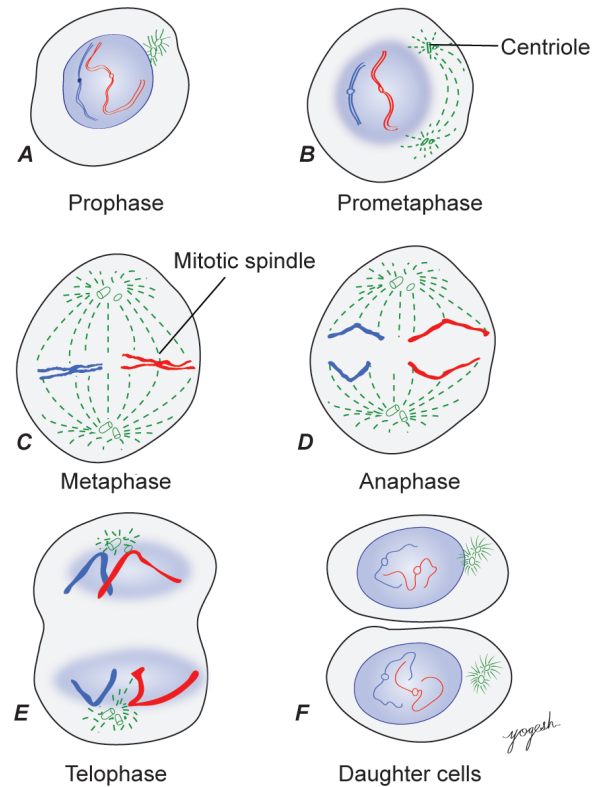


Fig. 3.11: Phases of mitosis

- **Telophase:** Events – chromosomes arrive at the opposite poles; mitotic spindle breaks, nuclear membrane starts forming.
- **Cytokinesis:** Event – cleavage furrow appears to separate daughter cells.
- At the end of one mitotic cycle, two cells are formed from a single cell.

Significance of Mitosis

- It helps in development and growth of an organism.
- It helps in replacing the damaged body cells.
- It contributes to replace old body cells.
- It produces two daughter cells that are genetically identical to the parent cells.

Meiosis

- Meiosis is the cell division that helps in the formation of gametes with haploid number of chromosomes.
- Meiosis consists of two cell divisions as first meiotic and second meiotic divisions.
- The first meiotic division has prophase I, metaphase I, anaphase I, and telophase I, whereas second meiotic division has prophase II, metaphase II, anaphase II, and telophase II.
- **Prophase I:** It is a prolonged phase and consists of the following phases (Fig. 3.12):
 1. **Leptotene:** Events – chromosome becomes visible and condensed; sister chromatids of each chromosome are closely placed.

2. *Zygotene*: Events – synapsis or conjugation (pairing of homologous chromosomes), paired chromosomes are called bivalent or tetrad chromosomes.
 3. *Pachytene*: Events – crossing over (there is an exchange of chromatin material in between approximated chromatids of homologous bivalent chromosomes). The point of contact of chromatids during crossing over is called chiasmata.
 4. *Diplotene*: Events – homologous chromosomes separate apart from each other.
- Diplotene phase is followed by metaphase I, anaphase I and telophase I. In anaphase I, there is no division of centromere.
 - Homologous chromosome moves toward the opposite poles. Hence, resultant daughter cells receive only haploid number of chromosomes.
 - The second meiotic division is equivalent of mitosis and just form two cells.
 - Thus, at the end of meiosis, four daughter cells with haploid number of chromosomes are produced.
 - Differences between mitosis and meiosis are listed in Table 3.2.

Significance of Meiosis

- Formation of gametes is the prime aim of meiosis.
- Meiosis helps to maintain constant chromosome number during sexual reproduction.
- Exchange of maternal and paternal genes that are carried by homologous chromosomes takes place.
- Meiosis (crossing over) helps to maintain genetic diversity and mixing of characters.

Differences between Mitosis and Meiosis

Q. Write the differences between mitosis and meiosis.

TABLE 3.2: Differences between mitosis and meiosis

Event	Mitosis	Meiosis
Occurrence	All cells of body	Only in germ cells
Process	It is an <i>equational</i> division	It is a <i>reductional</i> division
Prophase	No crossover of genetic material No synapsis	<i>Crossover</i> of genetic material takes place <i>Synapsis</i> occurs in zygotene phase
Metaphase	No chiasmata formation Chromosomes arrange at the equator	<i>Chiasmata</i> formation Homologous chromosome arranges on either side of equator
Anaphase	Centromere divides Chromatids move to the opposite pole	No division of centromere Whole chromosome moves to the opposite pole
Telophase	Daughter cells with the same number of chromosomes (46)	Daughter cells with a haploid number of chromosomes (23)
Number of daughter cells	Two	Four

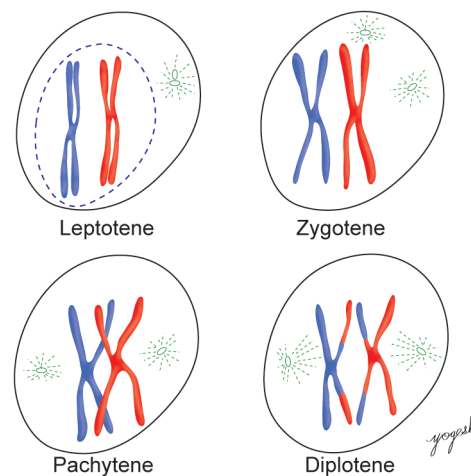
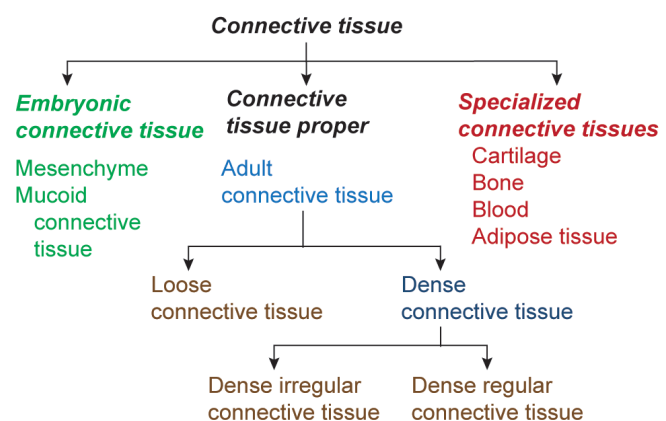


Fig. 3.12: Stages of prophase of first meiotic division

CONNECTIVE TISSUE

- The connective tissue is characterized by presence of *three components*: Cells, fibers, and extracellular matrix.
- Connective tissue gives definite shape to organ and body, supports other tissues, and performs various other functions.
- *Fibers of connective tissue*: The connective tissue has three different types of fibers in matrix:
 1. *Collagen fibers* are found almost in all connective tissues. It is the most abundant protein in the body.
 2. *Reticular fibers* are present in basement membrane, lymph nodes, and liver.
 3. *Elastic fibers* are present in blood vessels, lung, and ligamentum nuchae.
- Connective tissues are classified into three groups (Flowchart 3.1):
 1. *Embryonic connective tissue*: These are present predominantly during embryonic life. They are mesenchymal and mucoid connective tissue.
 2. *General connective tissue* or connective tissue proper: These are present in all organs of the body and are classified as follows:

Flowchart 3.1: Classification of connective tissue



- a. *Loose areolar tissue* consists of loosely woven connective tissue fibers and abundant adipocytes. It is present in the superficial fascia, lamina propria, surrounding blood vessels, nerves, viscera, muscles, parenchyma of glands, and in the mesentery.
 - b. *Dense irregular connective tissue* contains mostly irregular bundles of collagen fibers. Examples: Dermis of skin, dura mater, submucosa of intestinal tract, epineurium, pericardium, periosteum, tunica albuginea of testis, sclera, and capsules of various organs.
 - c. *Dense regular connective tissue* contains a compact parallel array of thick bundles (regularly) of collagen fibers. Examples: Tendon, ligament, stroma of cornea.
3. *Specialized connective tissue*: These are characterized by specialized nature of their extracellular matrix. It includes bone, cartilage, blood, adipose tissue, and lymphatic tissue.



Some Interesting Facts

- Goblet cells are the unicellular glands.
- Loose areolar tissue is the most widely distributed connective tissue in the body.
- The most abundant connective tissue fibers in the body are collagen fibers.

Skeleton



Competencies:

AN1.2 Describe composition of bone and bone marrow.

AN2.1 Describe parts, blood, and nerve supply of a long bone.

AN2.2 Enumerate laws of ossification.

AN2.3 Enumerate special features of sesamoid bone.

AN2.4 Describe various types of cartilage with its structures and distribution in body.

INTRODUCTION

- The skeleton of the human body consists of the bones and cartilages. These are made up of specialized connective tissue called *sclerous* or *skeletal tissue* (skeleton = dried in Greek).

Major Functions of Skeleton System

- Support:** Skeleton provides rigid support required for standing, weight-bearing, and locomotion.
- Protection:** Hard bones protect the inner viscera such as brain.
- Movement:** Skeleton provides attachment to various muscles that help in movements.
- Storage:** Bones store the minerals.
- Blood cell production:** Red bone marrow produces blood cells and platelets.

Types of Skeleton

- The components of skeleton are grouped into two types:
 - Axial skeleton
 - Appendicular skeleton
- Human body has

80 bones in axial skeleton	
+ 126 bones in appendicular skeleton	
Total	206 bones^{MCQ}

Axial Skeleton

- Axial skeleton is the central part of human skeleton that lies close to the central axis of the body.

- Axial skeleton includes (Fig. 4.1):

- Skull:** It is made up of cranial and facial bones. It protects brain, eyes, ear, nose, and oral cavity structures.
- Auditory (ear) ossicles:** These are three small bones in the middle ear: Incus, malleus, and stapes (the smallest bone).
- Hyoid bone:** It is located in the neck, just above the larynx and below the mandible (lower jawbone)
- Vertebral column or spine:** It consists of 33 vertebrae which include 7 cervical, 12 thoracic, 5 lumbar, sacrum (5 sacral vertebrae), and coccyx (4 coccygeal vertebrae).
- Rib cage:** It consists of 12 pairs of ribs, costal cartilages, and sternum. It protects heart and lungs.

Appendicular Skeleton

- The appendicular skeleton is the peripheral part of the human skeleton that consists of limbs and girdles that anchor the limbs with the axial skeleton. Appendicular skeleton has bilateral symmetry.
- Each half of appendicular skeleton consists of the following parts (Fig. 4.1):
 - Pectoral girdle:** It consists of scapula and clavicle or collar bone.
 - Bones of upper limbs:** They include 1 humerus, 1 radius, 1 ulna, 8 carpal bones, 5 metacarpals, and 14 phalanges.
 - Pelvic girdle:** It consists of two hip bones (right and left).
 - Bones of lower limbs:** They include 1 femur, 1 patella, 1 tibia, 1 fibula, 7 tarsals, 5 metatarsals, and 14 phalanges.

Some Interesting Facts

- The largest bone in the body is femur.
- The smallest bone in the body is stapes.
- Malleus is the smallest long bone in the body.
- Most slender long bone in the body is fibula.
- Hip bone is the largest flat bone in the body.
- Patella is the largest sesamoid bone.

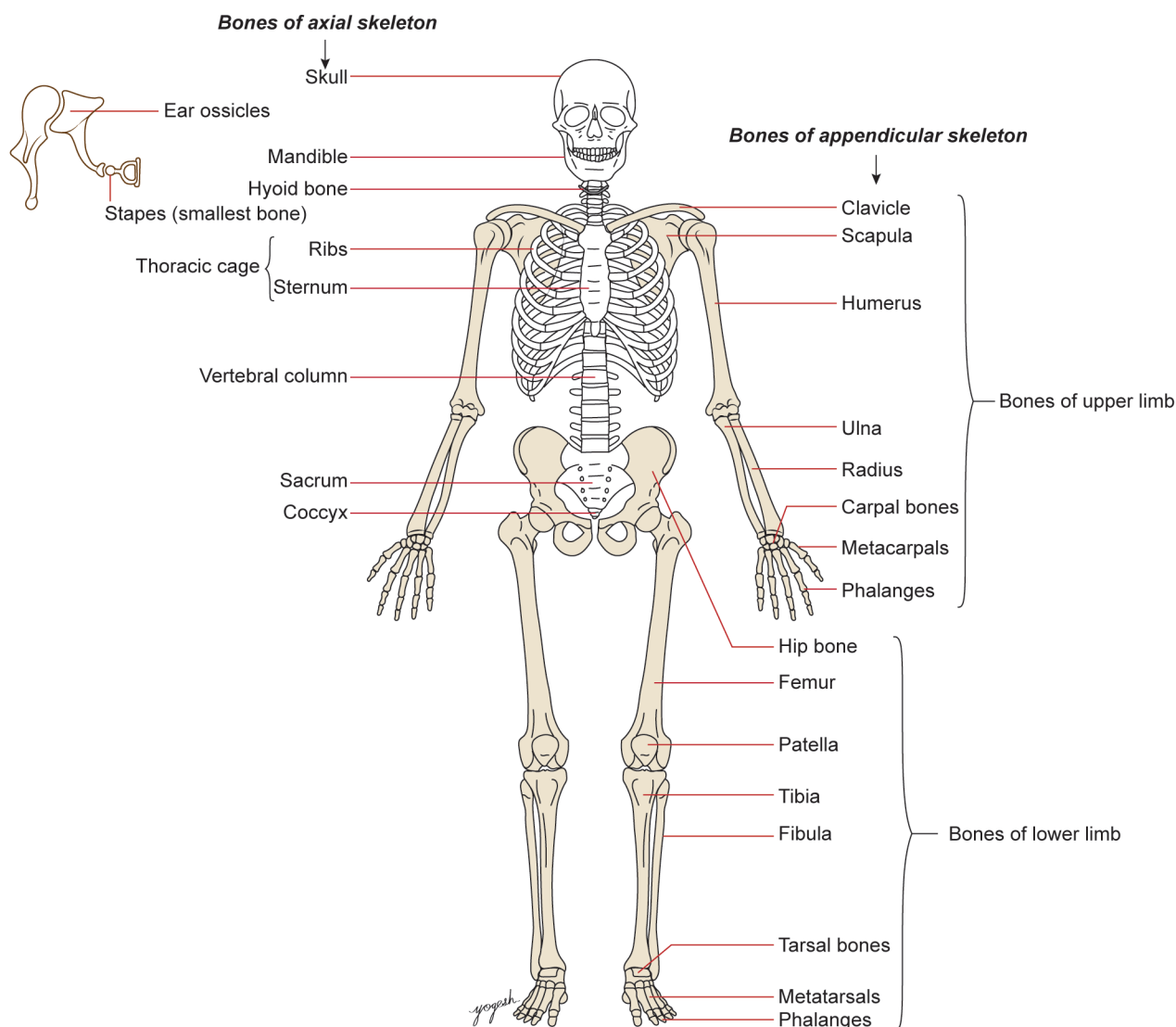


Fig. 4.1: Bone of axial and appendicular skeleton

BONES

- Bone is a specialized type of connective tissue that has extracellular matrix containing calcium salts. Bone consists of cells and mineralized matrix.
- Bone is a living and dynamic tissue that undergoes structural changes in response to physical stress and hormonal changes.

Functions of Bones

- The main functions of bones are as follows:
 1. **Support:** Bones provide rigid framework that maintains shape of the body and support
 2. **Protection:** Bones form a shield that protects vital organs such as brain, spinal cord, heart, lungs, eyes, and so on
 3. **Movement:** Bones act as levers that moves on muscle contraction
 4. **Hematopoiesis:** Bone marrow produces blood cells including RBCs, WBCs, and platelets
 5. **Storage:** Bones act as a storehouse of calcium, phosphorus, and other minerals. They store more

than 90% of body calcium. They release minerals into the bloodstream as per the body's need.

CLASSIFICATION OF BONES

The bones are classified in three ways:

1. Based on their shape
2. Based on the structure
3. Based on development.

Classification According to Shape

- According to the shape of the bone, they are classified into seven groups as follows (Fig. 4.2, Flowchart 4.1):

1. Long Bones

- In long bones, length exceeds the breadth and thickness.
- Long bones are further subdivided into typical and miniature long bones.
 - A. **Typical long bones:**
 - They have elongated shaft (diaphysis) and two expanded ends (epiphysis)
 - They ossify in the cartilage.

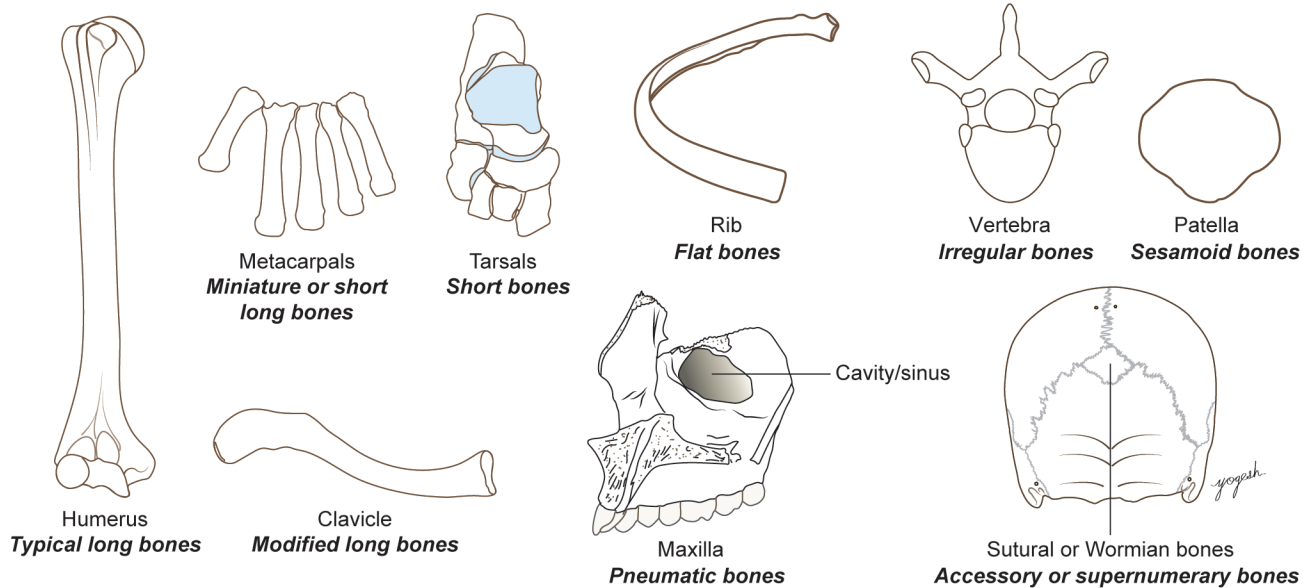
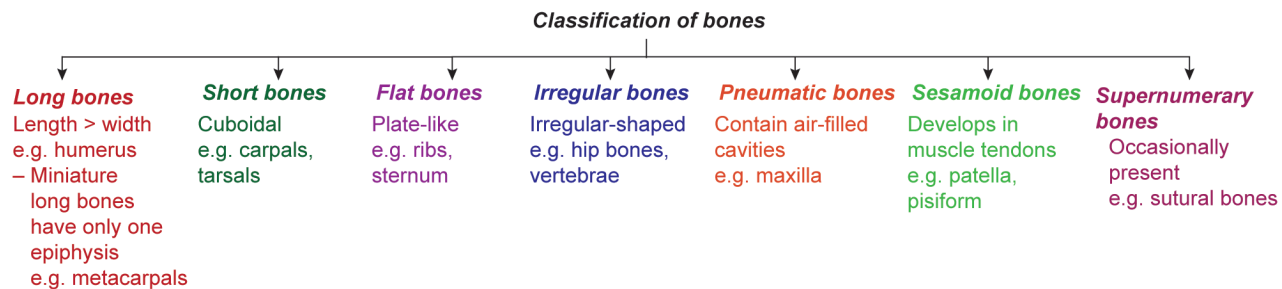


Fig. 4.2: Types of bones based on their shapes

Flowchart 4.1: Classification of bones



- They have a medullary cavity that contains bone marrow.
- They lie vertically in the body and are mostly found in the limbs.
- Examples: Humerus, radius, ulna, femur, tibia, and fibula

B. *Miniature or short long bones:*

- These are shorter than typical long bones.
- They have only one epiphysis. ^{MCQ}
- Examples: Metacarpals, metatarsals, phalanges.

2. Short Bones

- These are small and cuboidal in shape. They have 6 surfaces.
- Examples: Carpals (wrist bones) and tarsals (in foot).

3. Flat Bones

- These are plate-like, flat bones.
- They form boundaries of bony cavity to protect organs.
- For example: Bones of vault of skull, ribs, sternum, scapula.

4. Irregular Bones

- They have irregular shape.
- For examples: Bones forming base of skull, hip bones, vertebrae.

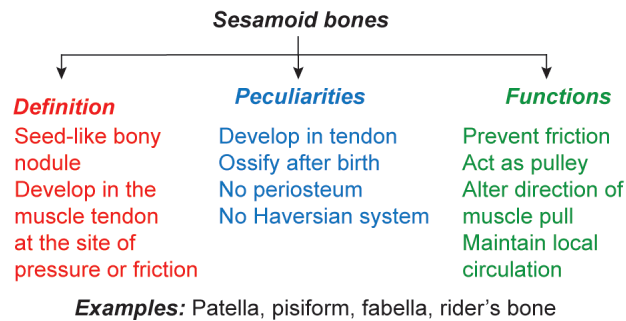
5. Pneumatic Bones

- These contain air-filled spaces or cavities.
- These are located around the nasal cavity.
- For example: Maxilla, frontal bone, sphenoid, and ethmoid bones. The air-filled cavities in these bones are called paranasal air sinuses.

6. Sesamoid Bones

Q. Write a short note on sesamoid bones.

- Definition: Sesamoid bones are seed-like bony nodules that develop in the muscle tendons at the site of pressure or friction of tendon with bone during movements (sesame = seed in Arab) (Flowchart 4.2).
- Peculiarities of sesamoid bones:
 1. They develop in tendons.
 2. They ossify after birth.
 3. They do not have periosteum.
 4. They do not have Haversian system.
- Functions of sesamoid bones
 1. Prevent friction of tendon and bone
 2. Act as pulley for muscle
 3. Alter the direction of muscle pull
 4. Maintain the local circulation
 5. Resist pressure
- Examples: Patella, pisiform, fabella, riders' bones (Table 4.1).

Flowchart 4.2: Sesamoid bones**TABLE 4.1:** Sites of sesamoid bones

Site	Name of sesamoid bone
Tendon of flexor carpi ulnaris	Pisiform
Tendon of quadriceps femoris	Patella
Lateral head of gastrocnemius	Fabella
Tendon of adductor longus (in professional riders)	Riders' bone
Tendon of adductor pollicis (on the ulnar side of the head of 1st metacarpal bone)	One sesamoid bone
Tendon of flexor pollicis longus (on radial side of head of 1st metacarpal bone)	Occasionally present
Tendon of flexor hallucis brevis (below the head of 1st metatarsal bone)	Two sesamoid bones
Tendon of peroneus longus (near its attachment with cuboid bone)	One sesamoid bone

7. Accessory or Supernumerary Bones

- These bones are not always present.
- **Examples:** Sutural or Wormian bones, os trigonum, os vesalianum, patella cubiti.

Some Interesting Facts

- Clavicle is considered as modified long bones because:
 1. It does not have medullary cavity,
 2. It is the only long bone that lies horizontally in the body, and
 3. It partly ossifies in membrane and partly in cartilage ^{Viva}
- All the metacarpals and metatarsals have epiphysis at their distal end except first metacarpal and first metatarsal which have epiphysis at their proximal ends. ^{MCQ}
- All short bones ossify in cartilage after birth, except the talus, calcaneum, and cuboid bones, which start ossification before birth.
- Flat bones consist of two plates of compact bones and intervening spongy bone and marrow cavity. In adult life, most of the flat bones and ends of long bones perform hematopoietic function.
- Pneumatic bones make the skull lighter and help in resonance of sound vibration.

- Paranasal air sinuses maintain humidity and temperature of inspired air and thus act as air-conditioning chambers. These air sinuses get infected in common cold.
- Patella is the largest sesamoid bone.
- Sesamoid bones are not true bones as they are not covered by periosteum. ^{Viva}
- All the bones of the body are covered by periosteum except sesamoid bones and ear ossicles. ^{MCQ}
- Accessory bones may be formed by appearance of extra ossification center in skull suture, and it forms sutural or Wormian bones.
- Accessory bones may also be formed by nonfusion of an epiphysis. For example: Failure of fusion of the posterior tubercle of talus with the rest of the bone → os trigonum.
- Failure of fusion of styloid process of 5th metatarsal with rest of the bone → os vesalianum.
- Failure of fusion of olecranon process of ulna with upper end of the ulna → patella cubiti.
- Accessory bones may be mistaken for fractures. ^{Clinical fact}
- Most of these bones are bilateral and they have smooth surfaces.
- Riders' bone is considered *heterotopic bone* as it develops in the tendon of adductor longus muscle in riders.
- Dentine and cement of teeth are also bones.
- Metaphysis is the growing end and most vascular part of the long bones. ^{MCQ}
- All the bones are made up of both compact and spongy bones, except inferior nasal concha.
- The commonest site of bone marrow aspiration is manubrium sterni in adults and iliac crest in children.

Developmental Classification

- According to the process of bone formation or ossification of bones are classified as:
 1. **Membranous or dermal bones:** They ossify in the membranes. For example, bones of vault of skull (frontal parietal), facial bones (maxilla).
 2. **Cartilaginous bones:** They ossify in the cartilage by endochondral ossification. For examples: Long bones of limbs (humerus, radius, ulna, femur, tibia, fibula), vertebrae, thoracic cage.
 3. **Membrano-cartilaginous bones:** They partly ossify in membrane and partly in cartilage. For example, clavicle, mandible, temporal, occipital, sphenoid bones.

Some Interesting Facts

- Developmentally, most of the bones are *somatic bones*. The bones derived from the pharyngeal arches are called *visceral bones*. For examples: Ear ossicles, styloid bone, hyoid bone, part of mandible.
- Clavicle is the first bone in the body to ossify.

Structural Classification

- In structural classification, the bones are classified based on the method of examination as follows:

A. Macroscopic classification (naked-eye examination) (Fig. 4.3, Table 4.2):

- Compact bones* do not have visible cavities.
- Cancellous bones* (spongy or trabecular bones) have visible cavities.

B. Microscopic classification (examination under microscope):

- Lamellar bone* consists of thin plates of bony tissue called lamellae. In compact bones, lamellae are arranged as Haversian system. In spongy bones, there are branching and anastomosing curved plates.
- Woven bones* consist of randomly arranged collagen fibers, and bone crystals. It resembles wrap and weft of woven fabric, hence called woven bones. For examples, young fetal bones, callus at fracture repair site.

TABLE 4.2: Differences between compact and spongy bones

Feature	Compact bone	Spongy bone
Visible cavities (on naked eye examination)	Absent	Present
Structure	Dense and solid	Composed of trabeculae or bony spicules
Haversian system	Present	Absent
Lamellae	Regularly arranged	Irregular
Bone marrow	Absent	Present
Strength	Strong and rigid	More flexible, shock absorbent
Locations	Diaphysis of long bones, outer and inner tables of skull	Flat bones, short bones, inner core of epiphysis of long bones, irregular bones

Some Interesting Facts

- Wolff's law:** The Wolff's law or trajectory theory of Wolff suggests that osteogenesis is directly proportional to stress and strain.
- Tensile force helps on bone formation, whereas compressive force induces bone resorption (removal). Thus, tensile and compressive forces cause bone remodelling.
- The cancellous bones show two types of lamellae (Fig. 4.4):
 - Pressure lamellae* which are arranged parallel to the line of weight transmission.
 - Tension lamellae* which are arranged at right angles to the pressure lamellae.
- Calcar femorale* is a vertical plate of dense cancellous bone that lies deep to the lesser trochanter of femur. It resists shearing forces between the neck and shaft of femur.

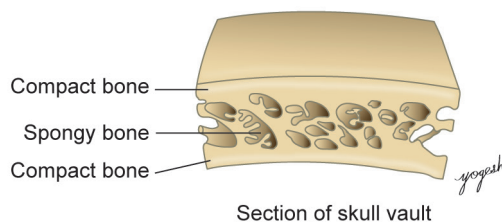


Fig. 4.3: Compact and spongy bones

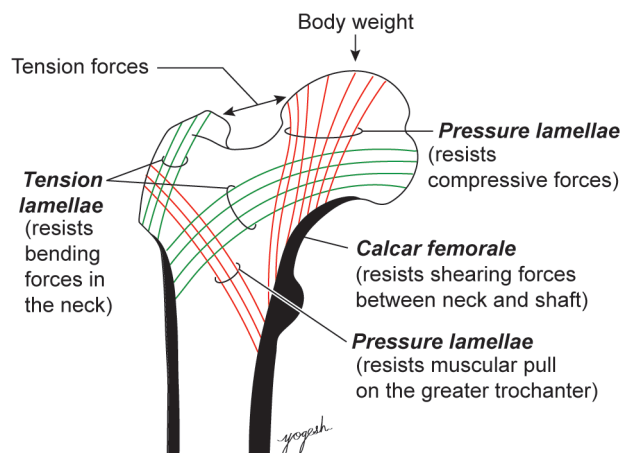


Fig. 4.4: Pressure and tension lamellae and calcar femorale (coronal section of the upper end of femur)

PARTS OF YOUNG LONG BONE

- Long bone develops in a preformed model of hyaline cartilage.
- Ossification* is the formation of bone.
- Center of ossification* is the area of the bone formation or ossification. It is of two types: Primary and secondary.
- Primary center of ossification* is the center that forms main part or shaft of the long bones. Primary centers appear before birth except for primary centers for carpals and tarsals (except talus, calcaneus, and cuboid) that appears after birth.
- Secondary center of ossification* is the center that forms the accessory part of the bones. It appears after birth except for the lower end of femur and sometimes for the upper end of tibia.
- Young long bone consists of 4 parts (Fig. 4.5):
 - Epiphysis
 - Epiphyseal or growth plate
 - Metaphysis
 - Diaphysis.

Epiphysis

- Epiphysis* is the part of long bone which ossify from secondary centers of ossification.

Types of epiphyses (Fig. 4.6, Flowchart 4.3):

- There are four types of epiphyses:
 - Pressure epiphysis:* It transmits the weight of the body. It is protected by the articular cartilage. For example: Heads of femur and humerus, condyles of tibia, lower end of radius.

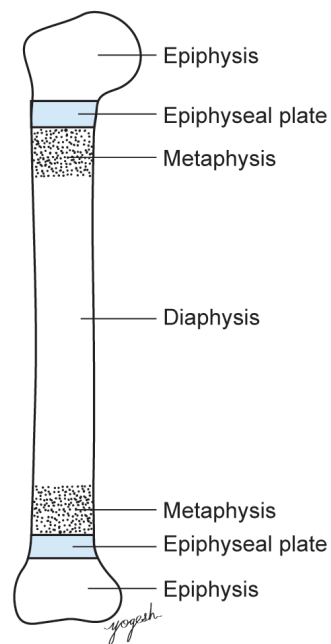


Fig. 4.5: Parts of young or growing long bone

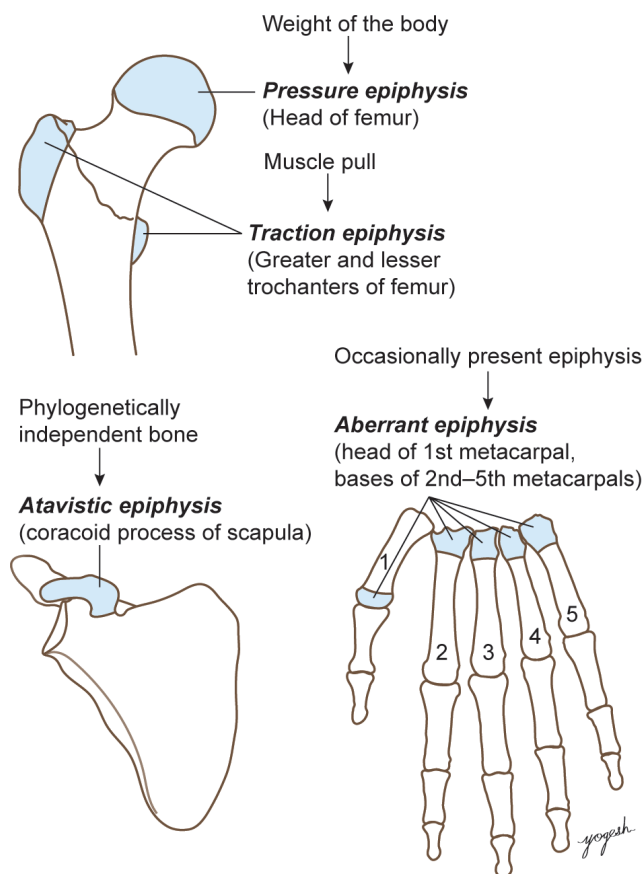
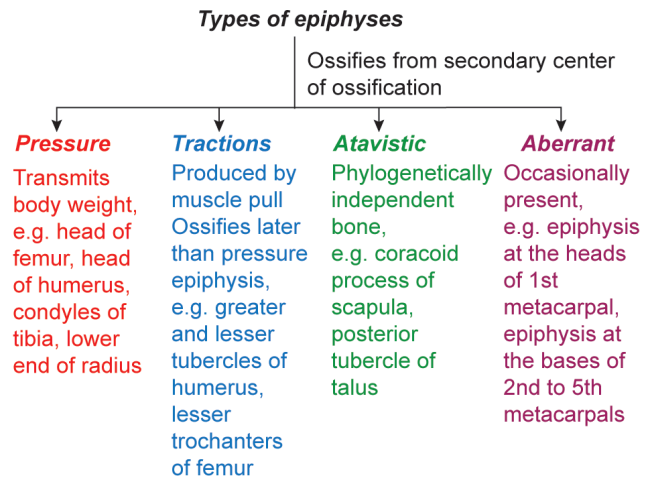


Fig. 4.6: Types of epiphyses. A: Pressure and traction epiphyses, B: Atavistic epiphysis, D: Aberrant epiphysis

2. **Traction epiphysis:** It is produced by the pull of the muscle. It ossifies later than the pressure epiphysis of the same bone. It is nonarticular.
For example, greater and lesser tubercles of humerus, greater, lesser trochanters of femur.

Flowchart 4.3: Types of epiphyses



3. **Atavistic epiphysis:** Phylogenetically, it is an independent bone, but in human being it is attached to another bone. Atavistic epiphysis gets nutrition from the bone with which it is fused.
For example, coracoid process of scapula, posterior tubercle of talus (also called os trigonum).
4. **Aberrant epiphysis:** It is occasionally present at unusual end of a shoot bone.
For example: Epiphysis at the head of 1st metacarpal, epiphysis at the bases of 2nd to 5th metacarpals.

Epiphyseal or Growth Plate

- It is a plate of hyaline cartilage which connects epiphysis with diaphysis in a growing bone.
- The proliferation of cells and growth of epiphyseal plate is responsible for increasing length of the long bone.
- At puberty, after completion of the growth of long bones, the epiphyseal cartilage is replaced by bone.
- The epiphyseal plate receives nutrition from both epiphyseal and metaphyseal arteries.

Metaphysis

- The epiphyseal ends of diaphysis are called metaphysis. Metaphysis is the most actively growing area of the long bone.
- Metaphysis receives profuse blood supply from nutrient, periosteal, and metaphyseal arteries. The nutrient and metaphyseal arteries form hairpin bends in growing bones. Therefore, microorganisms from blood may settle in these loops and cause osteomyelitis in children.
- After epiphysis fusion, communication is established between epiphyseal and metaphyseal arteries, and there are no hairpin bends. Hence, osteomyelitis is rare in this region in adult.

Diaphysis

- It is central elongated shaft of the long bone that ossifies from a primary center of ossification.



Some Interesting Facts

- The fusion of epiphysis and diaphysis in females occurs 2 to 3 years earlier, hence they are shorter than males.
- *Compound epiphysis* may have more than one secondary center of ossification. In such cases, all centers fuse to form a single epiphysis and finally fuse with diaphysis.
- Typical long bones have two epiphyses, one at each end. According to the law of ossification, the epiphysis or secondary center of ossification which appears first, unites last. The exception to this rule is lower end of fibula. ^{MCQ}
- The end of the long bone, which has epiphysis that fuses later is called growing end of the bone. ^{Viva}

BLOOD SUPPLY OF BONES

Q. Write a short note on blood supply of long bones.

Blood Supply of Long Bone

The typical long bone is supplied by four sets of arteries (Fig. 4.7, Flowchart 4.4):

1. Nutrient artery
2. Periosteal arteries
3. Metaphyseal or juxta-epiphyseal arteries
4. Epiphyseal arteries.

1. **Nutrient artery:** It enters the middle of the shaft of long bone through a nutrient foramen. It runs obliquely through the cortex. Then it divides into two branches – ascending and descending, in the medullary cavity. Each of these divides into number of small parallel branches, which enter the metaphysis and form hairpin loops. In metaphysis, these loops anastomose with epiphyseal, metaphyseal, and periosteal arteries. Therefore, metaphysis is the most vascular area of long bone. Area supplied: Nutrient artery supplies medullary cavity, inner 2/3rd of cortex and metaphysis.
2. **Periosteal arteries:** These are numerous small arteries. Ramify beneath the periosteum and enter the Volkmann's canal to supply the outer 1/3rd of cortex. These are more numerous at the muscular and ligamentous attachments.
3. **Metaphyseal or juxta-epiphyseal arteries:** They enter the metaphysis and reinforce the branches of epiphyseal and nutrient arteries. They are derived from the neighboring arteries.

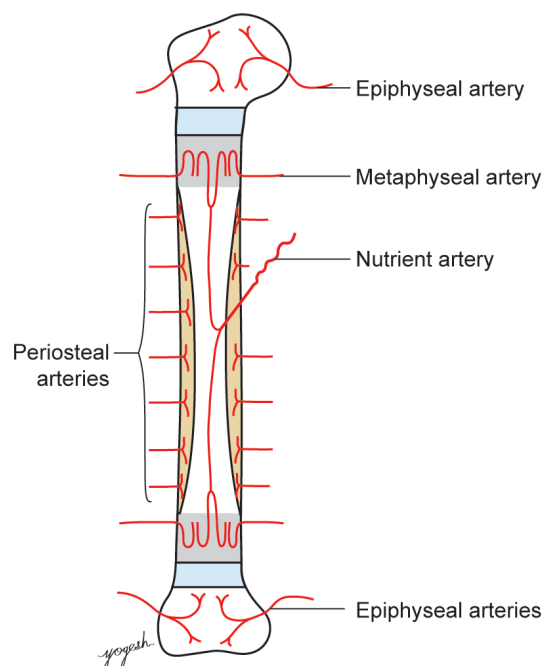


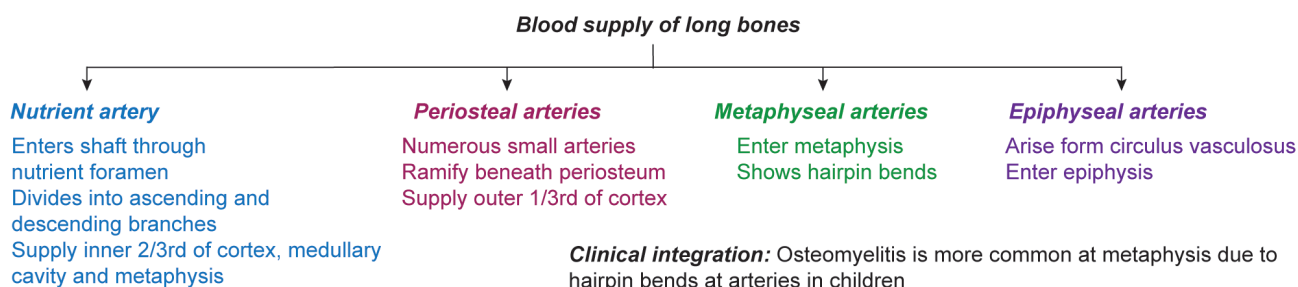
Fig. 4.7: Blood supply of typical long bone

4. **Epiphyseal arteries:** They arise from the arterial arcade called *circulus vasculosus* (anastomosis around the joint). They enter the epiphysis through numerous small foramina.

Blood Supply of Other Bones

- **Blood supply of short long bones:** The blood supply to the short or miniature long bones is similar to the blood supply of typical long bones except that:
 1. Its nutrient artery enters the middle of the shaft and forms a plexus.
 2. In adults, the periosteal arteries supply most of the bone and replace nutrient artery.
- The blood supply to the short or miniature long bones is similar to the blood supply of typical long bones except that:
 1. Its nutrient artery enters the middle of the shaft and forms a plexus.
 2. In adults, the periosteal artery supply most of the bone and replaces nutrient artery.
- Short bones are supplied by numerous periosteal vessels.

Flowchart 4.4: Blood supply of long bone



- Rib is supplied by:
 1. Nutrient artery which enters the rib just behind the tubercle.
 2. Periosteal arteries.
- Vertebra is supplied by three sets of arteries:
 1. One or two arteries that enter the body of vertebra through *basivertebral foramen*.
 2. Small vessels that pierce the anterolateral surface of the body.
 3. Small vessels that pierce the bases of transverse processes.

Some Interesting Facts

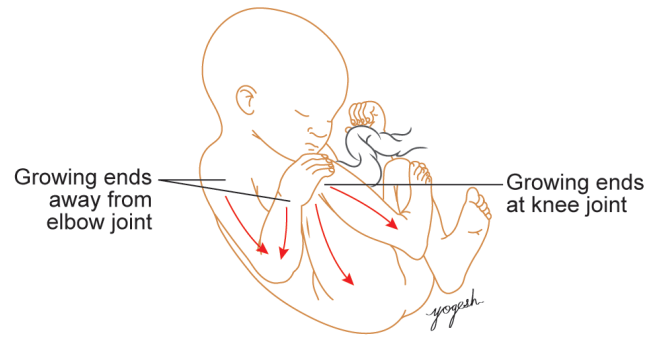
- The largest nutrient artery is the nutrient artery of tibia.
- The nutrient foramen is directed away from the growing end of the long bone.
- The growing ends of the long bones are as follows (*Mnemonic: Towards elbow I go, from the knee I flee*) (Fig. 4.8):
 - Humerus — upper end
 - Radius, ulna — lower end
 - Femur — lower end
 - Tibia — upper end
- Why do the movements not affect the nutrient artery?
Explanation: Before entering the nutrient foramen, the nutrient artery is tortuous. Hence, the movements do not affect the nutrient artery.
- Longest nutrient artery — the nutrient artery of tibia
- **Venous drainage of bones:** There are numerous veins in cancellous bones, such as vertebrae. In compact bone, they accompany arteries in Volkmann's canals.
- **Lymphatic drainage of bones:** There are no lymphatics in a bone except some accompanying lymphatic vessels of periosteal vessels. They drain to the regional lymph nodes.
- **Nerve supply of bones:** Bones are supplied by a plexus of nerve fibers. Periosteum is pain sensitive and innervated by sensory nerves. Autonomic nerves (sympathetic and parasympathetic) supply the vessels of bone.

Clinical Integration

- **Osteomyelitis:** Osteomyelitis is an infection of bone caused by bacteria. In typical young bones, due to hairpin bends of arteries in the metaphysis, circulating bacteria get trapped and this results in osteomyelitis. In adult long bones, there are no hairpin bends in metaphyseal arteries. Hence, osteomyelitis is more common in children than adults.

STRUCTURE OF BONE

- On cross-section, long bone shows diaphysis, epiphyses, and coverings (endosteum and periosteum) (Fig. 4.9).
- **Diaphysis/Shaft:** It is a tubular sheath covering a central cavity called *marrow cavity*. The tubular sheath does



Mnemonic: Towards elbow I go, from the knee I flee

Fig. 4.8: Direction of nutrient foramina in upper and lower limbs (red arrows)

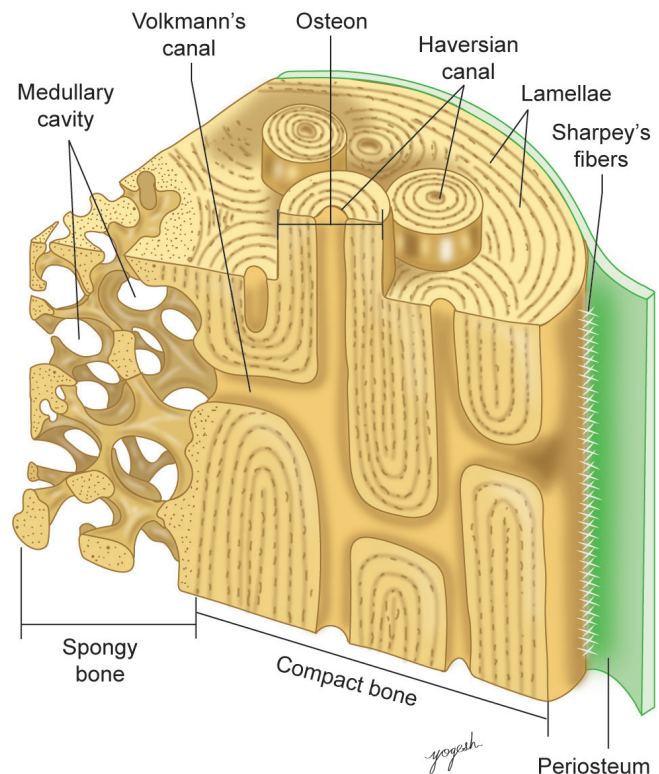


Fig. 4.9: Structure of compact bone

not have visible spaces. This type of bone is called *compact bone*.

- **Epiphyses:** Ends of long bone show a thin layer of compact bone covering a meshwork of bony plates. Meshwork of bony plates shows numerous spaces and looks similar to sponge. Hence, this kind of bone is called *spongy* or *trabecular* or *cancellous bone*. Ends of long bone-forming articular surfaces are covered by articular (hyaline) cartilage.
- **Periosteum:** Periosteum is a layer of connective tissue that covers external surface of bone except at two places: At muscle attachment, and at area covered by articular cartilage. The periosteum has two layers: Outer fibrous and inner cellular (osteogenic) layers.
Functions of periosteum:
 1. Protects integrity and shape of the bone
 2. Serves as anchor point for ligaments, tendons, and muscles.

3. Blood supply to the outer part through periosteal vessels.
4. Help in bone regeneration.
- *Endosteum* is a membranous layer that covers inner surface of bone, facing the marrow cavity, and space of spongy bone.
- Nutrient foramen is present in the middle of the shaft and provides passage to the nutrient artery.
- Bone consists of two basic components: Cells and bone matrix.

Bone Marrow

- Cavities of the bone are called *bone marrow*. Bone marrows are of the following two types:
 1. *Red bone marrow*: It performs hematopoietic functions. Entire bone marrow in fetus and young adult is red bone marrow. In the adults, red bone marrow is present only at ends of long bones, ribs, vertebrae, skull bone, sternum, and hip bone. Clinical fact
 2. *Yellow bone marrow*: With advancing age (in adult), red bone marrow from shafts of long bones get replaced with adipose (fat) tissue (yellow in color). Such a bone marrow is called yellow bone marrow.

Clinical Integration

- *Bone marrow aspiration*

Definition: Bone marrow aspiration is the procedure to withdraw a small sample of bone marrow using a needle.

Bone marrow may be performed for diagnostic or therapeutic purposes, such as investigation of blood disorders or collection of stem cells for transplantation. Common sites of bone marrow aspiration:

In adults: Manubrium of sternum, spinous process of lumbar vertebrae (other sites: Ribs, upper end of tibia). In children: Iliac crests of hip bones.

Cells of Bone Tissue

- Bone tissue consists of five types of cells:
 1. Osteoprogenitor cells: These are stem cells arising from mesenchymal tissue. They give rise to osteoblasts that form bone.
 2. Osteoblasts: They are bone-forming cells derived from osteoprogenitor cells. They synthesize collagen fibers and bone matrix proteins and secrete alkaline phosphatase.
 3. Osteocytes: Osteocytes are the mature bone cells that are trapped in the spaces in the matrix (lacunae). Conversion of osteoblasts to osteocytes takes three days. The life span of osteocytes is about 10–20 years. They maintain integrity of bones and help in remodeling of bone.
 4. Osteoclasts: They are large, multinucleated cells that remove bone. Osteoclast produces acid

phosphatase (tartrate-resistant). This is a useful clinical marker for osteoclast activity.

5. Bone-lining cells cover the surfaces of bone at sites where active bone formation or reabsorption is not taking place.

Bone Matrix

- Bone matrix consists of fibers, ground substance, and minerals.
- Fibers (90%) and ground substance (10%) form organic components of bone matrix, whereas minerals form inorganic components. Collagen fibers provide tensile *strength/resilience* to bone.
- Principal component of bone matrix is crystals of calcium phosphates (85% of total salts in bone). It also contains calcium carbonate, calcium fluoride, magnesium, sodium, and so on. These minerals form *needle-shaped crystals* called *hydroxyapatite*.

Structure of Compact Bones

- Compact bone does not show visible cavities on gross examination.
- *Examples:* Diaphysis of long bones, outer thin covering of epiphysis of long bones, outer and inner tables of flat bones (middle spongy bone form diploe), outer thin layer of all other bones.
- In a living state, compact bone on its outer surface is covered by *periosteum*, whereas inner surface by endosteum.
- In compact bone, lamellae are arranged in three different patterns as follows:
 - Haversian system of lamellae (concentric lamellae)
 - Interstitial lamellae
 - Circumferential lamellae (outer and inner)
- *Haversian system of lamellae* (Fig. 4.10):
 - *Osteon* is the structural and functional unit of compact bone (Fig. 4.11). Each osteon has a central *Haversian canal* and surrounding 4–5 *concentric lamellae*.
 - *Haversian (osteonal) canals* run parallel to the long axis of bone. In a living state, each Haversian canal contains loose connective tissue, capillaries, nerves, and lymphatics.
 - Between adjacent lamellae, small space called *lacunae* is present. Lacunae contain osteocytes (Fig. 4.10). Each lacuna is surrounded by radiating *canaliculi* that connect adjacent lacunae. Canaliculi contain cell processes of osteocytes. With the help of canaliculi, nutrients from capillaries of Haversian canal reach osteocytes that lie away from the canal.
 - Adjacent Haversian canals are connected with each other with the help of perpendicular *Volkman's canal*. They provide passage to periosteal vessels and nerve to Haversian canals.
 - Each osteon is surrounded by distinct refractile layer of mineralized bone matrix called cement line.

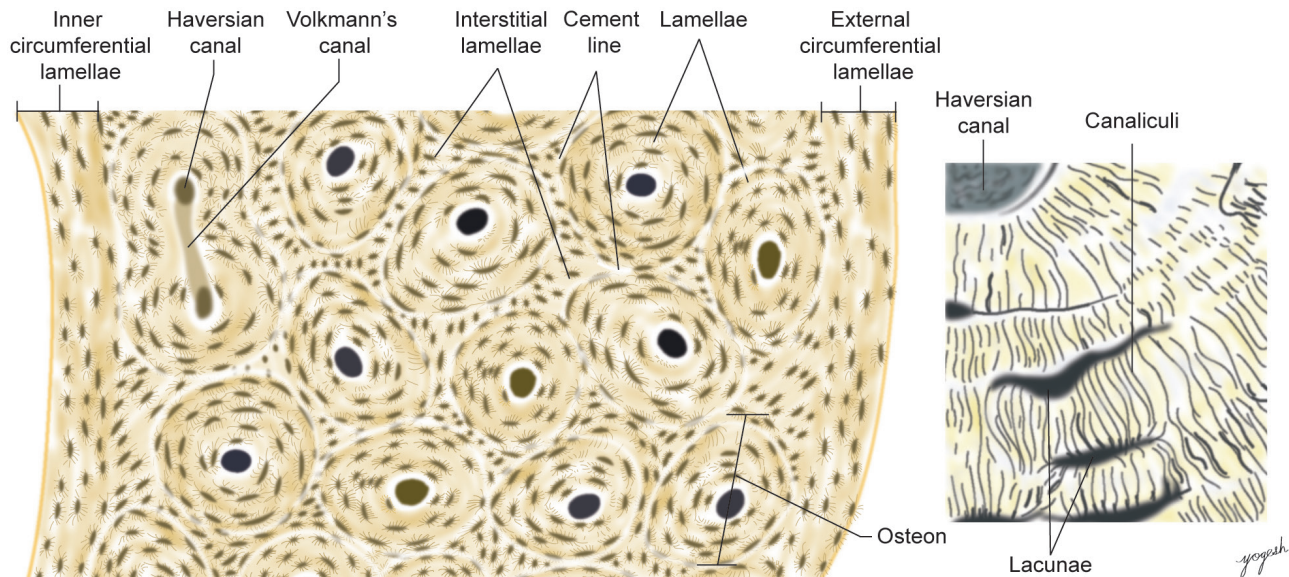


Fig. 4.10: Transverse section of compact bone/ground bone (low magnification on left, high magnification on right)

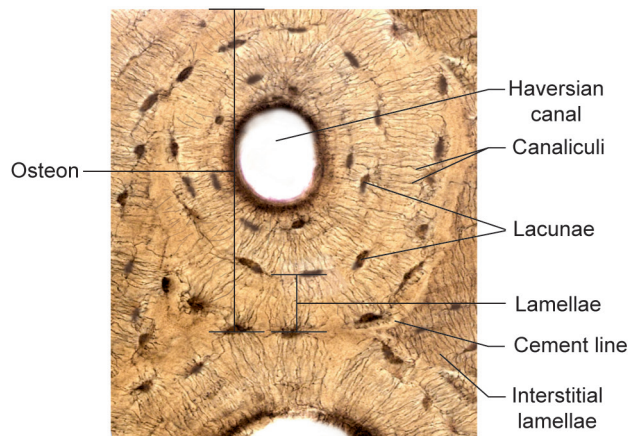


Fig. 4.11: Photomicrograph. Structure of osteon

- **Circumferential lamellae**
 - Surface of bone shows larger circumferential lamellae that encircle entire surface of bone.
 - There are *two types* of circumferential lamellae
 - *Outer circumferential lamellae* lie just beneath periosteum on outer surface of bone, whereas *inner circumferential lamellae* lie deep into endosteum and encircle marrow cavity.
- **Interstitial lamellae**
 - These are the fragments of the older osteons that lie between the adjacent and newly formed osteons.

Structure of Spongy Bone

- It is also called *cancellous bone* or *trabecular bone*.
- *Examples:* Inner core of epiphysis of long bones, short bones, flat, and irregular bones.
- All spongy bones have a thin covering of compact bone. They show sponge-like appearance having numerous cavities between irregular plates of bones. These bony spicules, plates, or rods are called trabeculae. They are oriented along the pressure lines.

- Trabeculae do not have Haversian system as thin trabeculae receive blood supply from marrow cavity. In trabeculae, osteocytes lie in cavities called lacunae.
- Trabeculae are covered by endosteum, osteoblasts, osteoclasts, and osteoprogenitor cells.

Some Interesting Facts

- Parathyroid hormone increases osteoclast activity and bone resorption that increases blood calcium level. Calcitonin hormone (secreted by parafollicular cells of thyroid gland) decreases osteoclast activity and decreases blood calcium level. Vitamin D helps in absorption of calcium from intestine.
- *Sharpey's fibers* (bone fibers or perforating fibers): At the site of attachment of ligaments and tendons, collagen fibers of periosteum are arranged obliquely and are continuous with extracellular matrix of bone. Such perforating fibers in the periosteum are Sharpey's fibers. The Sharpey's fibers of periodontal ligament help to attach cementum with periosteum of alveolar bone.
- Cavities of bone include Haversian canals, Volkmann's canals, bone marrow, and canals for nutrient vessels.

FORMATION AND GROWTH OF BONE

- The process of formation of bone is called *ossification*.
- Ossification may be
 1. *Intramembranous ossification* involves direct conversion of mesenchymal tissue to bone.
 2. *Endochondral (cartilaginous) ossification* involves conversion of mesenchyme to cartilage that later gets replaced by bone.

Intramembranous Ossification

- In intramembranous ossification, mesenchymal tissue forms bone. Bones formed by membranous

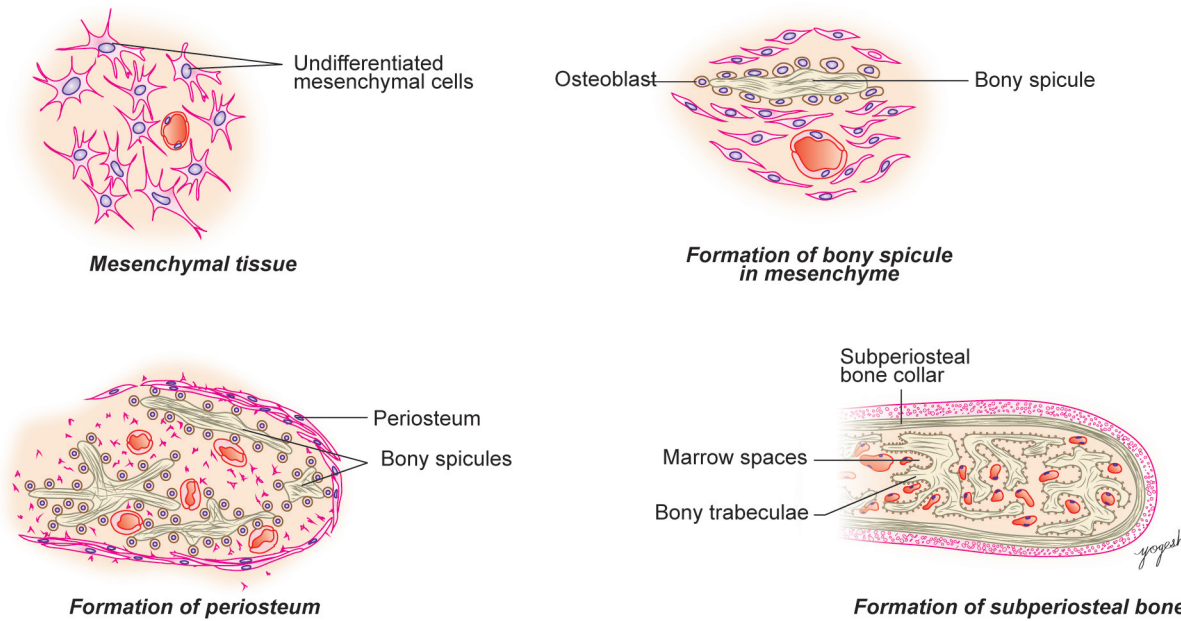
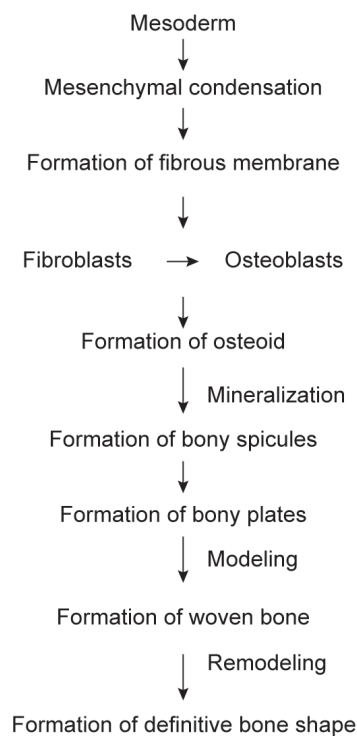


Fig. 4.12: Intramembranous ossification (Source: *Textbook of Human Embryology*, Yogesh Sontakke, 2nd edn., CBS Publishers).

Flowchart 4.5: Intramembranous ossification (Source: *Textbook of Human Embryology*, Yogesh Sontakke, 2nd edn., CBS Publishers)



ossification are called *membranous bones*. Examples: Bones of skull vault, mandible, clavicle (partly) (Fig. 4.12, Flowchart 4.5).

Stages of Intramembranous Ossification (Fig. 4.12)

- Star-shaped mesenchymal cells condense and differentiate into spindle-shaped fibroblasts that form a fibrous membrane. Fibroblasts differentiate to osteoblasts that lay down collagenous early bone matrix and form *uncalcified bone (osteoid)*.

- Osteoblasts deposit calcium salts in intercellular matrix and thus convert osteoid into calcified bony spicules. Trapped osteoblasts in the matrix get differentiated into osteocytes. Bony spicules fuse with each other to form plates of compact bone. Arrangement of collagen bundles running in different directions produces woven bone appearance.
- Waves of calcification and trapping of osteocyte processes in bony canaliculi form Haversian system. Fusion of progressively growing bone gives a primitive shape to the bone model. Continuous deposition and resorption of bone give definitive shape to the bone.

Endochondral Ossification (Fig. 4.13)

- Endochondral/cartilaginous ossification involves conversion of mesenchymal tissue into cartilage that later gets replaced by bone. Bones developed by cartilaginous ossification are called *cartilaginous bones*. Examples: All long bones (except clavicle), base of skull, vertebrae, ribs.

Stages of Endochondral Ossification

- Formation of cartilaginous model: At the site of mesenchymal condensation, chondroblasts appear and deposit hyaline cartilage.
- At the site of bone formation, cells of cartilage increase in size (hypertrophy) and hypertrophied cartilaginous cells deposit calcium. Soon, chondrocytes lose nutritional source and die because of calcified matrix to leave behind *primary areolae*.
- Perichondral vessels and osteogenic cells invade calcified matrix to form periosteal bud.
- Periosteal bud removes calcified matrix from the wall of primary areola and forms large cavities called *secondary areolae*. Osteogenic cells (osteoblasts) form a

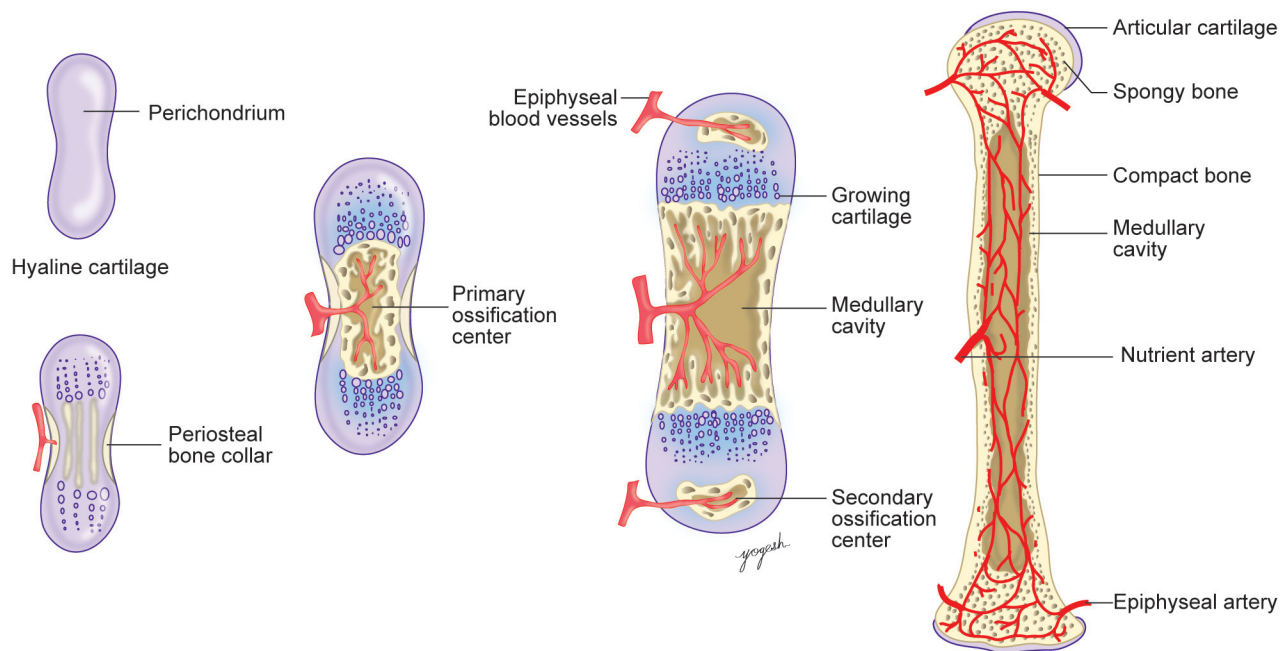


Fig. 4.13: Endochondral ossification (development of long bone) (Source: *Textbook of Human Embryology*, Yogesh Sontakke, 2nd edn., CBS Publishers)

gelatinous matrix along wall of secondary areolae to form a mass called **osteoid**.

5. Intercellular gelatinous matrix of osteoid gets calcified to develop a lamella of bone. Osteoblasts lay another lamella over the first one and so on. Osteoblasts trapped in lamellae form osteocytes. The multi-lamellar portion is called **trabecular bone**.

Growth of Long Bone

- The growth of the long bone after birth occurs by two methods: Appositional and endochondral growth.

Appositional Growth

- It involves the growth of the bone at the periphery to increase its diameter or thickness.
- In this growth, the periosteal collar increases in thickness by deposition of more layers on outer surface of bone. Simultaneously, osteoblasts remove lamellae from inner surface of bone leaving behind a marrow cavity.

Endochondral Growth

- It increases the length of the bone.

Stages of endochondral growth of long bone

- Length of bone increases by lengthening of *epiphyseal cartilage* and its simultaneous conversion into new bone.
- Zones of epiphyseal cartilage: Epiphyseal cartilage is the site of long bone growth (lengthening). It begins at about 12th week of gestation and continues till early adulthood. At the site of bone formation, epiphyseal cartilage shows the following zones (Fig. 4.14, Flowchart 4.6):

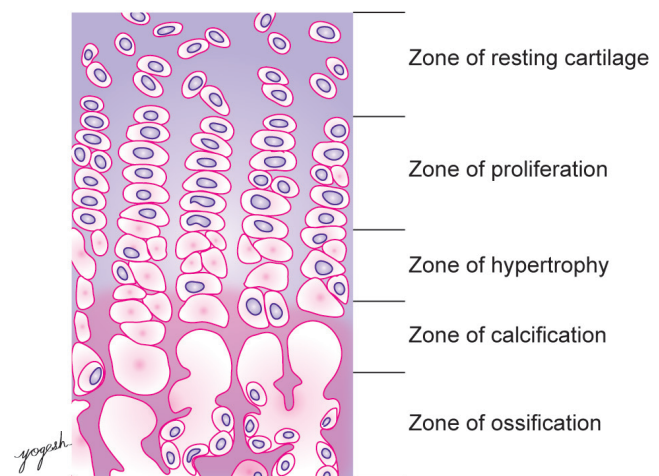
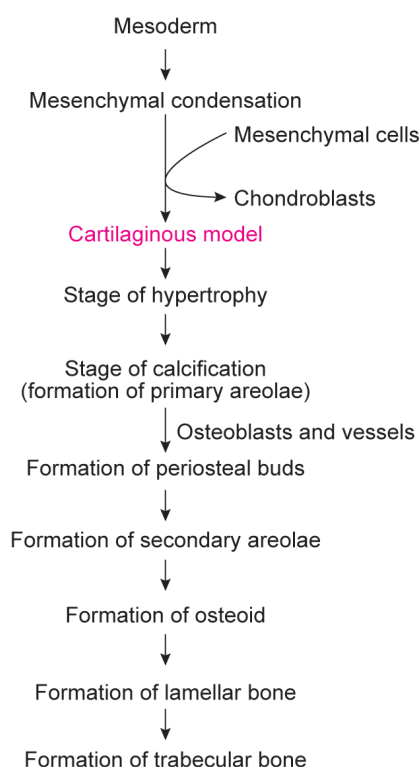


Fig. 4.14: Epiphyseal cartilage of a developing bone (Source: *Textbook of Human Embryology*, Yogesh Sontakke, 2nd edn., CBS Publishers)

1. **Zone of reserve cartilage:** This is resting cartilage portion. It shows small chondrocytes that lie singly in the lacunae.
2. **Zone of proliferation:** Cells of this zone undergo cell division. Chondrocytes of this zone are larger and more in number than that of zone of reserve cartilage.
3. **Zone of hypertrophy:** Cells of this zone are bigger in size (hypertrophic). They have clear cytoplasm. These cells get arranged in columns.
4. **Zone of calcified cartilage:** In this zone, calcium gets deposited in cartilage matrix. It results in apoptosis and loss of cartilage cells. Calcified cartilage zone forms temporary supporting framework for deposition of a new bone.

Flowchart 4.6: Endochondral ossification (Source: *Textbook of Human Embryology*, Yogesh Sontakke, 2nd edn., CBS Publishers)



- 4
5. **Zone of resorption:** In this zone, small blood vessels and osteoprogenitor cells from the marrow cavity invade zone of calcified cartilage. In the zone of resorption, portion of calcified cartilage is present in the form of longitudinal spicules. On surface of longitudinal spicules, osteoblasts start depositing bone, and thus form mixed spicules later, mixed spicules get anastomosed with each other to form bony trabeculae.

Remodeling of Bone

- Bone is a dynamic tissue. Continuous bone deposition and bone resorption is going on. Bone maintains their shape during growth by the removal of unwanted bone by osteoclasts. This process is called bone remodeling.
- It occurs in the following two ways: Surface and internal remodeling.
 1. **Surface remodeling** involves the resorption of bone from a conical subperiosteal region towards the end of the long bone.
 2. **Internal remodeling** involves the reabsorption of bone to maintain the proper thickness of the periosteal bone. It helps in the growth of the medullary cavity.
- Osteoclasts play an important role in bone resorption.

Factors Affecting Bone Growth

- They include the following factors:
 1. **Nutritional factors:** Vitamin D, calcium, vitamin A, vitamin C.

2. **Hormonal factors:** Growth hormone, thyroid and parathyroid hormones, estrogen, and testosterone.
3. **Mechanical stress.**
4. **Genetic factors.**

Clinical Correlation

- When bone growth is completed, epiphyseal cartilage stops proliferation and epiphysis fuses with diaphysis.
- Sex hormones stimulate the ossification of epiphyseal plates leading to union of epiphysis with diaphysis. In females, estrogen causes early closure of epiphysis with diaphysis and hence, the height of females is shorter than males.
- **Medicolegal significance:** The center of ossification at the lower end of femur occurs at the age of 9 months of intrauterine life. It has medicolegal significance for the age determination of the newborn.
- **Osteogenesis imperfecta/brittle-bone disease** involves lack of collagen type I fibers and defective calcification. Hence, bones break easily. Other symptoms include short height, hearing loss, blue sclera, and loose joints.
- **Scurvy:** Deficiency of vitamin C results in inadequate synthesis of collagen fibers and organic matrix. In scurvy, spongy bones show reduced trabeculae, whereas compact bone shows thinner cortex.
- **Rickets:** Vitamin D deficiency in rickets causes reduced mineralization of bone matrix in young individuals. It causes bowing of long bones.
- **Osteomalacia:** It is a disease of adulthood characterized by the softening of the bones. It is caused by impaired bone mineralization.
- **Osteoporosis:** It mostly occurs in old age, especially in postmenopausal women because of reduced estrogen levels. There is increased bone resorption in osteoporosis.
- **Osteoma** is a benign tumor of osteoblasts, whereas osteosarcoma is a malignant tumor arising from osteoblasts. *Note:* Benign tumor does not spread; malignant tumor can spread to distinct sites.
- **Cleidocranial dysostosis:** It is a congenital condition that has defective membranous ossification. In this condition, the clavicle is completely or partially absent, and there is defective development of cranial bones with large fontanelles and delayed closure of sutures.
- **Paget's disease (osteitis deformans):** It has uncontrolled osteoclastic activity that causes excessive bone resorption. It results in the formation of thick, bulky, weak osteoid bone.

BOX 4.1: Ossification and its Laws

- **Ossification:** It the process of formation of new bone.
- **Center of ossification:** It is the area of the bone formation or beginning of ossification. It is of two types:
 - **Primary center:** It is the center that forms main part or shaft of the long bones. Primary centers appear before birth except for carpals and tarsals (except talus, calcaneus, and cuboid) that appear before birth.

- **Secondary center:** It is the center that forms the accessory part of the bones. It appears after birth except for the lower end of femur and sometimes for the upper end of tibia.
- **Epiphysis** is the part of the bone that develops from the secondary center of ossification, whereas the diaphysis develops from the primary center of ossification.
- **Law of union of epiphysis:** Typical long bones have two epiphyses, one at each end. The epiphysis or the secondary center of ossification which appears first unites last and the epiphyseal center which appears last unites first. Exception to this rule: The epiphysis for the lower end of the fibula appears first and fuses first. Thus, the fibula is only the long bone that violates the law of union of epiphysis (Fig. 4.15). *MCQ, Viva*
- The end of the long bone which has epiphysis that fuses later is called *growing end of the bone*.
- The fusion of the epiphysis and diaphysis in the females occurs 2 to 3 years earlier; hence, they are shorter than males.

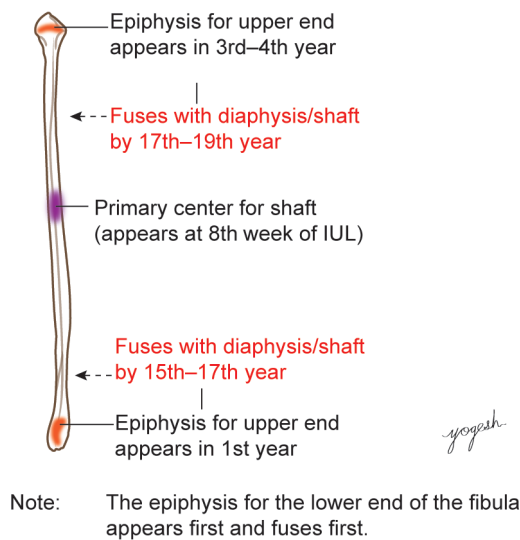


Fig. 4.15: Violation of the law of union of epiphysis by fibula

FRACTURE OF A BONE

- **Definition:** Fracture is a break in the continuity of the bone.
- The most commonly fractured bone is clavicle in children and adults and radius in elderly people (above 50 years). *MCQ*
- Fractures are grouped as:
 1. *Traumatic fractures* that occur on trauma
 2. *Spontaneous fractures* that occur spontaneous in the pathological conditions causing weakness of bones, such as osteoporosis, bone diseases and tumors
- Fractures may also be grouped as:
 1. *Simple or closed fractures:* In these fractures, the fractured bones are not exposed to the exterior through skin.

2. *Compound/open fractures:* In these fractures, the fractured bone is exposed to the exterior through wound or injured skin and more than one long bone are fractured.

Repair of Fractured Bone

- Immobilization is the prime important factor for proper healing of the fractured bone.

Stages of repair of fractured bone (Fig. 4.16):

- **Formation of fracture hematoma:** It develops by collection of blood from ruptured capillaries at the fracture site.
- **In 2–3 days:** New capillaries and stem cells invade from the surrounding tissue into the hematoma.
- **After 1 week:** Formation of temporary callus: Uncommitted stem cells from fibroblast and chondroblast. These fibroblasts form fibrous network between fractured ends, whereas chondroblasts form islets of fibrocartilage in fibrous network. This fibrous network with islets of fibrocartilage is called temporary or fibrocartilage callus.
- **Formation of bony callus:** The osteoprogenitor cells of periosteum of adjacent bony part proliferate and form osteoblasts. These osteoblasts invade temporary callus and lay down the woven bone at the site of fracture to form bony callus or primary bone.
- **Formation of secondary bone:** The bony callus is gradually replaced by secondary or mature bone.
- **Remodeling:** It takes place to restore the original bony structure.

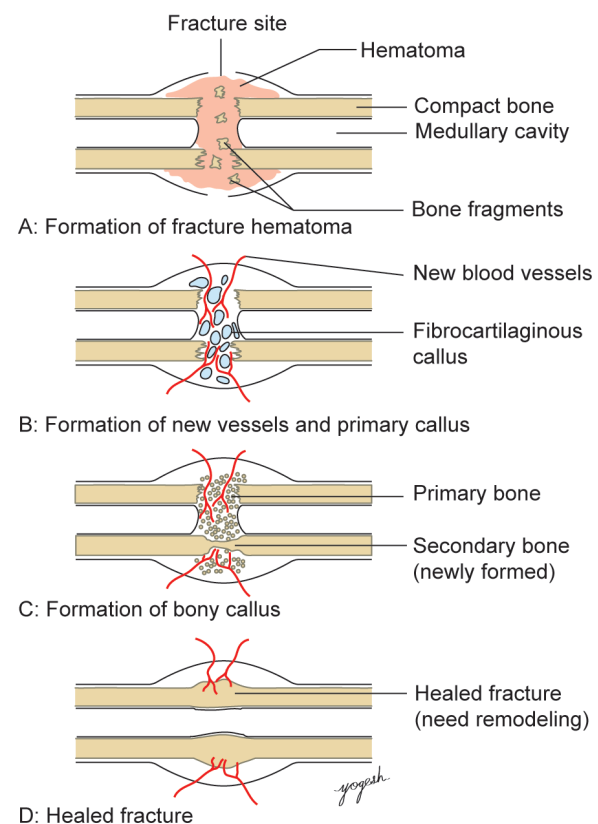


Fig. 4.16: Repair of fractured bone

CARTILAGE

- Cartilage is a specialized connective tissue.
- Cartilage comprises cells (5%) and extracellular matrix (95%).
- Cartilages may be grouped as:
 - Temporary cartilages – that are replaced by bone.
 - Permanent cartilages – that persist throughout the life.

General Features of Cartilage

1. Cartilage is avascular and receives nutrition by diffusion.
2. Cartilage does not have lymphatics.
3. Cartilage is surrounded by perichondrium, except articular cartilage and fibrocartilage.
4. Cartilage does not have nerves except for perichondrium.
5. Cartilage shows interstitial and appositional growths.

Functions of Cartilage

1. Supports the body parts.
2. Cushioning and shock absorption in joints.
3. Smooth joint movements in synovial joints
4. Forms growth plate in bones
5. Provide flexibility to the skeletal framework.

Structure

- Cartilage consists of cells (3–5%), fibers (15%), ground substance (5%), and water (60–80%).
- *Cells of cartilage:* Cartilage consists of three types of cells:
 1. *Chondrogenic cells* differentiate to give rise to other cells of cartilage. They are located in the perichondrium.
 2. *Chondroblasts* are young cartilage cells that divide mitotically to form chondrocytes.
 3. *Chondrocytes* are mature cartilage cells. They deposit extracellular matrix in the cartilage.
- *Fibers:* The matrix of the cartilage has the following types of fibers:
 - Type I collagen fibers in fibrocartilage
 - Type II collagen fibers in hyaline cartilage
 - Elastic fibers in elastic cartilage
- *Ground substance:* The ground substance of the cartilage consists of:
 1. Proteoglycans, such as chondroitin sulphate, keratan sulphate, heparan sulphate.
 2. Glycoproteins such as chondronectin.

Some Interesting Facts

- Cartilage shows two types of growth as follows:
 1. *Interstitial growth:* It is an addition of cartilage on its surface. It takes place before maturation (hardening of matrix) of cartilage. Cartilage cells divide in interstitial growth throughout the substance of the cartilage.

2. *Appositional growth:* It is the formation of new cartilage within the existing cartilage by division of chondrocytes. After maturation, cellular layer of perichondrium deposits new cartilage layers in appositional growth.

- Cartilage shows limited and slow growth. Matrix of cartilage is dynamic. Routinely old matrix is removed, and a new matrix is deposited. This is called internal remodeling.
- For the differences between bone and cartilage, refer to Table 4.3.

Types of Cartilages

- There are three types of cartilages (Figs 4.17 and 4.18, Tables 4.3 and 4.4, Flowchart 4.7):
 1. Hyaline cartilage
 2. Elastic cartilage
 3. Fibrocartilage.

Hyaline Cartilage

- Historically, hyaline cartilage has a glass-like (transparent) matrix. Hence, it is called hyaline cartilage (*hyalos* = glass in Greek).
- The hyaline cartilage contains collagen fibers. The refractive indices of collagen fibers and the ground

Flowchart 4.7: Types of cartilages

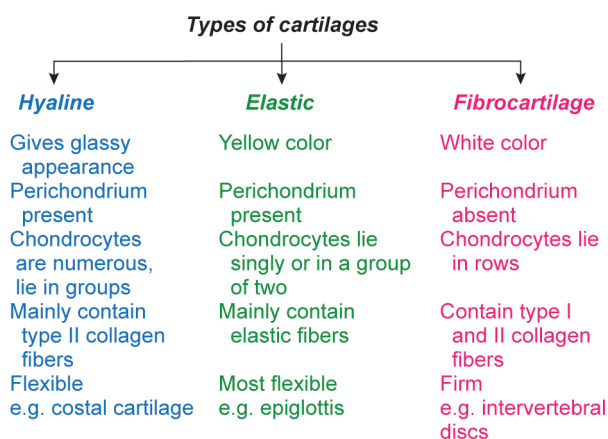


TABLE 4.3: Differences between bones and cartilage

Characteristic	Bone	Cartilage
Composition	Hard and rigid due to calcium salts	Flexible and resilient due to collagen and proteoglycans
Vascularity	Highly vascular	Avascular
Nerve supply	Rich	No nerve supply except perichondrium
Cells	Osteocytes, osteoblasts, osteoclasts	Chondrocytes, chondroblasts
Function	Support, protection, hematopoiesis	Cushioning, flexibility
Growth potential	Higher	Limited

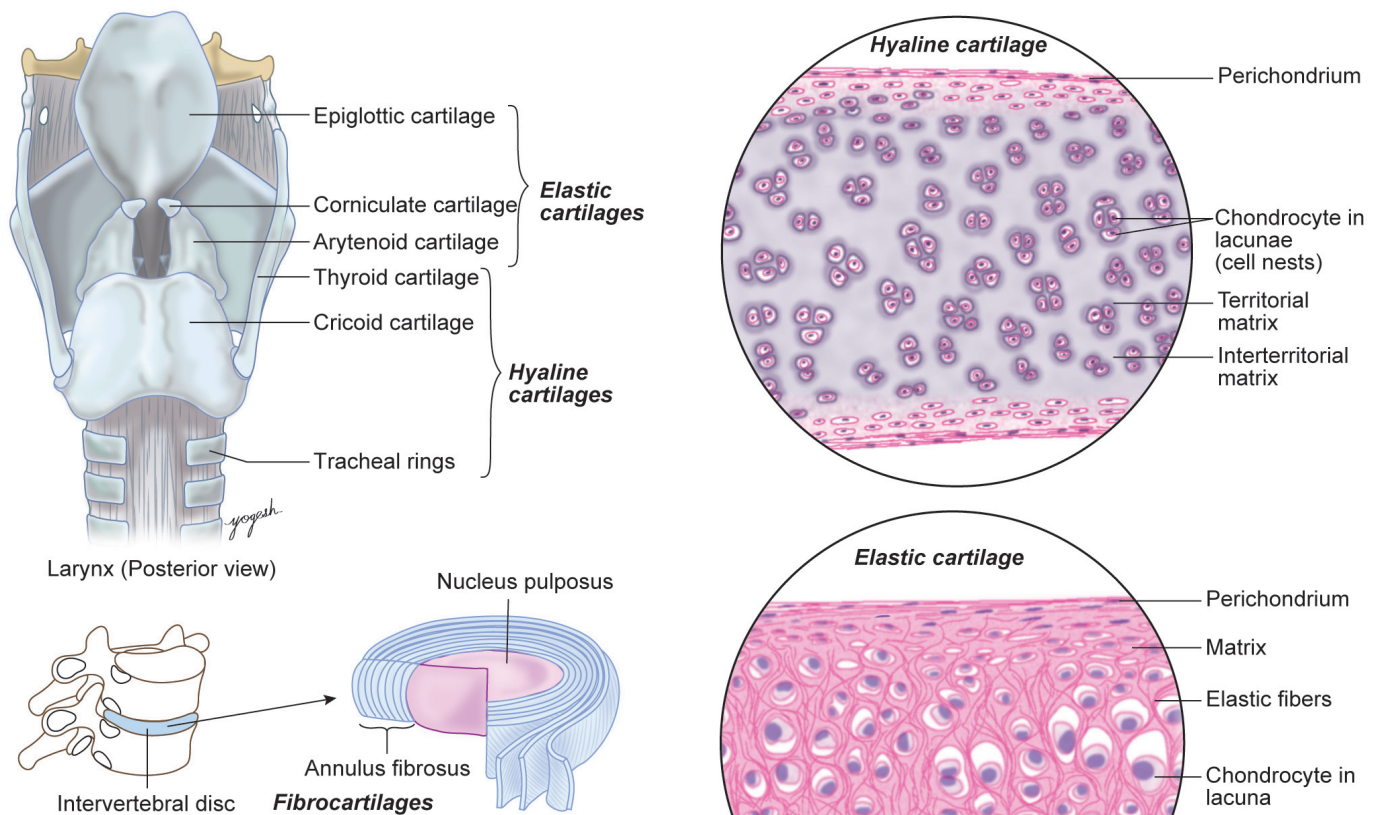


Fig. 4.17: Types of cartilages

substance are same. This gives homogenous glassy appearance to the cartilage.

- Hyaline cartilage gets ossified with advancing age. Hyaline cartilage is the most abundant type of cartilage in the human body.
- *Example:* It is present at the following locations: Fetal skeleton, articular cartilages, nose cartilage, costal cartilages, laryngeal cartilages (thyroid, cricoid, and arytenoids cartilages), trachea and bronchi, and developing bones (epiphyses).

Elastic Cartilage

- It gives resilience, pliability, and elasticity to the organ.
- Fleshy dissected elastic cartilage is yellowish in color; hence, it is called *yellow elastic cartilage*.
- Elastic cartilage contains a dense meshwork of elastic fibers that give elasticity and yellow color to the cartilage.

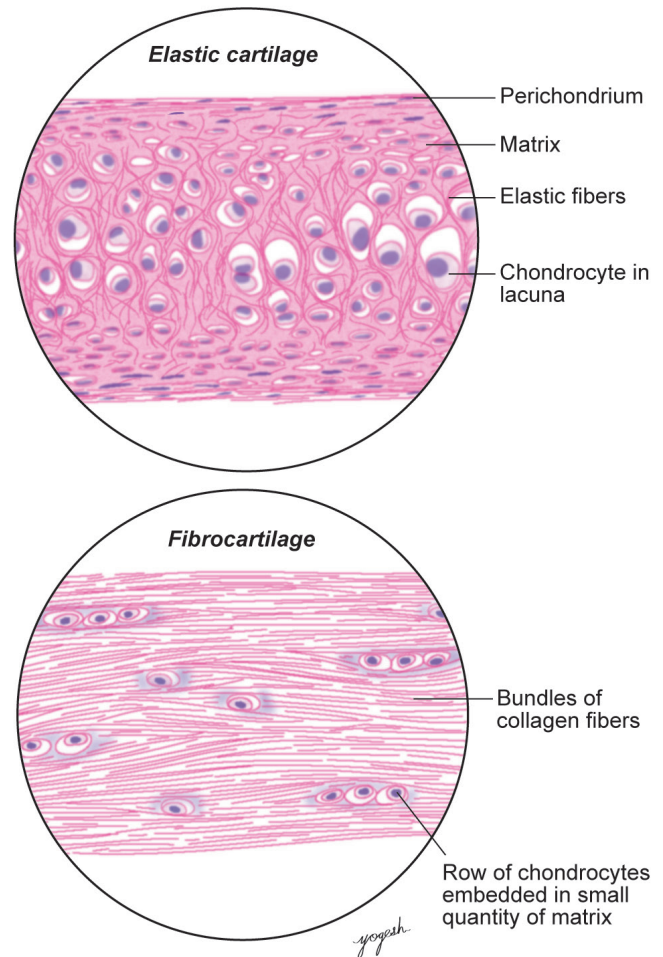


Fig. 4.18: Types of cartilages

TABLE 4.4: Differences between hyaline, elastic and fibrocartilage

Feature	Hyaline cartilage	Elastic cartilage	Fibrocartilage
Color	Glassy (bluish white)	Yellow	White
Perichondrium	Present (except in articular cartilage)	Present	Absent
Chondrocytes	Numerous, lie in groups (cell nests)	Lie single or in group of two	Lie in rows
Cells	Chondrocytes	Chondrocytes	Chondrocytes and fibroblasts
Fibers	Type II collagen fibers	Few type II collagen fibers, elastic fibers	Type I and type II collagen fibers
Elasticity	Flexible	Most flexible	Firm
Locations	Costal cartilage	Epiglottis	Intervertebral disc

- *Examples:* Elastic cartilage is present in pinna of external ear, walls of external acoustic meatus, auditory tube, epiglottis, tips of arytenoids, corniculate, and cuneiform cartilages of larynx.

Fibrocartilage

- It contains bundles of collagen fibers that give white color to cartilage. Hence, this cartilage is also called *white fibrocartilage*.
- Fibrocartilage is combination of dense regular connective tissue and hyaline cartilage.
- It is formed at sites of great pressure, for example:
 1. Intervertebral discs
 2. Pubic symphysis
 3. Articular discs of sternoclavicular and temporomandibular joints
 4. Menisci
 5. Glenoidal labrum
 6. Acetabular labrum
 7. Articular disc of wrist joint and at the sites of tendon attachment with bones (a few places).



Some Interesting Facts

- The most abundant cartilage in body is hyaline cartilage.
- Thyroid cartilage is the largest hyaline cartilage.
- Cartilage of the ear auricle is the largest elastic cartilage.

Clinical Facts

- *Achondroplasia (dwarfism):* It occurs due to defective endochondral ossification. It occurs due to mutation of fibroblast growth factor receptor 3 (FGFR3) gene that results in defective conversion of cartilage to bone.^{MCQ} Its clinical features include:
 - Abnormally short individual or dwarf
 - Disproportionally shorter limbs than trunk
- Achondroplasia is the commonest deformity of endochondral ossification.^{MCQ}
- Cleidocranial dysostosis is the commonest congenital anomaly of membranous ossification.^{MCQ}
- *Cellular cartilages* are seen during embryonic life. They consist of numerous cells and minimal matrix.
- Damaged cartilages repair slowly due to their avascular nature. It causes difficulty in chondrocyte migration to the site of injury.

Joints

Competencies:

AN2.5 Describe various joints with subtypes and examples.

AN2.6 Explain the concept of nerve supply of joints and Hilton's law.

- **Definition:** A joint is the articulation of two or more bones or cartilages that permits movement.

Some Interesting Facts

- All the 206 bones in the body form joints except hyoid bone. ^{MCQ}
- All joints are not movable. Some joints are immovable, and some permit only slight movements.
- Some joints fuse with the advancing age. Thus, the number of joints decreases with increasing age. For example, four coccygeal vertebrae fuse to form a single coccyx.
- Joints of thoracic cavity permit the movements of respiration.
- **Articular surface:** It is a surface of bone that forms a joint. It may be margin of the flat bone or ends of the long bone.
- **Dislocation** is an abnormal separation of articular surfaces of bones.
- Knee joint is the largest joint in the body.
- Hip joint is the largest ball and socket joint.
- Incudostapedial joint is the smallest ball and socket joint. The most common type of joints in the body are hinge joints.

CLASSIFICATION OF JOINTS

Q. Write a short note on classification of joints.

- The joints are classified on the following basis:
 1. Structural classification
 2. Functional classification.

Structural Classification

- Based on the type of connecting tissue and presence of joint cavity, joints have the following types and subtypes (Fig. 5.1, Flowchart 5.1):

- Greek: *Joint* = Arthron; *Derived terms:* Arthrology, synarthrosis, arthritis.
- Latin: *Joint* = Articulatio; *Derived terms:* Articulation.

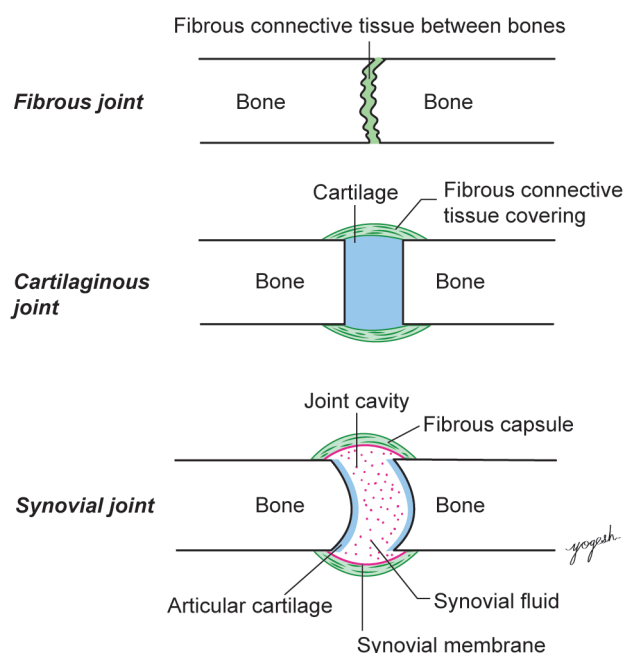
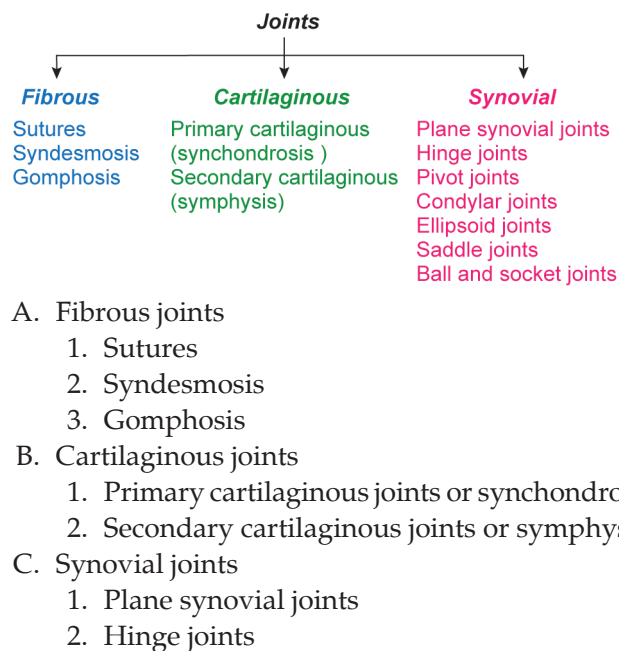


Fig. 5.1: Types of joints

Flowchart 5.1: Structural classification of joints



A. Fibrous joints

1. Sutures
2. Syndesmosis
3. Gomphosis

B. Cartilaginous joints

1. Primary cartilaginous joints or synchondrosis
2. Secondary cartilaginous joints or symphysis

C. Synovial joints

1. Plane synovial joints
2. Hinge joints

3. Pivot joints
4. Condylar joints
5. Ellipsoid joints
6. Saddle joints
7. Ball and socket joints.

Functional Classification

- Based on the mobility, the joints are classified into three types:
 1. *Immovable joints or synarthrosis*: For example, cranial sutures.
 2. *Slightly movable joints or amphiarthroses*: For example, pubic symphysis.
 3. *Freely movable joints or diarthroses*: For example, synovial joints.

FIBROUS JOINTS

Q. Write a short note on fibrous joints.

- **Definition**: In fibrous joints, the articulating bones are united by fibrous connective tissue (Fig. 5.2, Flowchart 5.2).
- **Features**:
 - These are immovable joints or *synarthroses*.
 - It does not have joint cavity.
 - They provide stability and help in protection.

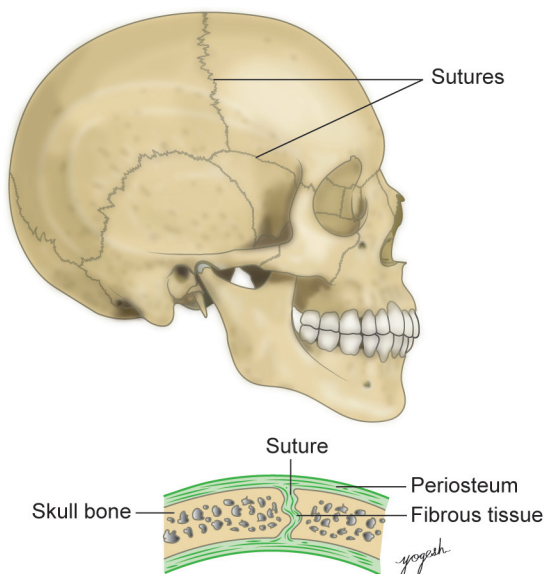


Fig. 5.2: Sutures

Classification of Fibrous Joints

The fibrous joints are classified into three types:^{MCQ}

1. Sutures
2. Syndesmoses
3. Gomphoses.

Sutures

- In sutures, the bones are connected by a thin layer of fibrous connective tissue, or sutural ligament (*sutura* = stitch in Latin).
- Sutures are present only in skull bones.^{Viva}
- Sutures permit slight movement during childbirth and in children.
- Sutures ossify with advancing age.

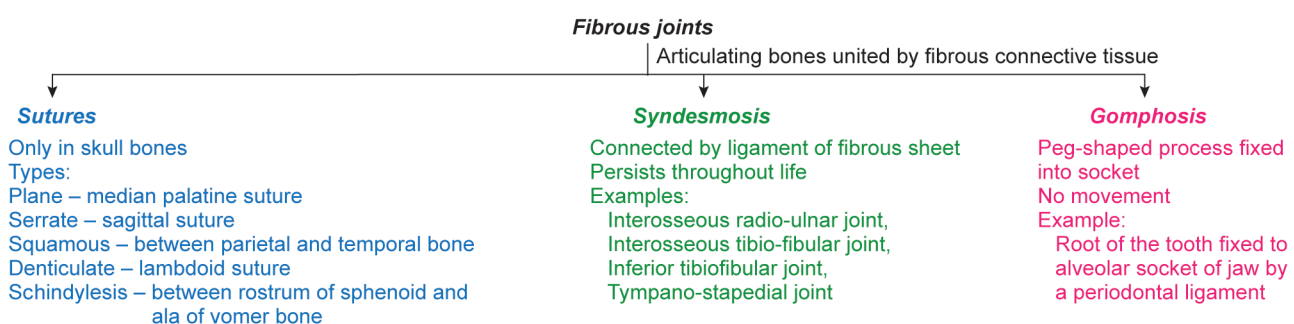
Types of sutures

- Depending on the shape of articulating surface and margins, the sutures are classified into the following subtypes (Fig. 5.3):
 1. *Plane suture*: Plane and smooth articular margins. For example, median palatine suture (joint between palatine processes of two maxillae)
 2. *Serrate suture*: Reciprocally serrated and into locking articular surfaces in jigsaw fashion. For example, sagittal suture of skull.
 3. *Squamous suture*: Overlapping edges of bone. For example, suture between parietal and squamous part of temporal bone.
 4. *Denticulate suture*: Interlocking margins of suture, like teeth of saw. For example, lambdoid suture.
 5. *Schindylesis*: Ridge of one bone fits into the groove of the other. For example, joint between the rostrum of sphenoid and upper margin of vomer bone.

Clinical Integration

- **Synostosis**: In the elderly, the sutures undergo obliteration/fusion. This union is called synostosis (*syn* = union, *osteo* = bone). On synostosis, the suture completely loses capacity of movement; hence, skull fractures are common in elderly. *Synostosis* begins on deeper aspect of the suture and gradually extends onto the superficial aspect.

Flowchart 5.2: Fibrous joints



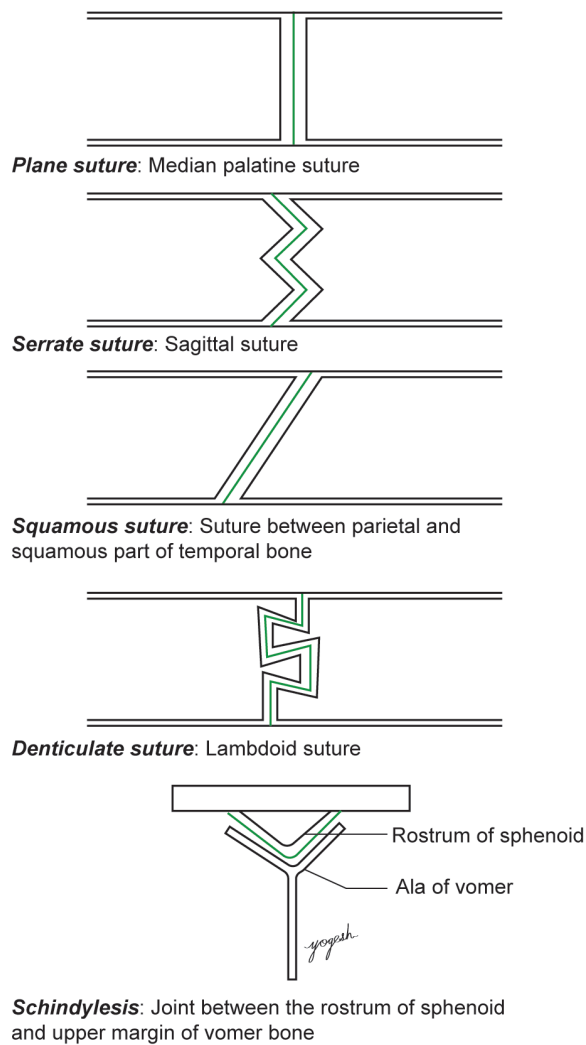


Fig. 5.3: Types of sutures

Syndesmoses

- In syndesmoses, the bones are, connected with each other by fibrous connective tissue sheet/ligaments (*syndesmosis* = ligament in Greek) (Fig. 5.4).
- They permit slight degree of movements.
- These membranes or ligaments persist throughout the life.
- *For example:*
 - Interosseous radioulnar joint,
 - Interosseous tibiofibular joint,

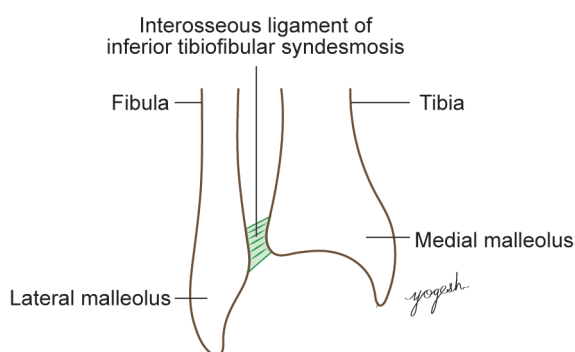


Fig. 5.4: Syndesmosis at inferior tibiofibular joint (coronal section passing through the ankle joint, right anterior view)

- Inferior tibiofibular joint,
- Tympanostapedial joint. ^{MCQ}

Gomphosis or Peg-and-socket Joints

- In gomphosis, a peg-shaped process is fixed into the socket by fibrous connective tissue (Fig. 5.5).
- It does not permit the movement.
- For example, the root of the tooth is fixed to the alveolar socket of jaw by a periodontal ligament.

CARTILAGINOUS JOINTS

Q. Write a short note on cartilaginous joints.

- In cartilaginous joints, the articulating bones are connected by hyaline or fibrocartilage.
- *Features*
 - These are slightly movable joints or amphiarthroses.
 - They do not have joint cavity.

Classification of Cartilaginous Joints

- The cartilaginous joints are of two types (Table 5.1, Flowchart 5.3):
 1. Primary cartilaginous joints
 2. Secondary cartilaginous joints.

Primary Cartilaginous Joints

- These are called *synchondroses*.
- In primary cartilaginous joint, the bones are connected by a plate of hyaline cartilage (Fig. 5.6).

Features

- Bones are connected by a plate of hyaline cartilage.
- These are *temporary* joints. At certain age, the cartilaginous plate is replaced by bone with ossification.
- These are immovable.
- They are designed for bone growth.

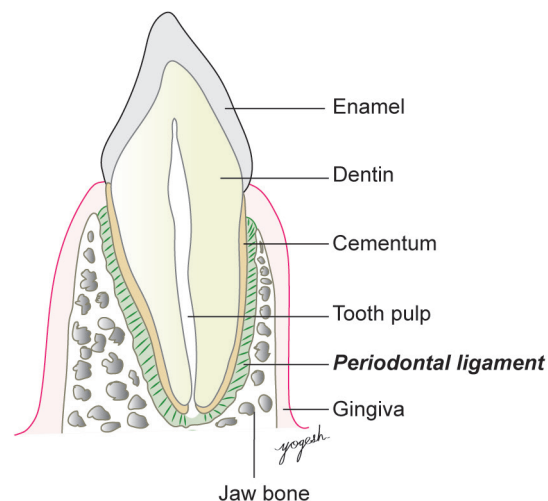
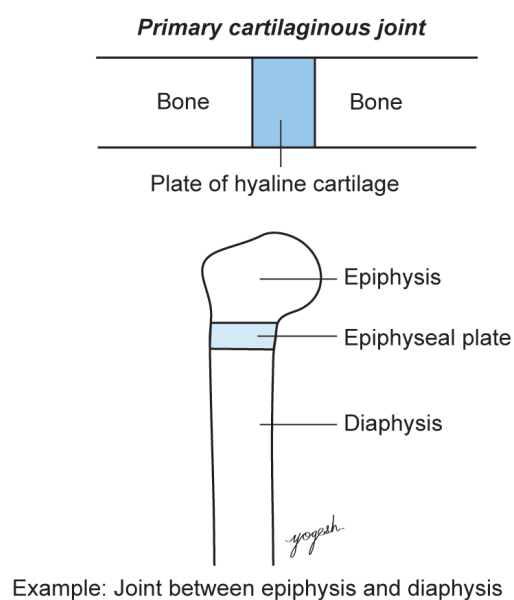
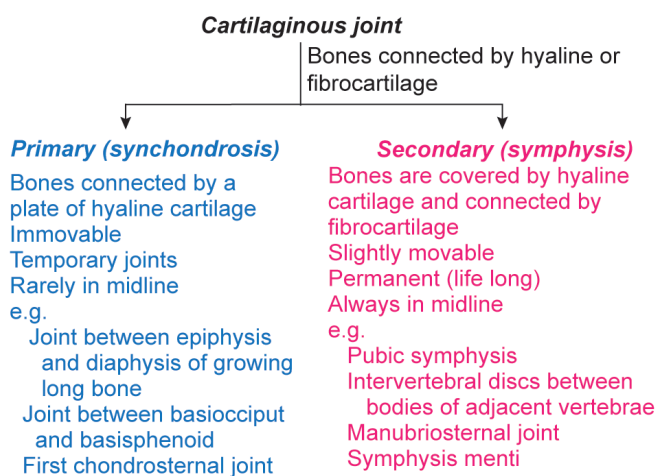


Fig. 5.5: Gomphosis (peg and socket variety): *Example:* Tooth in alveolar socket fixed with periodontal ligament.

TABLE 5.1: Difference between primary and secondary cartilaginous joints

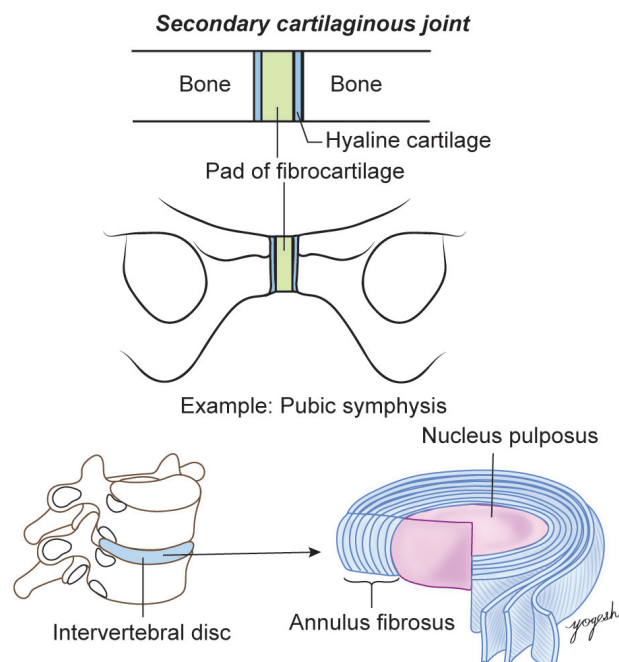
Q. Write a short note on the difference between primary and secondary cartilaginous joints.

Feature	Primary cartilaginous joints	Secondary cartilaginous joints
Connected bones	Bones are connected by hyaline cartilage.	Articular surfaces are covered by hyaline cartilage and united by fibrocartilage
Types of cartilage	Hyaline cartilage connects the bones	Fibrocartilage connects the hyaline cartilage covered ends of bones
Movement	Immovable	Slightly movable
Duration	Disappear with age	Permanent (lifelong)
Location	Rarely in midline	Always in midline
Common example	Epiphyseal plates in long bones, first chondrosternal joint	Intervertebral disc, pubic symphysis

**Fig. 5.6:** Primary cartilaginous joint**Flowchart 5.3:** Cartilaginous joints

Example^{MCQ}

1. Joint between epiphysis and diaphysis of growing long bone.
2. Joint between basiocciput and basisphenoid.
3. First chondrosternal joint.

**Fig. 5.7:** Secondary cartilaginous joint

Secondary Cartilaginous Joints

- These are called *symphysis*.
- In the secondary cartilaginous joint, the articular surfaces of the bones are covered by hyaline cartilages and connected by a pad of fibrocartilage (Fig. 5.7).

Features

- These are *permanent* joints. They persist throughout the life except for symphysis menti.
- The articular surfaces are covered by hyaline cartilages and united by a pad of fibrocartilage.
- They typically occur in the midline.
- Only limited movements are permitted in these joints.

Example

1. Pubic symphysis.
2. Intervertebral discs between bodies of adjacent vertebrae.
3. Manubriosternal joint.
4. Symphysis menti (between two halves of mandible, this is not a true symphyseal joint).

Some Interesting Facts

- All the symphyseal joints belong to the axial skeleton except, pubic symphysis which belongs to appendicular skeleton.

Clinical Integration

- **Growth of long bone:** Primary cartilaginous joint between the epiphysis and diaphysis of long bone is a site of bone growth. At certain age, this joint ossifies.

SYNOVIAL JOINTS

Q. Write a short note on synovial joint.

Q. Draw a well-labelled diagram showing the structure of synovial joint.

- In synovial joints, the articulating surfaces are covered by hyaline cartilages and separated by a cavity.
- These are highly evolved and mobile joints. Hence, called *diarthrodial joints*.

Characteristic Features of Synovial Joints (Fig. 5.8)

1. **Joint cavity:** Presence of joint cavity is a characteristic feature of synovial joints. It lies between the articular surfaces. It is enclosed by articular capsule. It is filled with synovial fluid.

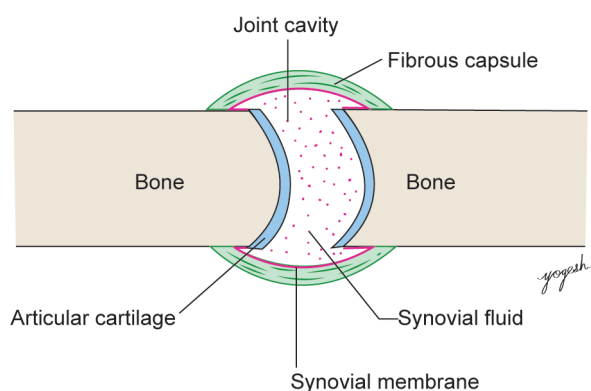


Fig. 5.8: Schematic diagram of typical synovial joint

2. **Articular surfaces:** The smooth articular surfaces are covered with hyaline articular cartilage.
3. **Synovial membrane and fluid:** Articular capsule is internally lined by synovial membrane which produces synovial fluid.
4. **Intra-articular disc or meniscus** is fibrocartilage that divides the joint cavity incompletely or completely or some joints.
5. **Ligaments:** It is supported by capsular ligament and other ligaments.
6. **Movements:** It permits various movements to certain extents.

Classification of Synovial Joints

Q. List the types of synovial joints.

The synovial joints are classified as follows (Flow-chart 5.4):

1. Plane or gliding joints
2. Uniaxial joints
 - a. Hinge joint
 - b. Pivot joint
3. Biaxial joints
 - a. Condylar joints
 - b. Ellipsoid joints
4. Multiaxial joints
 - a. Saddle joint
 - b. Ball and socket joints.

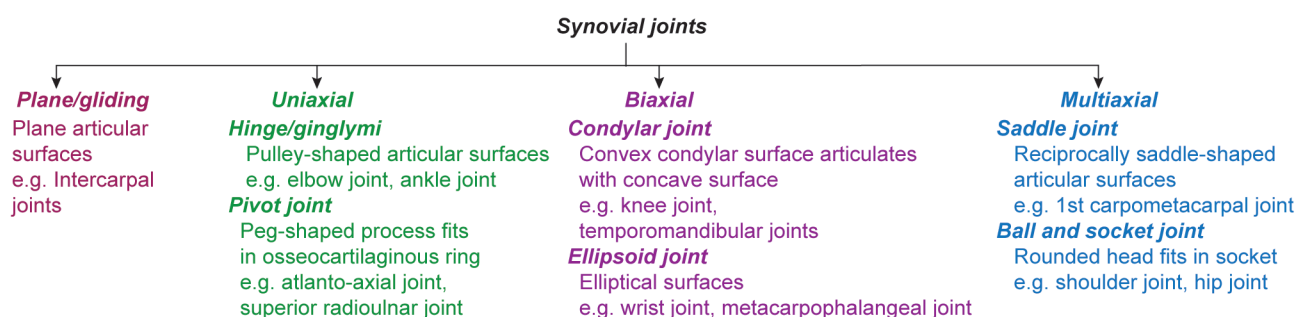
1. Plane or Gliding Joints

- In plane synovial joints, the articular surfaces are plane or flat (Fig. 5.9).
- **Movements:** They permit gliding movements.

Examples

- Intercarpal joints
- Intertarsal joints
- Intermetacarpal and intermetatarsal joints
- Joints between articular processes of adjacent vertebrae.

Flowchart 5.4: Synovial joints



Compound joint: More than two bones forming joint; e.g. ankle joints, elbow joint

Complex joint: Intra-articular disc divides the joint cavity into two compartments; e.g., temporomandibular joint, knee joint

Additional examples:

Plane joint: Cricothyroid joint, cricoarytenoid joint, superior tibiofibular joint, interchondral joints, costovertebral joints, costotransverse joint, acromioclavicular joint, carpometacarpal joints (except first), tarsometatarsal joints, chondrosternal joints (except first), sacroiliac joint.

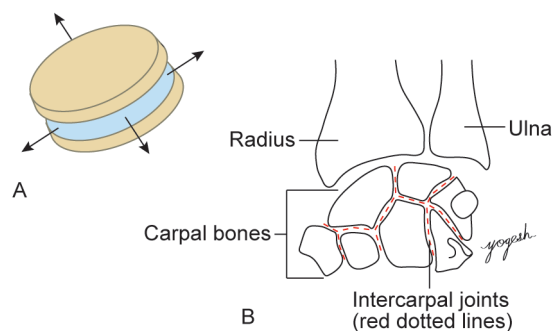


Fig. 5.9: Plane or gliding joint. A: Schematic representation. B: Intercarpal joints representing plane synovial joint

2. Hinge Joints or Ginglymi

- In hinge joint, articular surfaces are pulley-shaped.
- **Movements:** These are *uniaxial joints*. They permit movements in one plane around a transverse axis (Fig. 5.10).

Examples

- Elbow joint
- Ankle joint
- Interphalangeal joints.

3. Pivot or Trochoid Joints

- In pivot joint, the articular surface of one bone is pivot or peg which is surrounded by *osseocartilaginous ring* (Fig. 5.11).
- **Movements:** It is *uniaxial joint*. It permits limited rotation movements along the vertical axis.

Examples

- Atlanto-axial joint (dens or odontoid process of axis vertebra is pivot that is surrounded by ring of arch of atlas and transverse ligament of atlas).
- Superior radioulnar joint (head of radius is pivot that rotates within the ring formed by annular ligament and radial notch of ulna).

4. Condylar Joints

- In condylar joint, the articular surfaces are condylar – one is convex, and another is concave (Fig. 5.12).
- **Movements:** It is *biaxial joint*. It permits movements in two directions – up and down and side to side.
- **Examples:**
 - Knee joint
 - Right and left temporomandibular joints.

5. Ellipsoid Joint

- In ellipsoid joints, articular surfaces are elliptical, one of them is convex, and another concave (Fig. 5.13).
- **Movements:** It is *biaxial joint*. It permits movements in *two axes* – flexion and extension around transverse axis and adduction and abduction around the anteroposterior axis. A combination of these movements produces *circumduction*.

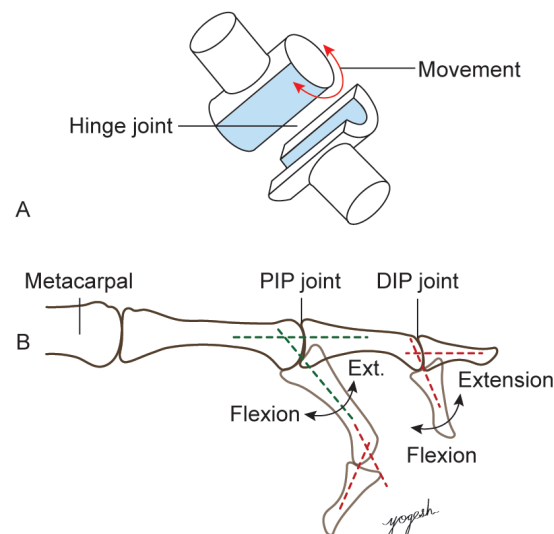


Fig. 5.10: Hinge joint or ginglymi. A: Schematic representation. B: Movements at proximal and distal interphalangeal joints represent hinge joint. PIP: Proximal interphalangeal joint, DIP joint: Distal interphalangeal joint

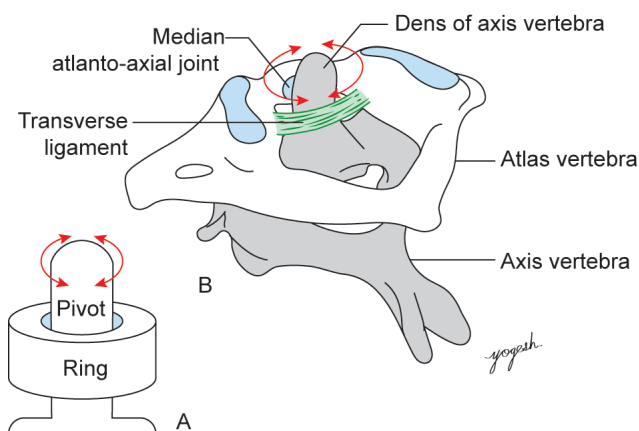


Fig. 5.11: Pivot joint. A: Schematic representation. B: Median atlantoaxial joint representing pivot joint

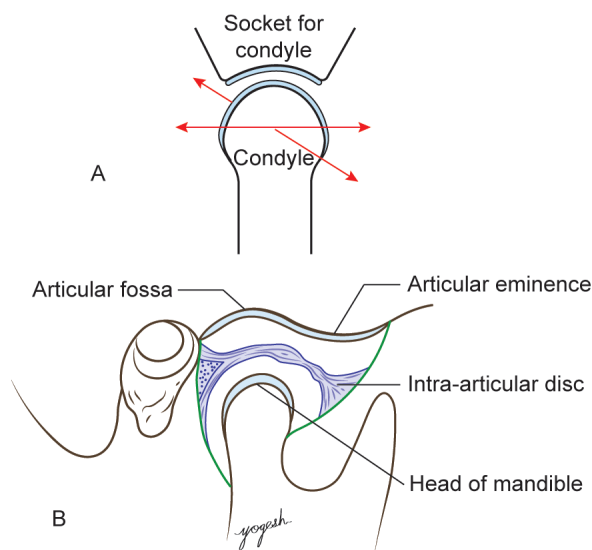


Fig. 5.12: Condylar joint. A: Schematic representation. B: Temporomandibular joint representing condylar joint.

Examples:

- Radiocarpal or wrist joint
- Metacarpophalangeal joints
- Metatarsophalangeal joints
- Atlanto-occipital joints.

6. Saddle or Sellar Joints

- In saddle joints, the articular surfaces are reciprocally saddle-shaped, that is, concavo-convex (Fig. 5.14).
- **Movements:** It is *multiaxial joint*. It permits free movements in two axes and some movement in third axis as conjunct rotation (flexion and extension, adduction, and abduction).

Examples:

- First carpometacarpal joint
- Sternoclavicular joint
- Incudomalleolar joint
- Calcaneocuboid joint.

7. Ball Socket or Spheroidal Joints

- In ball and socket joint, globular/rounded convex surface of one bone fits into a cup-shaped socket of another bone (Fig. 5.15).
- **Movements:** It is multiaxial joint. It permits movements around an indefinite number of axes. It can perform flexion, extension, adduction, abduction, medial and lateral rotation, and circumduction.

Examples:

- Shoulder joint
- Hip joint
- Talocalcaneonavicular joint
- Incudostapedial joint.

COMPONENTS OF SYNOVIAL JOINTS

Q. Describe the components of the synovial joints.

- The synovial joint consists of
 1. Articular cartilage
 2. Synovial fluid
 3. Articular capsule
 4. Synovial membrane
 5. Ligaments
 6. Articular disc
 7. Bursae.

Articular Cartilage

- The *articular surfaces* are covered by a thin plate of hyaline cartilage, called *articular cartilage*. This articular cartilage is avascular, non-nervous and elastic. Articular cartilage is not covered by perichondrium.
- Its proteoglycan – hyaluronic acid maintains hydration which resists compressive forces.
- **Functions**
 - It provides a smooth gliding surface and reduces compressive forces during weight bearing and joint movements.
 - It regulates the growth of epiphysis.

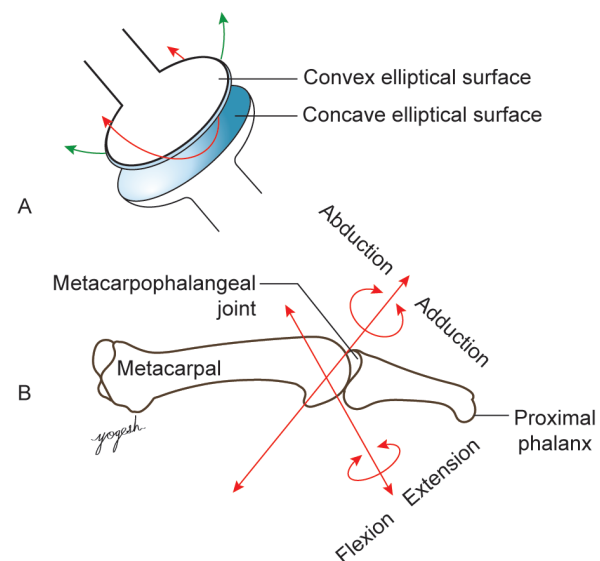


Fig. 5.13: Ellipsoid joint. A. Schematic representation. B. Metacarpophalangeal joint representing ellipsoid joint

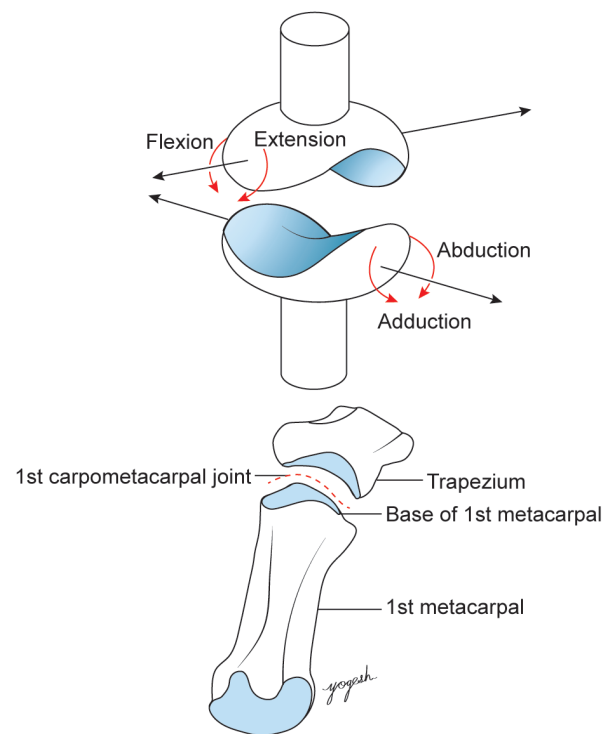


Fig. 5.14: Saddle joint. A. Schematic representation. B. First carpometacarpal joint representing saddle joint

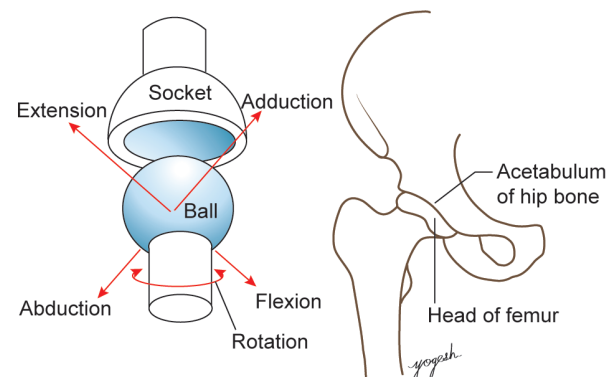


Fig. 5.15: Ball and socket joint. A. Schematic representation. B. Hip joint representing ball and socket

- *Changes in articular cartilage with age:*

Articular cartilage shows degenerative and proliferative changes with advancing age.

- *Degenerative changes* occur in the central part of the cartilage. The collagen fibers are exposed and disrupted.
- *Proliferative changes* occur in the periphery of the cartilage. The enlarged portion of the cartilage get ossified to form osteophytes.
- Articular cartilage receives nutrition from
 - Synovial fluid
 - From adjacent capillaries by diffusion
 - From epiphyseal vessels by diffusion.

Articular Capsule

- It consists of two components:
 1. Outer fibrous capsule
 2. Inner synovial membrane.
- *Fibrous capsule*
 - It completely invests the joint cavity. It is attached to the bone near the articular surfaces. It consists of bundles of collagen fibers.
 - *Functions*
 - Fibrous capsule supports and stabilizes the joint.
 - It permits movements up to certain extent and then restricts movements and prevents dislocation of the joint.
 - Numerous sensory nerves supply the fibrous capsule. These nerves get stimulated on stretching of capsule and prevent the movement beyond the comfort zone. This is known as 'watchdog' action of the capsule.
- *Synovial membrane*
 - It is a highly vascular, thin connective tissue membrane.
 - It lines the inner aspect of fibrous capsule and nonarticular part of the bones that lie within the capsule.
 - *Functions*
 - It secretes synovial fluid and hyaluronic acid.
 - It removes particulate matter and workout cartilage cells by phagocytic activity.

Synovial Fluid

- It is a viscous and glairy fluid. It fills the joint cavity. It is secreted by synovial membrane.
- The viscosity of the fluid depends on the hyaluronic acid which is essential for lubrication.
- *Composition:* It contains hyaluronic acid, monocytes, lymphocytes macrophages, synovial cells and proteins.
- *Functions*
 - Nourishes articular cartilages.
 - Lubricates joint cavity.

Some Interesting Facts

- In cold temperatures, the viscosity of the synovial fluid increases. This makes joints stiff in winter.
- *Morning stiffness:* Viscosity of the synovial fluid decreases with joint movements. Hence, the person may feel stiffness in the morning hours, and stiffness lessens after some time.
- *Joint cracks:* Sometimes a noise or cracking sound is produced when the articular surfaces are separated forcefully. This sound is produced due to the development of vacuum within the joint on forcible separation of articular surfaces.
- All the symphyseal joints belong to the axial skeleton except, pubic symphysis which belongs to appendicular skeleton.
- All the articular cartilages of synovial joints are made up of hyaline cartilages, except for temporomandibular, sternoclavicular, and acromioclavicular joints are made up of fibrocartilage.^{MCQ}
- Articular cartilage of patella is the thickest articular cartilage.
- Shoulder joint is the most mobile joint.
- The most commonly dislocated joint is elbow joint in children and shoulder joint in adults.
- Anterior tibiofibular ligament is the most commonly sprained ligament of the body.
- The most commonly involved joint in osteoarthritis is knee joint.
- Primary cartilaginous joints disappear with advancing age.
- Osteoarthritis is the most common bone disease.

Ligaments

- These are thickened bands of collagen fibers that support the joint. The ligaments are of two types: True and accessory.
- *True ligaments:* These are produced by thickening the part of fibrous capsule. They are not separable from the true capsule, hence, called intrinsic ligaments. For example, lateral temporomandibular ligaments.
- *Accessory ligaments:* These are additional ligaments that connect the bones forming the joints. They may be intra-capsular or extracapsular. For example, sphenomandibular ligaments, stylomandibular ligaments.
- *Functions:*
 - True ligaments support, stabilize, and prevent excessive and undesirable movements of the joint
 - Accessory ligaments support the joint and limit the range of movements.
- *Sprain* is a tear in the ligaments. It caused painful swelling of the joint.

Articular Disc or Meniscus

- Some joints have a fibrocartilaginous articular disc or meniscus.

- Articular disc or meniscus is attached to the periphery to the fibrous capsule and divides the joint cavity partially or completely. Such joints are called complex joints.
- *Examples:*
 - Articular disc of temporomandibular joint, sternoclavicular joint, inferior radioulnar joints.
 - Menisci are present in knee joint, acromioclavicular joint.
- *Functions:*
 - Helps in lubrication.
 - Divides the joint cavity into two compartments.
 - Permits gliding and angular movements.
 - Prevents wear and tear of articular cartilages.

Bursae

- Bursae are pouch-like sacs of connective tissue filled with synovial fluid.
- Bursae are located between tendon and bone between muscle and bone, between skin and bone, and between skin and tendon.
- *Functions:* Bursae reduce friction and facilitate movements of tendon, muscle, and skin over the hard surfaces.
- *Synovial tendon sheath* is a tubular synovial coat over the tendons. It is a modified bursa. It prevents friction of the tendon while passing through a tunnel.

Fat Pads or Haversian Glands

- These are pads of fats associated with the synovial joints.
- These are placed between synovial membrane and fibrous capsule, or between synovial membrane and bone.
- These pads of fat help in lubrication and accommodate the joint space according to the change in size with joint movements.
- *Examples:*
 - Acetabular fat of hip joint
 - Infrapatellar fat of knee joint.

Classification of Synovial Joints Based on Articulating Bones and Intra-articular Disc

- Based on the number of bones articulating at the joint, they are classified as simple and compound joints.
1. *Simple joints:* In these joints, only two bones take part in the formation of a joint. Examples: Interphalangeal joints of fingers and toes (Fig. 5.16).
 2. *Compound joints:* In these joints, more than two bones take part in the formation of a joint (Fig. 5.16).
Examples:
 - a. Ankle joint – articulating bones: Tibia, fibula, and talus.
 - b. Elbow joint – articulating bones: Humerus, radius, and ulna.

- c. Radiocarpal (wrist) joint – articulating bones: Radius, scaphoid, lunate, and triquetral.

3. *Complex joints:* In these joints, the intra-articular disc divides the joint cavity into two compartments (Fig. 5.16).

Examples:

- a. Temporomandibular joint
- b. Knee joint
- c. Sternoclavicular joint
- d. Acromioclavicular joint.^{MCQ}

Clinical Integration

- *Osteoarthritis:* It is a degenerative condition of articular cartilage. It involves weight-bearing joints. It involves wear-out and degenerative changes in articular cartilage. Due to these changes, articular bones start rubbing together and cause a lot of pain during movements.
- *Osteophytes:* Sometimes, in old age, the articular cartilage overgrows and later gets ossified to form osteophytes (pseudo-bone)
- *Rheumatoid arthritis:* It is a chronic, progressive inflammatory autoimmune disease involving synovial membrane. It leads to thickening of synovial membrane, and in later stages, it causes degeneration of articular cartilage. It commonly affects small joints of hands and feet.
- *Arthroplasty* is a surgical repair or replacement of a joint.
- In Table 5.2, the differences between osteoarthritis and rheumatoid arthritis are listed.

TABLE 5.2: Differences between osteoarthritis and rheumatoid arthritis

Feature	Osteoarthritis	Rheumatoid arthritis
Affected structure	Articular cartilage	Rheumatoid arthritis
Joints involved	Large weight bearing joints	Small joints of limbs
Age	Middle age	Any age
Etiology	Wear and tear with aging and joint overdose	Autoimmune disease, genetic and environmental factors
Pain	Worsens with activity	Constant joint pain, more in morning
Symmetry	Typically, unilateral	Often bilateral (symmetrical)

Some Interesting Facts

- Close packed position is the most stable position of the body.
- Loose packed position is the most unstable position of the joint.
- Shoulder joint is the most unstable joint in the body.
- Iliofemoral ligament is the strongest ligament of the body.

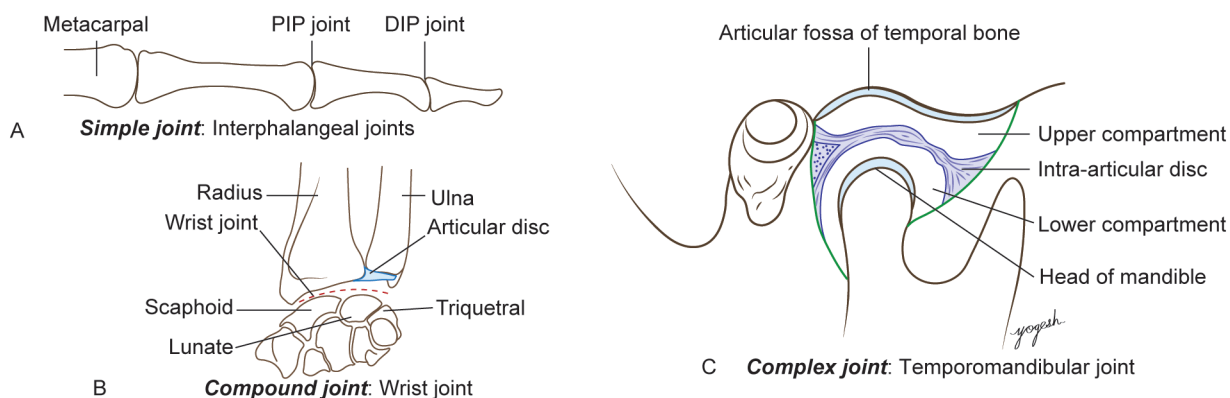


Fig. 5.16: Simple, compound, and complex joints (PIP: Proximal interphalangeal joint, DIP joint: Distal interphalangeal joint)

MOVEMENTS OF SYNOVIAL JOINTS

- The movements of the synovial joints are grouped as
 - Active movements:** These are produced when an individual uses his/her own muscles and strength.
 - Passive movements:** These are produced when external force acts at the joint. It may include gravity or force by the examining doctor.
- Active movements are further subdivided as follows:
 - Gliding or slipping movements.
 - Angular movements: Flexion, extension, adduction, and abduction.
 - Rotary or circular movements
 - Rotation
 - Circumduction
 - Special movements: Inversion, eversion, protraction, retraction, elevation, depression.

Gliding Movements

- They take place in plane synovial joints. In these movements, one bone slips over the other to limited extent.
- Gliding movements occur in small joints of hands, foot, and vertebral column.

Flexion and Extension

- Flexion is the movement that decreases the joint angle, whereas the extension increases the joint angle.
- These movements occur around transverse axis.
- For example:**
 - At elbow joint, the flexion decreases angle from 180° , whereas extension increases angle up to 180° . Forward movement of forearm is flexion, whereas its reverse movement is extension at elbow joint.
 - In ankle joint, in flexion, the dorsum of foot is elevated. Hence, it is termed *dorsiflexion*. In reverse, the plantar aspect of foot is depressed; hence termed *plantarflexion*.

Adduction and Abduction

- Adduction** is the movement of body parts towards the mid-sagittal plane of the body.

- Abduction** is the movement of body parts away from the midsagittal plane of the body.
- Adduction and abduction occur around the antero-posterior axis except in carpometacarpal joint of thumb where it occurs around the transverse axis.
- For adduction and abduction of fingers, the middle finger represents the axis of hand, whereas for toes, the second toe represents the axis of foot.

Rotation

- Rotation occurs around a vertical axis.
- For example**
 - Medial and lateral rotation of humerus around its vertical axis
 - Turning head from side to side (no movements) at atlanto-axial joint around the axis passing through the dens/odontoid process of axis passing through the dens/odontoid process of axis vertebra
 - Supination and pronation of forearm.

Circumduction

- Circumduction is the combination of four angular movements (flexion and extension, adduction and abduction) in successive orders, describing a cone.
- In circumduction, the base of the cone is formed by the distal end of the moving body part and apex by the joint.
- Circumduction is possible in biaxial and multiaxial joints such as shoulder, hip, and ankle joints.

Special Movements

Inversion and eversion

- In *inversion*, the sole of foot faces inward and medially, and the medial border of the foot is raised.
- In *eversion*, the sole of foot faces outward and laterally, and the lateral border of the foot is raised.
- These movements help in walking on uneven surfaces.

Protraction and retraction

- In *protraction*, the body part is moved forward in a plane parallel to the ground.

- In *retraction*, the protracted body part is moved backward in a plane parallel to the ground.
- For example: Protraction and retraction of mandible (lower jaw).

Elevation and depression

- In *elevation*, the body part is moved upward, whereas in *depression*, the body part is moved downward.
- For example, depression of mandible in opening the jaw, elevation of mandible in closing the jaw.

Accessory movements

- Accessory movements cannot be performed by the individual but can be performed by examiner by applying external forces.
- Accessory movements include actions such as joint distraction (pulling the joint apart), joint compression (pushing the joint together) and joint rotation (twisting the joint). These are usually performed by physiotherapist to assess and treat the musculoskeletal problems.

BLOOD SUPPLY AND INNERVATION OF SYNOVIAL JOINTS

Blood Supply

- Synovial joints receive blood supply through peri-articular network of arteries called *circulus articularis vasculosus*.
- This network is derived from epiphyseal vessels and other surrounding vessels.

Nerve Supply

- The synovial joint receives the following nerve fibers.
 - Sensory fibers that convey pain sensation
 - Sensory fibers that convey proprioception
 - Autonomic fibers which are vasomotor

Some Interesting Facts

- The joint capsule has numerous Ruffini's corpuscles that act as proprioceptive receptors.
- The joint capsule, ligaments, and synovial membrane have free nerve endings that are sensitive to pain.
- Articular cartilage and intra-articular discs have no nerves. Synovial membrane is highly vascular. Articular cartilage is avascular.

Hilton's law Viva

Hilton's law states that the nerves supplying the joint also supply (Fig. 5.17):

1. The muscles that act on that joint and
2. The skin covering the joint.

Clinical significance: The irritation of the nerves supplying the joint due to trauma or any other disease causes reflex spasm of the muscle. This fixes the joint in a position of greater comfort. The pain of the joint is referred to the skin covering the joint.

- **Gardner's observation:** The part of the joint capsule that is rendered taut by the contraction of a group of muscles is supplied by a nerve that innervates their antagonistic muscles. This is essential for joint stability.

- **Segmental innervation of muscles regulating joint movements of the limbs**

According to Last's formulation: Four continuous spinal segments control the movement of a particular joint as follows (Fig. 5.18):

- Upper two spinal segments control one movement
- Lower two spinal segments control opposite movement.

For example:

Joint	First action and segmental innervation	Opposite action and segmental innervation
Hip	Flexion: L2, L3	Extension: L4, L5
Knee	Extension: L3, L4	Flexion: L4, L5
Ankle	Dorsiflexion: L4, L5	Plantar flexion: S1, S2

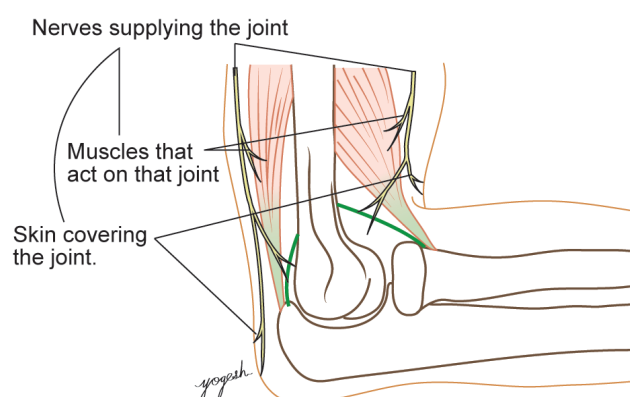


Fig. 5.17: Hilton's law

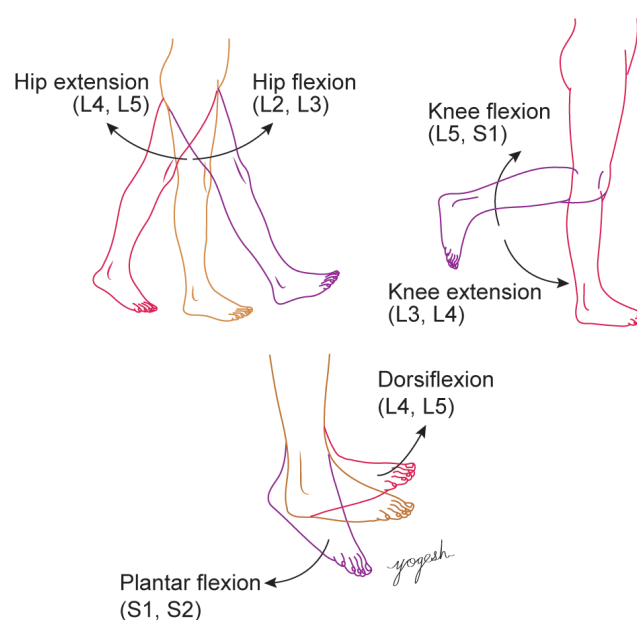


Fig. 5.18: Last's formulation: Segmental innervation of lower limb joints

FACTORS MAINTAINING THE STABILITY OF JOINTS

- The stability of the synovial joints is maintained by the following factors:
 - Shape of the bones provides stability to the joints, especially in hip joint, the head of femur fits in the socket of hip bone, and in ankle joint, the malleoli of tibia and fibula hold the talus in position.
 - Ligaments prevent the excessive movements of the joint.
 - Muscles and tendons: The tone of different groups of muscles acting at the joint is the most important and indispensable factor in maintaining the stability of the joint.

Clinical Integration

- Dislocation of joint:** It is a condition in which the bones forming the joint are forced out of their normal position, causing a separation of the joint surfaces.
- Causes of dislocation of joint:** Trauma, muscle weakness, muscle paralysis, overstretching of joints.

POSITION OF THE JOINT

Close Packed Position

- In this position, the joint surfaces become completely congruent, their area of contact is maximal, and they are tightly compressed.
- In this position joint capsule and supporting ligaments are taut, hence no further movements are possible, and the surfaces cannot be pulled apart.
- In this position, articular surfaces become prone to trauma.

Loose Packed Position

- In this position, the articular surfaces are incongruent, and joint space is freely mobile. Joints are prone to dislocation in this position (Table 5.3).

BIOMECHANICS OF BODY

- Biomechanics** is the study of mechanics and movements including analysis of forces, motion, and structural aspects of the body.
- Kinesiology** is the study of geometry of survives and their associated movements. It is the science of movements.

Planes of Motion

- They include the following planes:
 - Sagittal plane:** It divides the body into two equal halves, right and left.
 - Coronal or frontal plane:** It passes longitudinally at right angle to the sagittal plane. It divides the body into anterior and posterior portions.
 - Horizontal or transverse plane:** It is a cross-sectional plane that passes parallel to the horizon

TABLE 5.3: Close and loose packed position of the joints

Joint	Close packed position	Loose packed position
Shoulder	Abducted and laterally rotated	Semi-abducted
Elbow	Fully extended	Slightly flexed (70–80°) with midprone forearm
Hip	Extended and medially rotated	Semiflexed
Knee	Fully extended	Semiflexed
Ankle	Dorsiflexed	Plantarflexed

and divides the body into upper and lower portions.

- Axis of rotation** is the imaginary line around which the bone rotates.
- Degree of freedom** is the number of independent movements allowed at a joint.
- A joint has up to 3 degrees of angular freedom. For example: Flexion and extension in sagittal plane; adduction and abduction in coronal plane; and internal and external rotation in horizontal plane.

Levers

- Definition:** A lever is a rigid segment or beam that moves or rotates around a fixed hinge or fulcrum
- For movements of the lever, force is required to overcome the resistance.
- In the human body, the joint system consists of
 - Fulcrum (F)** is a synovial joint.
 - Lever (L)** is represented by rigid bones.
 - Resistance (R)** is represented by the weight of the body part or gravity.
 - Force or effort (E)** is generated by muscles that move lever (bones) at the fulcrum (joint) against the resistance (body weight).

Classes of Levers

- Based on the position of joint/fulcrum and force/efforts of the muscles and resistance/load of the body of weight, the levers are classified into three types:

First-class lever

- Here, the joint (fulcrum, F) is located between the pull of contracting muscles (effort, E) and the weight of the body part (resistance, R) (Fig. 5.19).
- Examples:**
 - Action: Turning the face upward
 - Fulcrum: Atlanto-occipital joint
 - Efforts: Posterior neck muscles
 - Resistance: Weight of the skull.

Second-class lever

- Here, the weight of the body part (resistance, R) is located between the joint (fulcrum, F) and the pull of the contracting muscles (effort, E) (Fig. 5.19).

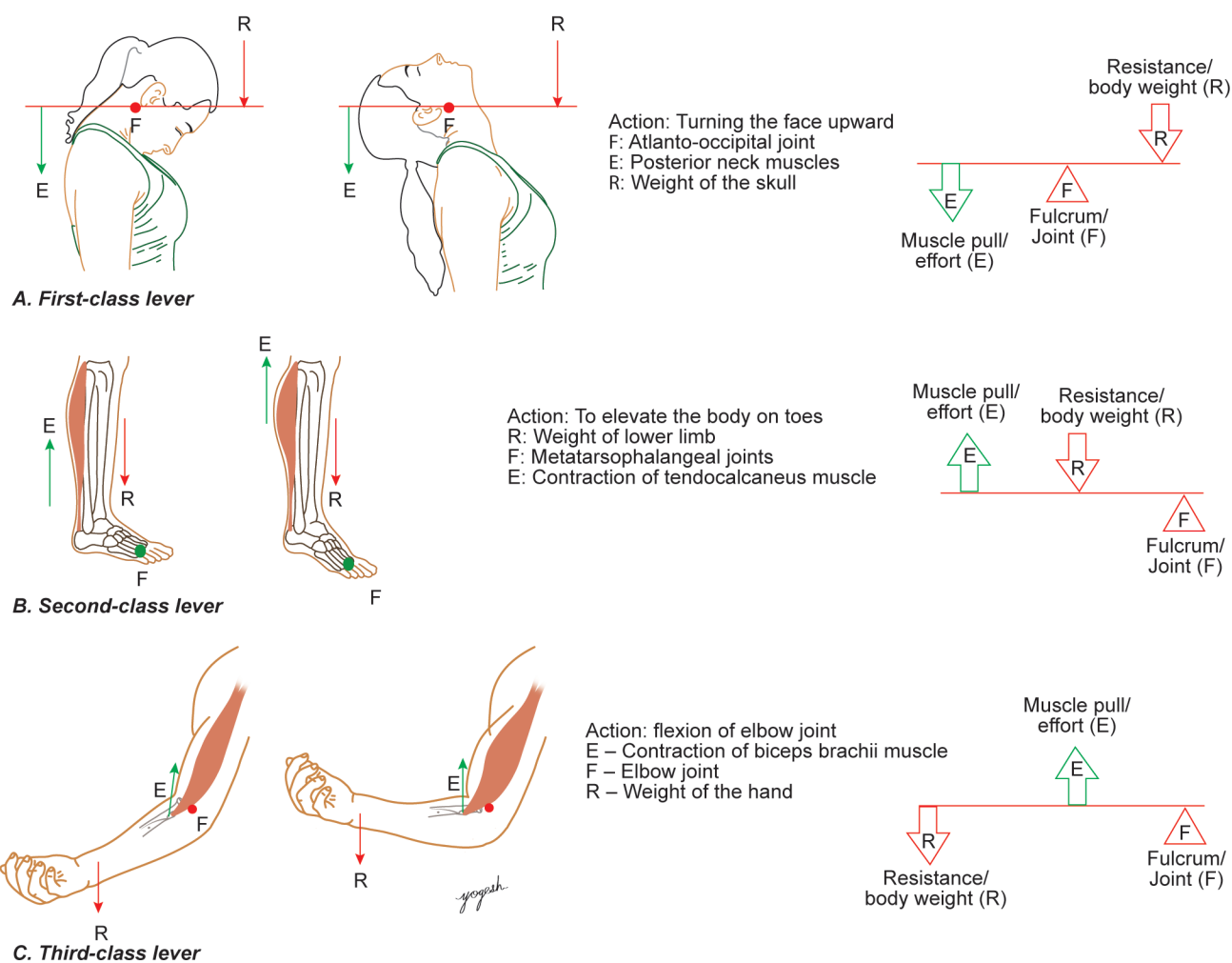


Fig. 5.19: Classes of levers

- *Example:*
 - Action: To elevate the body on toes
 - Resistance (R): Weight of lower limb
 - Fulcrum (F): Metatarsophalangeal joints
 - Efforts (E): Contraction of tendocalcaneus muscle.

Third-class lever

- Here, the pull of contracting muscles (effort, E) is located between the joint (fulcrum, F) and the weight of the body part (resistance, R) (Fig. 5.19).
- *For example:*
 - Action: Flexion of elbow joint
 - Effort (E): Contraction of biceps brachii muscle

- Fulcrum (F): Elbow joint
- Resistance (R): Weight of the hand.

Some Interesting Facts

- First-class levers help for maintenance of balance, for example, balancing head on the first cervical vertebra requires a small amount of effort to lift the body weight.
- Second-class levers are best suited for power. For example, to elevate the body weight on toes. They can carry a reasonable amount of weight but to a lesser extent.
- Third-class levers are best suited for range of motion. For example, flexion at elbow joint. They can lift great weight to a greater extent.

Muscular System



Competencies:

- AN3.1** Classify muscle tissue according to structure and action
- AN3.2** Enumerate parts of skeletal muscle and differentiate between tendons and aponeurosis with examples.
- AN3.3** Explain shunt and spurt muscles.

INTRODUCTION

- Muscle is a contractile tissue. The muscle tissue consists of the cells called *myocytes* or *muscle fibers*. The myocyte is elongated or spindle-shaped cell (*mus* = mouse, in Latin).
- In muscle,
 - *Sarcolemma* is plasma membrane.
 - *Sarcoplasm* is cytoplasm.
 - *Sarcoplasmic reticulum* is endoplasmic reticulum.
 - *Sarcosome* is mitochondria (*sarcos* = flesh, *plasma* = thing in Greek).
- All the muscles are derived from mesoderm except a few are derived from ectoderm such as arrector pilorum, muscles of iris, myoepithelial cells of glands.

Major Functions of the Muscular System

1. Movement of body
2. Maintenance of posture
3. Respiration
4. Production of body heat
5. Communication speaking, writing facial expression
6. Contraction of organs and vessels
7. Pumping of blood.

CLASSIFICATION OF MUSCLES

Structural Classification

- Structurally the muscle is classified based on the presence of striations in their cytoplasm as follows (Fig. 6.1, Table 6.1, Flowchart 6.1):
 1. *Striated muscles*: Skeletal muscle, cardiac muscle
 2. *Nonstriated muscles*: Smooth muscle.

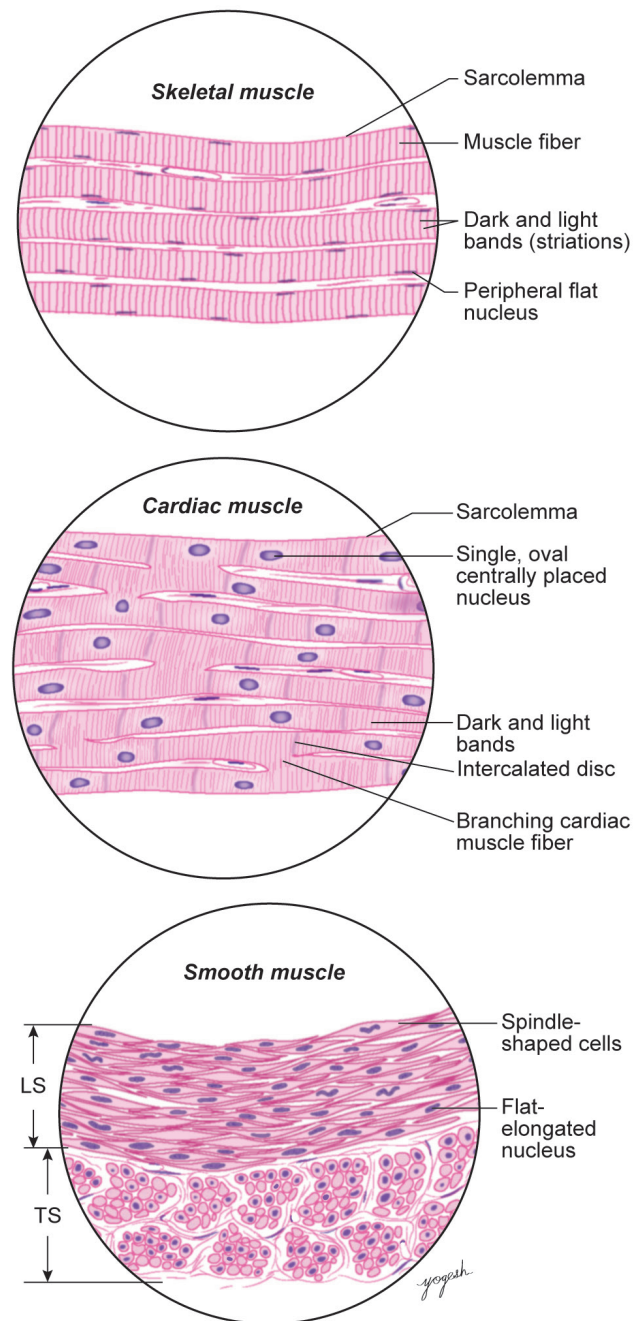
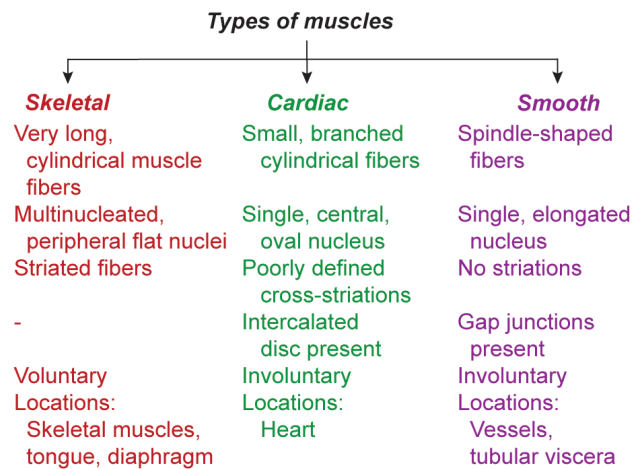


Fig. 6.1: Types of muscles (LS: Longitudinal section, TS: Transverse section)

Flowchart 6.1: Types of muscles

Functional Classification

- Based on physiological control, the muscles are classified as follows:
 1. *Voluntary muscles*: Skeletal muscles
 2. *Involuntary muscles*: Cardiac muscles, smooth muscles.
- Voluntary muscles are under control of our will.
- The differences between skeletal, cardiac, and smooth muscles are listed in Table 6.1.
- Some cells have developed contraction capacity, these are myoepithelial cells and myofibroblasts.
 1. *Myoepithelial cells* are spindle-shaped epithelial cells. They are located around the secretory acini of glands. They lie between the basement membrane and epithelial cells. They help in expulsion of secretion in these glands.
 2. *Myofibroblasts* appear at the site of wound healing, and their contraction helps in wound healing.

BASIC PROPERTIES OF MUSCLES

- The muscles have the following four basic properties:
 1. *Contractility* is the ability to shorten with force.
 2. *Excitability* is the capacity to respond to stimuli which may be neuronal or chemical.
 3. *Extensibility* is the capacity to regain the normal shape on removal of stimulus.
 4. *Elasticity* is the capacity to assume a desired shape regardless of the stretch.

SKELETAL MUSCLES

- These are most abundant muscle in the human body. They are also called striated or somatic or voluntary muscle.

Part of Skeletal Muscle

- Typical skeletal muscle has two ends — origin and insertion and two parts — fleshy and fibrous (Fig. 6.2).

Two Ends

- Typical muscle has two ends as follows:
 1. *Origin* is the end of muscle that remains fixed during the contraction.
 2. *Insertion* is the end of the muscle which moves during the contraction.

Note: If by the external force, the insertion end of the muscle is fixed, then the origin end of the muscle will move during muscle contraction. This is called *reversal of muscle action*.

Recent concept: Some authors use proximal and distal attachments instead of origin and insertion. In limbs, origin is proximal attachment, whereas insertion is distal attachment.

TABLE 6.1: Differences between skeletal, cardiac, and smooth muscles

Q. List the differences between skeletal, cardiac, and smooth muscles.

Characteristic feature	Skeletal muscle	Cardiac muscle	Smooth muscle
Muscle fiber	Very long, unbranched cylindrical (20 μm –12 cm)	Small, branched cylindrical (50 μm –100 μm)	Small, unbranched spindle-shaped (20 μm –5 mm)
Nuclei	Multinucleated, peripherally placed, flat	Single, centrally placed, oval	Single, centrally placed, elongated
Striations	Well-defined cross-striations	Poorly-defined cross-striations	Absent
Cell junction	Absent	Intercalated discs	Gap junctions
Function	Voluntary	Involuntary	Involuntary
Innervations	Motor nerves	Autonomic nerves	Autonomic nerves
Mitosis	None	None (new concept: limited)	Present
Regeneration after injury	Limited	None	Present
Rhythmicity	Absent	Present	Present
Function	Movements of body parts	Pumping of blood from heart	Movement of viscera
Stretch receptors	Present	Absent	Absent
Locations	Skeletal muscles, tongue, esophagus, diaphragm	Heart, superior and inferior vena cava, pulmonary veins	Vessels, tubular viscera, and organs

Two Parts

- Typical skeletal muscle has two parts as follows (Fig. 6.2):
 1. *Fleshy part*: It is contractile portion and is called 'belly.'
 2. *Fibrous part*: It is noncontractile and inelastic part. Fibrous part may be:
 - a. *Tendon* – cord or rope-like fibrous part
 - b. *Aponeurosis* – flatted fibrous sheet.

Raphe

- Raphe is a linear fibrous band formed by the interdigitation of the muscle fibers. It is stretchable (Fig. 6.3).
- Examples:
 - Linea alba
 - Pterygomandibular raphe
 - Mylohyoid raphe
 - Pharyngeal raphe
 - Anococcygeal raphe.

Clinical Integration

Q. List the common sites of intramuscular injections.

- *Intramuscular injection*: The fleshy part of the skeletal muscle is commonly utilized by giving intramuscular injections (Fig. 6.4).
- The common sites of intramuscular injection are as follows:

Muscle	Site
1. Deltoid muscle	Middle part of deltoid muscle (upper and outer quadrant of shoulder region)
2. Gluteus maximus	Upper and outer quadrant of gluteal region
3. Vastus lateralis	Anterolateral aspect of middle part of thigh

MICROSCOPIC STRUCTURE OF SKELETAL MUSCLE

- Skeletal muscle consists of
 1. Muscle fiber
 2. Supporting tissue

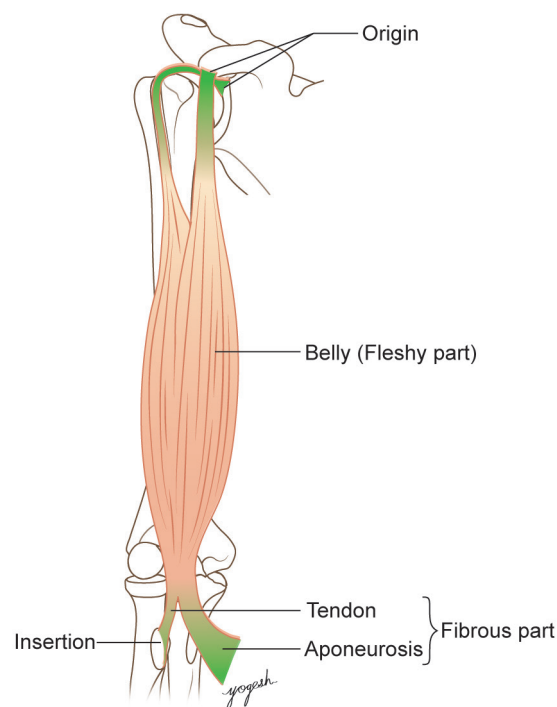


Fig. 6.2: Part of skeletal muscle

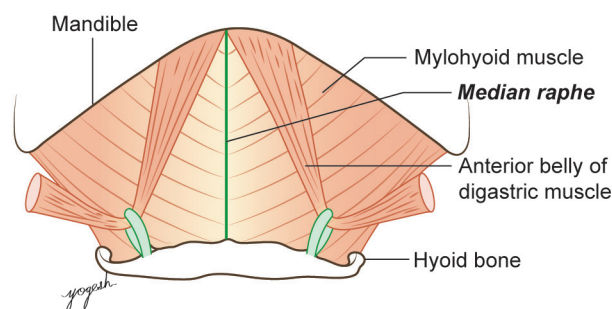


Fig. 6.3: Raphe: Median raphe of mylohyoid muscle

- Supporting tissue of the skeletal muscle: It consists of (Fig. 6.5)
 1. *Endomysium* – is a layer of reticular fibers that covers individual muscle fibers.
 2. *Perimysium* – covers a bundle or fascicle of muscle fibers.
 3. *Epimysium* – covers the entire muscle.
- Supporting tissue becomes continuous with a tendon, at the junction of muscle and belly. Blood vessels and nerve fibers are present in all layers of connective tissue.

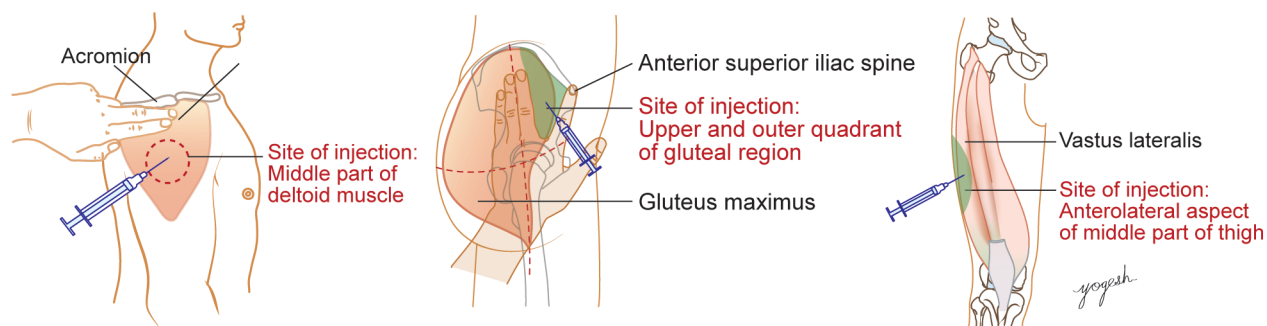


Fig. 6.4: Common sites of intramuscular injections

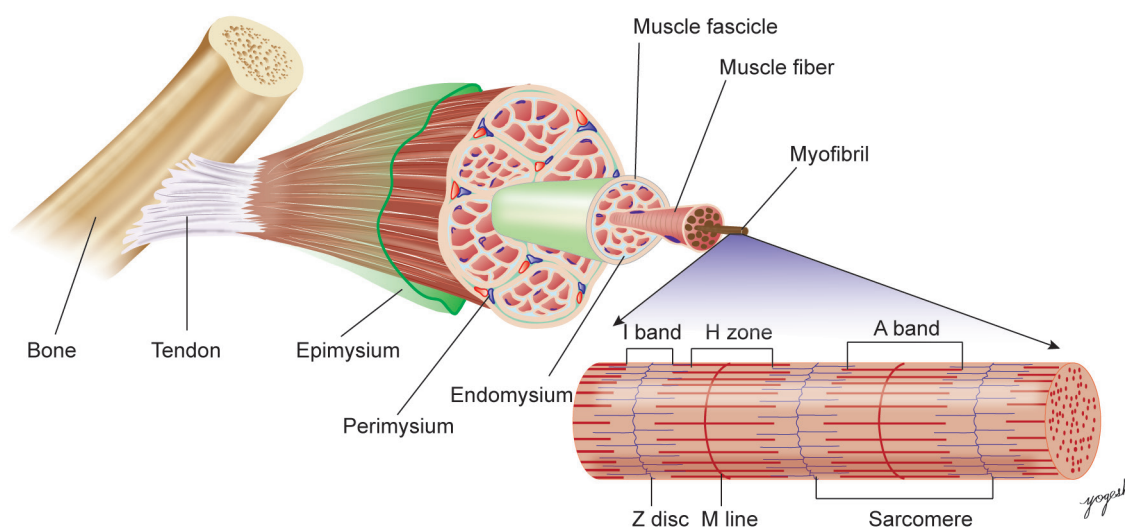


Fig. 6.5: Structure of skeletal muscle. The entire skeletal muscle is covered by epimysium. Perimysium covers a bundle of muscle fibers called fascicles, whereas endomysium is a layer of reticular fibers that cover an individual muscle fiber

Muscle Fibers

- These are contractile parts of skeletal muscle.
- Each muscle fiber (muscle cell or myocyte) is long (10–100 mm).
- *Multinucleated syncytium*: Each muscle fiber is cylindrical it has multiple oval flat nuclei located at the periphery of the fiber just beneath the plasma membrane.
- Sarcoplasm (cytoplasm) shows transverse striations of alternate dark and light bands due to longitudinally oriented myofibers.
- Myofibers consist of bundles of myofilaments. These are of two types: Thick or myosin filaments and thin or actin and associated filaments. The arrangement of myofilaments gives striated appearance to muscle fiber.

- In polarized light microscope, muscle fibers show *dark or anisotropic (A) band* and *light or isotropic (I) band* (Fig. 6.6).
- In the center of light (I) band a dark *Z line* (Z-disc, Zwiischenscheibe line) is present.
- In the center of dark (A) band, a narrow lighter zone called *H band* is present. In the center of H-band, a central dense *M-line* is present.
- *Sarcomere* is the structural and functional unit of myofibrils. It lies between two adjacent Z line, it is about 2–3 μm .

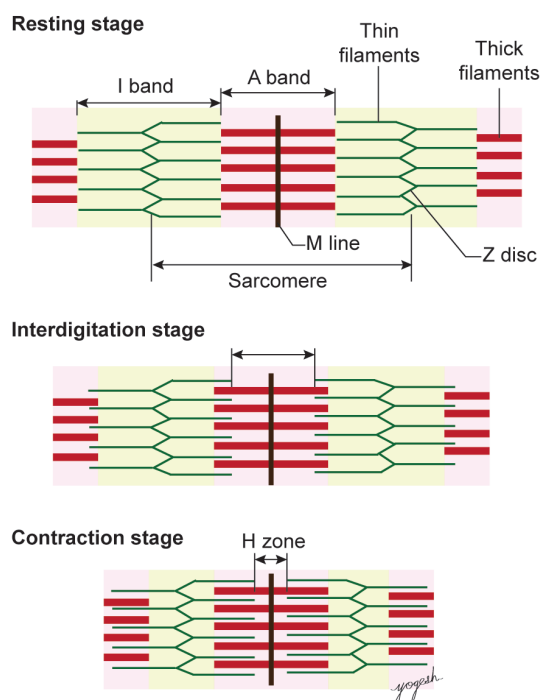


Fig. 6.6: Ultrastructure of skeletal muscle and sliding filament theory (sarcomere length in different stages of muscle contraction.)

Some Interesting Facts

- *Myofibrils*: There are two types of myofibrils: Thin and thick filaments.
- *Thick filaments* mainly consist of myosin II molecules which show projecting myosin heads. These myosin heads have two binding sites: One for ATP and another for actin.
- *Thin filament* consists of two chains of actin and associated proteins, such as tropomyosin and troponin complex. Troponin complex consists of troponin C (binds Ca^{++}), troponin T (binds with tropomyosin), and troponin I (binds with actin chain) (Fig. 6.6).
- *Muscle contraction*
 - During muscle contraction, the length of sarcomere shortens due to overlapping of thick and thin filaments.
 - According to sliding filaments theory, nerve stimulation induces Ca^{++} ion release in sarcoplasm. This Ca^{++} binds with troponin C and exposes myosin binding sites of action, then myosin heads bind with actin filament. Further, attachment of ATP releases the myosin head from actin, and energy released in conversion of ATP to ADP induces bending of myosin heads and causes power stroke. Binding of myosin heads to new site of actin induces next cycle. This process causes movement or sliding of thin filament over thick filament.

Clinical Integration

- **Rigor mortis:** It is stiffening of the muscles of the body after death. It starts with 2 to 4 hours after death lasts for 2 to 4 days, and there after gradually disappears.
Explanation: For muscle relaxation, the bond between myosin and actin should be released, which requires ATP molecules. After death, there is depletion of ATP, and the muscles remain in contracted state. ATPs are also required to pump out Ca^{++} ions from muscle fibers. Lack of ATPs results in gradual accumulation of Ca^{++} in muscle $\rightarrow$ muscle contraction. After 2 days, the cellular enzymes and natural decomposition break down the muscle proteins and cause release of rigor mortis.

TYPES OF SKELETAL MUSCLES FIBERS

Q. List the differences between red and white fibers.

- Based on the diameter and color, the muscle fibers are grouped as type I or red fibers and type II or white fibers (Table 6.2).
- **Type I or red fiber:** These are slow twitch or slow oxidative fibers. They contract slowly, but their contractions are more sustained. They are resistant to fatigue. For example, postural muscles, muscles of limbs. ^{MCQ}
- **Type IIb or white fibers:** These are thick fibers or fast glycolytic fibers. They are high twitch fibers that can generate more force of contraction. They mostly generate energy from anaerobic glycolysis and hence fatigue easily. Example: Muscle of eyeball and fingers. ^{MCQ}
- **Type IIa or intermediate fibers:** These are medium-sized fibers.

TABLE 6.2: Differences between red fibers and white fibers

Characteristic	Red fibers	White fibers
Another name	Type I or slow oxidative fibers	Type IIb or fast glycolytic fibers
Fiber diameter	Small	Large
Color in living	Red	Light pink
Myoglobin quantity	More	Less
Mitochondria	More	Less
Force of contraction	Weak	Strong
Mode of contraction	Slow-twitch	Fast-twitch
Fatigability	Resistant to fatigue	Easily fatigued
Mode of energy generation	Oxidative phosphorylation	Anaerobic glycolysis
Glycogen content	Less	More
Examples	Postural and limb muscles	Precise, rapid muscles: Muscles of eyeball, fingers
Blood supply	Rich	Poor
Nerve supply	Small nerve fibers	Large nerve fibers

Clinical Integration

- Red fibers are useful for long distance running. White fibers are useful for rapid and skilful movement. Exercise improves aerobic metabolism of red fibers.

FASCICULAR ARCHITECTURE

- The muscles may have varied fascicular arrangements: Parallel, convergent, spiral, cruciate, sphincteric, and pennate (Fig. 6.7).

Parallel Muscle

- The muscle fasciculi are parallel to the line of muscle pull. The arrangement provides maximum range of movement. They have less number of fibers and; hence, produce less force of contraction.
- The parallel fasciculi may have the following arrangements:
 1. *Quadrilateral.* Example: Thyrohyoid, pronator quadratus.
 2. *Strap-like* with tendinous intersections. Example: Rectus abdominis.
 3. *Fusiform.* Example: Biceps brachii, digastric.

Convergent Muscle

- The muscle fasciculi converge at the insertion point, these are powerful muscles with a limited range of movement.
- The convergent arrangement may be:
 1. *Triangular.* Example: Adductor longus
 2. *Fan-shaped.* Example: Temporalis.

Spiral or Twisted Muscle

- The muscle fasciculi have twisted arrangements near the muscle insertion, such arrangements help to change the direction of pull.
- *Example:* Pectoralis major, trapezius, latissimus dorsi, supinator.

Cruciate Muscle

- The muscle fibers are arranged in strata which cross each other in the form of 'X' manner.
- *Examples:* Sternocleidomastoid, masseter, adductor magnus.

Sphincteric Muscle

- The muscle fasciculi are arranged around the opening or orifice their contraction close the opening.
- *Examples:*
 1. Orbicularis oculi around the palpebral fissure (eye).
 2. Orbicularis oris around the oral orifice (mouth).

Pennate Muscle

- The fasciculi are arranged in an oblique manner to the line of muscle pull the arrangement resembles the

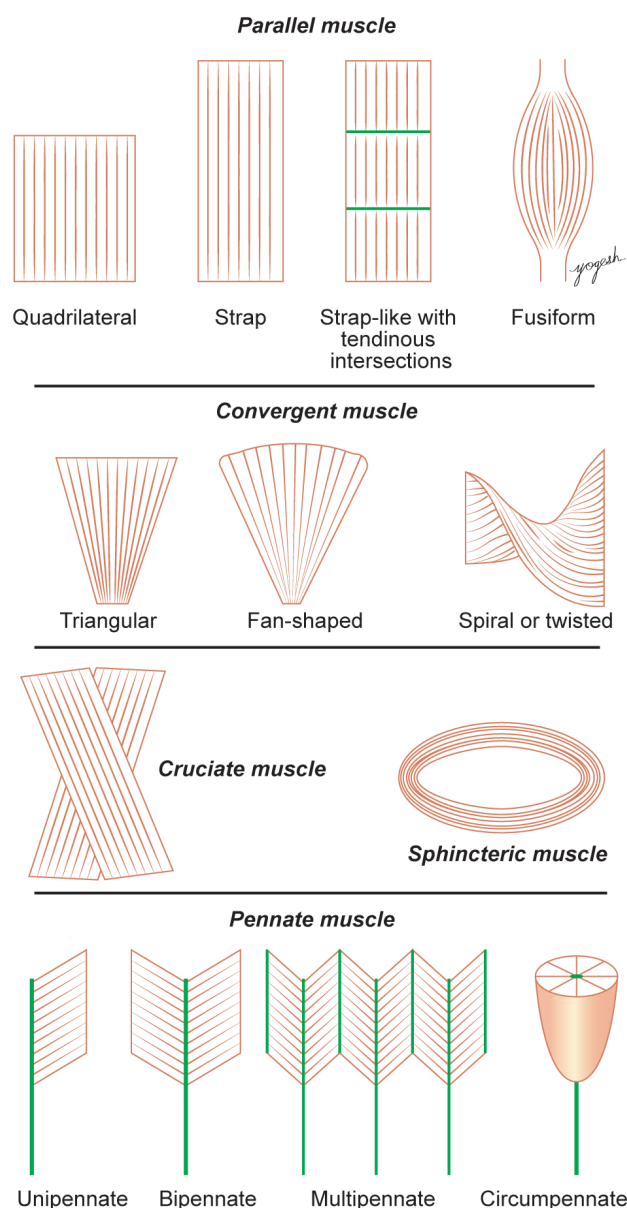
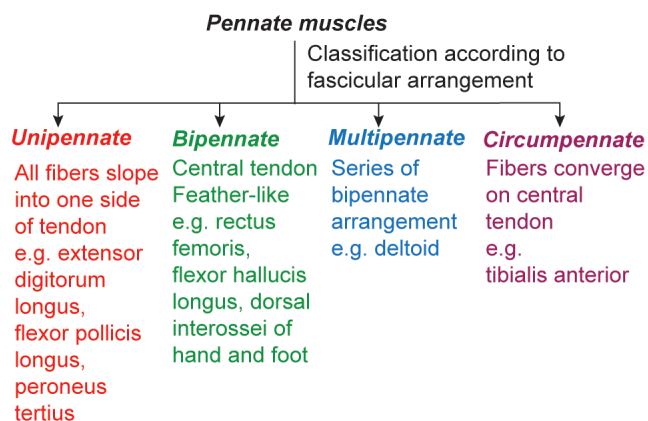


Fig. 6.7: Fascicular architecture of skeletal muscle

feather; hence, termed pennate. It has greater force of contraction. It has the following subtypes (Flowchart 6.2):

1. **Unipennate:** All the fibers slope into side of the tendon along one. It gives one-half feather appearance. Examples, extensor digitorum longus, flexor pollicis longus, peroneus tertius.
2. **Bipennate:** Tendon is formed in the central axis, and muscle fibers slope into two sides of the central tendon. It gives feather-like appearance. Examples, rectus femoris, flexor hallucis longus, dorsal interossei of hand and foot.
3. **Multipennate:** It has a series of bipennate arrangements. It has multiple septa that give origin and another set of septa that give insertion. For example, deltoid.
4. **Circumpennate:** It has a central tendon and fibers converge from all directions on the tendon. Example: Tibialis anterior.

Flowchart 6.2: Pennate muscles



NOMENCLATURE OF MUSCLES

- The muscles are named according to location, shape, action, number of heads, attachments, direction of fibers, size of muscle, and so on.

Location

Anterior: Tibialis anterior

Posterior: Tibialis posterior

Lateral: Vastus lateralis

Medial: Vastus medialis

Superior: Superior rectus of eyeball, supraspinatus

Inferior: Inferior rectus of eyeball, infraspinatus.

Region

Back (dorsal side): Latissimus dorsi

Pectoral region: Pectoralis major

Temporal fossa: Temporalis

In between ribs: Intercostal muscles

Gluteal region: Gluteus maximus

Femoral region: Rectus femoris.

Shape

Triangular: Deltoid

Quadrangular: Quadratus femoris

Rhomboid (diamond): Rhomboid major

Trapezoid: Trapezius

Serrated: Serratus anterior

Straight (rectus): Rectus abdominis

Slender: Gracilis

Round (teres): Teres major.

Actions

Flexor: Flexor carpi ulnaris

Extensor: Extensor digitorum

Adductor: Adductor longus

Abductor: Abductor pollicis longus

Supination: Supinator

Pronation: Pronator teres

Elevation: Levator scapuli
Depression: Depressor anguli oris
Dilator: Dilator pupillae
Constrictor: Constrictor pupillae.

Number of Heads or Parts

Two: Biceps brachii
Three: Triceps brachii
Four: Quadriceps femoris
Two parts: Digastric.

Attachments

Sternocleidomastoid – attached to sternum, clavicle and mastoid process.
 Stylohyoid – attached to styloid process and hyoid bone.

Direction of Fibers

Straight: Rectus abdominis
Transverse: Transverse abdominis
Oblique: External oblique abdominis.

Size

Big: Pectoralis major
Small: Pectoralis minor
Long: Adductor longus
Short: Adductor brevis
Broad: Latissimus dorsi.

Depth

Superficial: Flexor digitorum superficialis
Deep: Flexor digitorum profundus
External: External oblique abdominis
Internal: Internal oblique abdominis.

BLOOD SUPPLY MUSCLES

1. Muscles are highly vascular to fulfil the need for metabolic activity.
2. Muscles receive neurovascular bundles through *neurovascular hiatus*. The blood vessels enter the substance of muscle and ramify into delicate capillaries in endomysium.
3. Each muscle fiber is accompanied by a set of parallel capillaries.

Some Interesting Facts

- One square cm of the muscle is supplied by about 8 m long capillary bed.
- The entry point of artery into muscle may be as follows:
 1. At one end of the muscle, such as gastrocnemius
 2. In the middle of the muscle, such as biceps brachii
 3. By multiple anastomosing vessels, such as adductor magnus.

- *Vascular pedicle* of a muscle is a segment of the muscle supplied by a single artery and vein. Based on the number of the vascular pedicles, the muscles are classified into the following types:

1. Type I muscles have a single vascular pedicle. For example, tensor fascia lata.
2. Type II muscles have single dominant and several minute vascular pedicles. For example, gracilis.
3. Type III muscles have two dominant vascular pedicles from two different source arteries. For example, gluteus maximus.
4. Type IV muscles have multiple vascular pedicles. For example, sartorius, tibialis anterior.
5. Type V muscles have one dominant and multiple secondary pedicles. For example, latissimus dorsi.

Clinical Integration

- *Muscle stiffness:* Severe exercise results in accumulation of lactic acid in muscles that cause muscle stiffness. This lactic acid is removed by venous blood slowly, and muscle stiffness gets resolved.
- *Muscle graft:* It is an important part of reconstructive and plastic surgery. Muscle graft is prepared as a part of muscle with its neurovascular bundle.

NERVE SUPPLY OF SKELETAL MUSCLE

- The muscle fibers are supplied by alpha-efferent fibers arising from multipolar anterior horn neurons of spinal cord. These are myelinated, large-diameter fibers.
- *Motor unit:* It consists of one anterior horn neuron and all the muscle fibers supplied by it. Small motor units are present in precision-acting muscles (muscles of eyeball), whereas large motor units are present in postural muscles.
- *Motor end plate:* It is the junction between muscle fiber and nerve terminal.
- Muscle spindles are the sensory organs located in the muscle. Muscle spindles are supplied by myelinated gamma efferent fibers that arise from gamma motor neurons of anterior horn of spinal cord.

Neuromuscular Junction/Motor End Plate

- It is the junctional complex of the axon terminal and muscle fiber (Fig. 6.8)
- At the terminal end, axon loses its myelination and divides into many terminal branches. Each terminal branch expands at its end (*terminal button*) and forms junctional zone of muscle fiber at *solo plate* (part of sarcolemma).
- *Terminal button* of axon contains secretory vesicles containing acetylcholine and numerous mitochondria.
- *Solo plate* or *motor end plate* forms a number of folding that contain many receptors for acetylcholine.

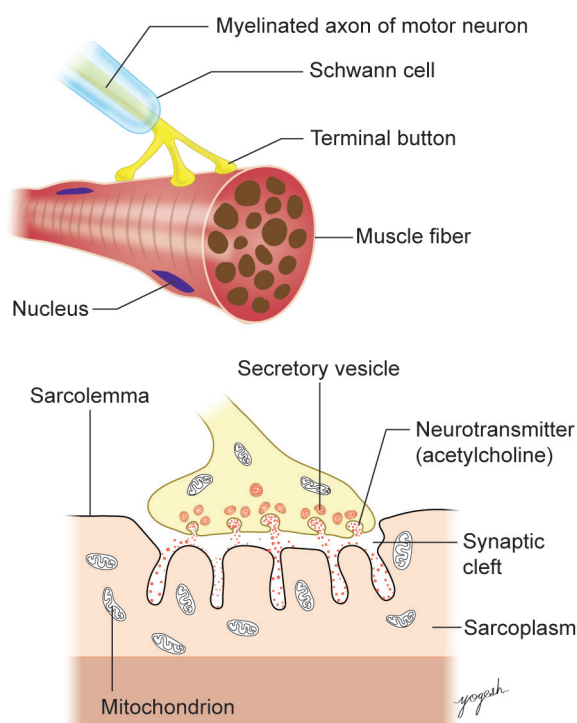


Fig. 6.8: Neuromuscular junction

- *Synaptic cleft* is the narrow gap (40–100 nm) between axonal terminal button and motor end plate. Neurotransmitter needs to cross synaptic cleft.
- Acetylcholinesterase (AChE) is the enzyme that destroys acetylcholine quickly.

Clinical Correlation

Myasthenia gravis

- It is an autoimmune disease in that antibodies are found against acetylcholine receptors (AChR). These antibodies progressively damage acetylcholine receptors and muscle slowly becomes weak (nonresponsive to acetylcholine). *Note: Myasthenia* = weakness of muscle, *gravis* = serious.
- **Neurotoxins:** Many snake venoms contain neurotoxins that bind with acetylcholine receptors. It may cause paralysis of respiratory muscles and death of the individual.

Muscle Spindle

- Muscle (neuromuscular) spindle is a spindle-shaped sensory end organ of skeletal muscles (Fig. 6.9).
- Length: 5–10 mm
- Diameter: 100 mm.

Structure (Fig. 6.9)

- It consists of capsules, sensory neurons, gamma motor neurons, and intrafusal muscle fibers.
- **Capsule:** Muscle spindle is enclosed within fusiform connective tissue fibers.
- **Intrafusal muscle fibers:** Muscle spindle has intrafusal muscle fibers that are enclosed within the capsule.

Note: Extrafusal fibers form the main bulk of the muscle.

- There are two types of intrafusal fibers:
 1. **Nuclear bag fibers:** Many nuclei are located in the middle of the fiber.
 2. **Nuclear chain fibers:** Nuclei are arranged in a single row. *Nuclear bag fibers* are long and extend outside the capsule up to the endomysium of adjacent extrafusal fibers.
- Nerve supply of muscle spindle:
 - Muscle spindle is supplied by *gamma motor neurons* and sensation is carried by sensory afferent nerve fibers (type Ia and II). *Note:* Extrafusal (main muscle) fibers are supplied by alpha motor neurons.
 - Type Ia fibers have annulospiral nerve endings that surround central area of nuclear chain and bag fibers.
 - Type II fibers have floral spray endings that are present in peripheral part of bag fibers.
 - The sensory neurons get stimulated by stretching of muscle fibers.

Functions

- During muscle contraction, stretching of muscle spindle stimulates sensory nerve fibers (type Ia and type II).
- These sensory fibers provide inputs to the CNS about muscle stretch and help modulate the activity of motor neurons supplying the same muscle.

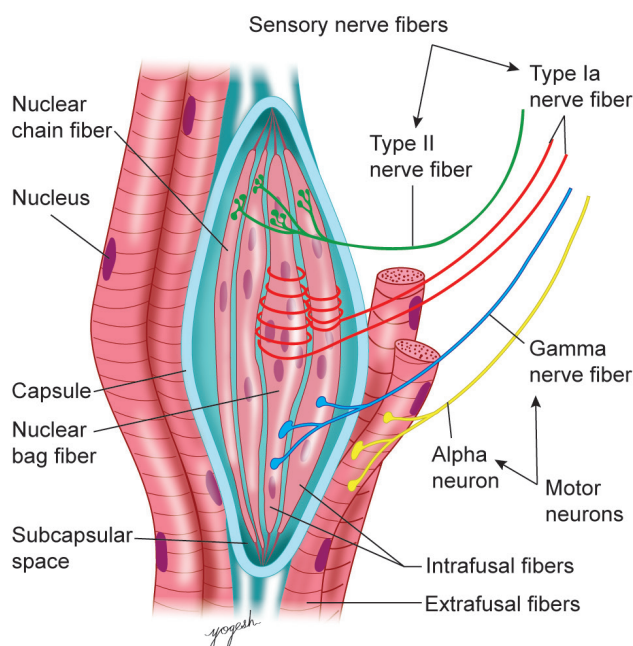


Fig. 6.9: Muscle spindle. Extrafusal (main muscle) fibers are supplied by alpha motor neurons. Muscle spindle is supplied by gamma motor neurons. Sensation is carried by type Ia fibers (annulospiral nerve endings) from central area of nuclear chain and bag fibers, whereas by type II fibers (floral spray endings) from peripheral part of bag fibers. The sensory neurons get stimulated by stretching of muscle fibers.

Clinical Integration

- **Stretch reflex:** It is a myotatic reflex. It can be elicited by a blow upon a muscle tendon that, in reflex induces muscle contraction. Blow using hammer on a tendon of muscle causes stretching of muscle spindles that, through sensory inputs, stimulate alpha motor neurons and finally produce muscle contraction. For example, biceps reflex (Fig. 6.10).
- **Stretch reflex** is the most important reflex for maintaining the health of the muscle.

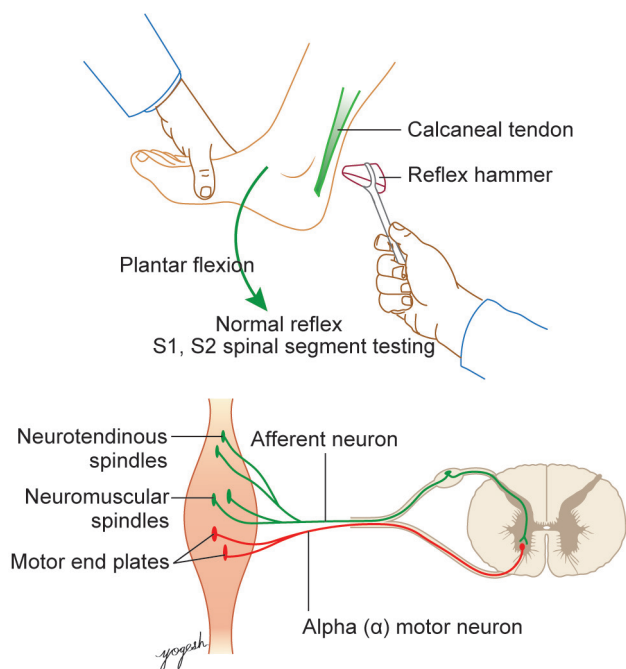


Fig. 6.10: Stretch reflex. A: Calcaneal tendon reflex. B: Pathway for simple reflex

Golgi Tendon Organ (Neurotendinous Spindles)

- It is a proprioceptive sensory receptor located at the junction of muscle and its tendon (musculotendinous junction) (Fig. 6.11).
- **Function:** It detects the changes in muscle tension during muscle contraction. It protects the muscle from

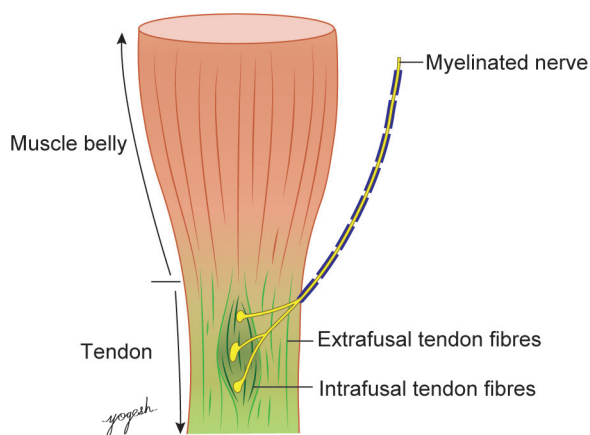


Fig. 6.11: Golgi tendon organ (a neurotendinous spindle)

damage by preventing excessive force generation. It sends the inhibitory signals to the motor neurons through inhibitory interneurons.

- **Structure:** It is a spindle-shaped encapsulated sensory unit. It consists of loosely arranged collagen fibers and club-shaped nerve endings.
- **Innervation:** It is supplied by myelinated nerve fibers that lose their myelin sheath before piercing the capsule. These neurons enter the dorsal horn of spinal cord and inhibit the anterior horn (motor) neurons through interneurons.

LUBRICATING MECHANISMS OF TENDONS

Synovial Bursa

- It is a closed sac of a membrane containing a thin film of slippery fluid (*bursa* = a purse, in Latin) (Fig. 6.12).
- The bursa is a lubricating device that helps diminish friction and allows free movement of muscle tendons.
- They are present where tendons rub against bone, cartilage, ligament, or other tendons; hence they are commonest in the limbs.
- They are also found close to the joints where skin rubs against underlying bony structures, for example, the prepatellar bursa.
- They occasionally communicate with the joint cavity, for example, suprapatellar bursa. Subdeltoid/subacromial bursa is the largest synovial bursa in the body.

Types of Bursae

The bursae are of the following three types:

1. **Subtendinous bursa:** They are present between tendon and bone, tendon and ligament, or between two adjacent tendons. Most of synovial bursae of the limbs belong to this type.
2. **Articular bursae** are present near the joints. For example, the bursa between the dens of axis (second cervical vertebra) and transverse ligament of atlas (first cervical vertebra).
3. **Subcutaneous bursae** are present between the skin and bony prominence near the joints. For example, prepatellar (housemaid's bursa) and superficial infrapatellar bursa (Clergyman's bursa).

Clinical Integration

Bursitis is the inflammation of the bursa. It leads to swelling and pain.

Adventitious bursa: These are formed from tissue spaces of loose areolar tissue subjected to continuous pressure and friction. For examples:

Porter's shoulder is the formation of bursa between clavicle and skin in porters.

Tailor's ankle is the formation of bursa between lateral malleolus and skin in tailors.

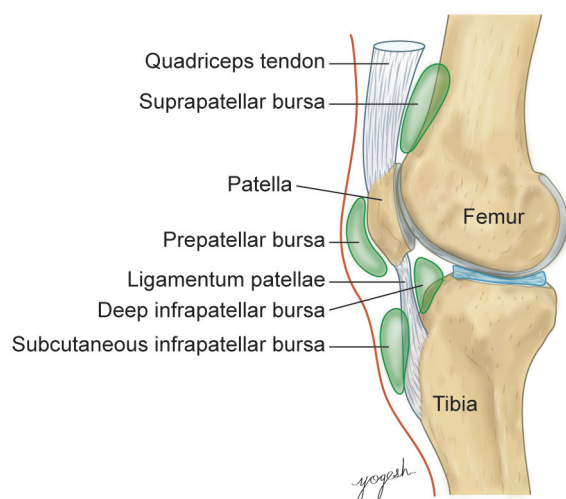


Fig. 6.12: Bursae surrounding knee (right, medial view)

Synovial Sheaths

- *Synovial tendon sheath* is a tubular synovial coat over the tendons. It is a modified bursa. It prevents friction of the tendon while passing through a tunnel (Fig. 6.13).
- It extends about 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 blood vessels and nerves enter the tendon through the mesotendon.
- The synovial sheath has two concentric layers (parietal and visceral) of synovial membrane which are separated by a thin layer of synovial fluid.
- At the site of excessive movements, the mesotendon 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.

ACTIONS OF MUSCLES

- On stimulation, the muscle contracts and produces movements. The range of the movements depends on:
 1. Length of fleshy fibers
 2. Number of fibers
 3. Power or force of contraction.

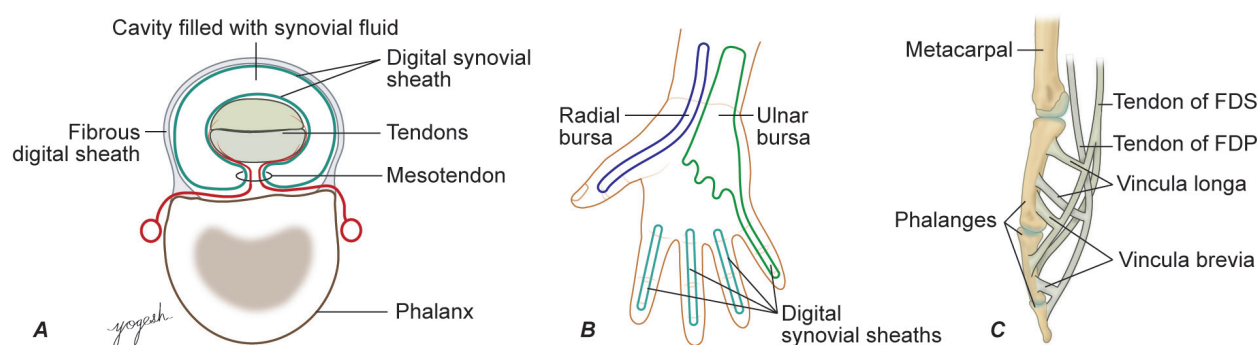


Fig. 6.13: A. Digital synovial sheath and mesotendon (cross-section of the digit, superior view). B. Synovial sheaths of the flexor tendons of hand. C. Vincula longa and brevia (FDS: Flexor digitorum superficialis, FDP: Flexor digitorum profundus).

Muscle Tone

- **Definition:** Muscle tone is the amount of tension or contraction in a muscle at rest.
- **Functions:** Muscle tone helps in maintenance of body posture and keeping body straight during sitting and standing.
- Muscle tone is maintained by a set of motor units (muscle fibers). All motor units are not contracting simultaneously. At a given time, spine of the motor units, contracts to maintain the muscle tone constantly.
- *Hypotonia* is decreased muscle tone. *Hypertonia* is increased muscle tone.
- **Factors affecting muscle tone:**
 1. Neurological conditions
 2. Exercise
 3. Age
 4. Physical therapy.

Tension and Length Relationship

- *Muscle excursion* is the displacement of myotendinous junction throughout the range of motion (Fig. 6.14).
- In muscle contraction, tension is the force built up within the muscle during muscle contraction.
- Stretching builds tension within the muscle during muscle contraction. Muscle shortens by one-half to one-third of its normal resting length during muscle contraction. The action of the muscle is strongest when it is slightly stretched.

Types of Muscle Contraction

Muscle contractions are of the following types:

1. *Isometric contractions:* The length of the muscle does not change, and tension does not increase. For example, holding the hand in outstretched position. *Viva*
2. *Isotonic contractions:* The length of the muscle changes and tension is constant. For example, the movement of fingers and hands. *Viva*
3. *Concentric contractions:* The length of the muscle decreases, tension is increased. For example, most of the movements are produced by concentric contractions.
4. *Eccentric contractions:* The length of the muscle decreases, and the desired tension is maintained. For example, lowering the arm to the side of the body.

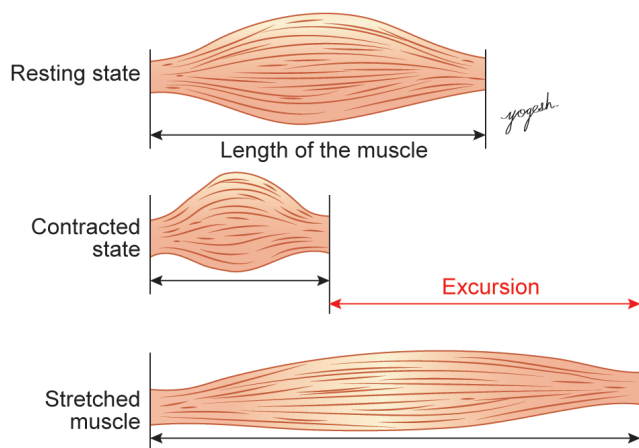


Fig. 6.14: Excursion of muscle

Active and Passive Insufficiency of Muscles

- *Active insufficiency* is the point where the muscle cannot be shortened further. It occurs in the contracting muscles.
- *Passive insufficiency* is the point where the muscle cannot be elongated any farther without damage to its fibers. It occurs in the antagonistic muscle that is relaxed during the movements.

Group Action of Muscles

- The muscles are grouped as follows:
 1. Prime movers or agonists
 2. Antagonists or opponents
 3. Fixators
 4. Synergists.

Prime Movers or Agonists

- These are the group of muscles primarily responsible for producing a specific movement at the joint. They are chief or prime muscles.
- For example, biceps brachii is a prime mover for flexion at the elbow joint (Fig. 6.15).

Antagonists or Opponents

- These are the group of muscles that oppose the action of prime movers. They undergo controlled relaxation during contraction of prime movers and help to produce smooth and precise movements.
- For example, for the flexion of the elbow joint, biceps brachii is prime mover, and triceps brachii is antagonist. These muscles reverse their role in extension at the elbow joint (Fig. 6.15).

Fixators or Stabilizers

- The fixator muscles contract to stabilize the origin of the prime mover so that it can act efficiently.
- For example, muscles around shoulder stabilize scapula so that biceps can contract to produce flexion at the elbow effectively.

Synergists

- The synergist muscles assist the prime movers in executing a movement. They do not necessarily perform the same action as the prime mover.
- If a muscle crosses more than one joint, the synergists prevent undesired action at the proximal joints.
- For example:
 1. Long flexors of fingers cross the wrist joint and other joints of fingers. While making first, extensors at wrist prevent unnecessary flexion by the long flexors of fingers at the wrist joint. Thus, here extensors of wrist act as synergists.
 2. Brachioradialis acts as a synergist to the biceps brachii to produce flexion to the elbow.

Spurt Muscle

- The spurt muscle origin at a distance from the joint and inserted near the joint where it acts. It is prime mover of the joint. For example, brachialis (Fig. 6.16).

Shunt Muscle

- The shunt muscle origin near the joint and inserted at a distance from the joint where it acts. It is a synergist. For example, brachioradialis (Fig. 6.16).

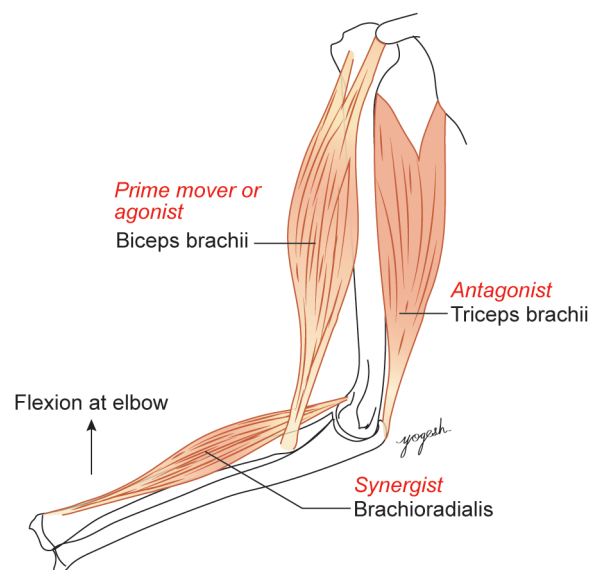


Fig. 6.15: Concept of prime mover and antagonists

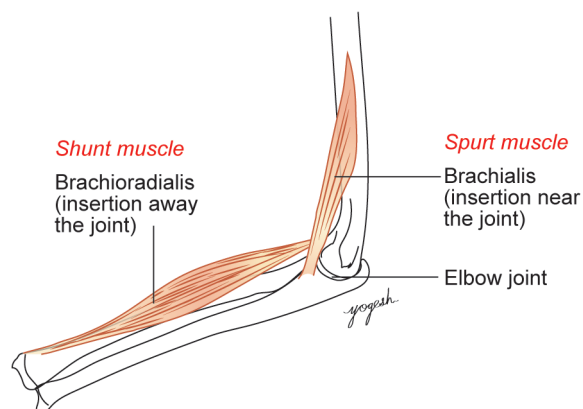


Fig. 6.16: Concept of spurt and shunt muscles

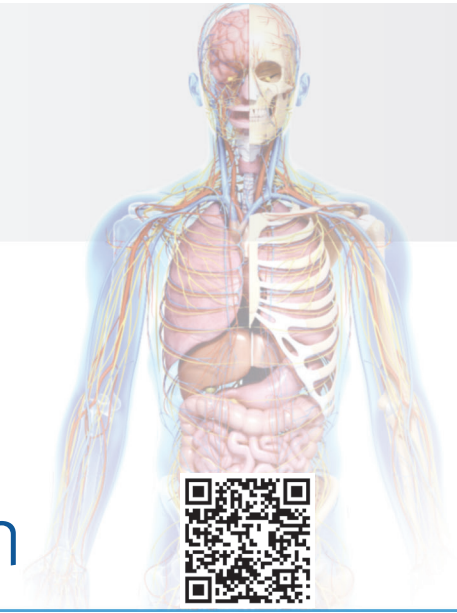
Clinical Integration

- **Poliomyelitis:** It is an infection caused by poliovirus. This virus enters the body through oral route, which later enters the nervous tissue and affects the motor neurons of spinal cord. It may cause permanent lower motor paralysis and muscle weakness.
- **Paralysis** is the loss of voluntary muscle function. It may be due to damage to brain, spinal cord, and peripheral nerves.
- **Upper motor neuron paralysis** involves loss of control of cerebral cortex over the anterior horn cells of spinal cord. It results in spastic paralysis and exaggerated tendon reflexes.
- **Lower motor neuron paralysis** involves damage to the anterior horn cells of spinal cord or peripheral nerve supplying the muscle. It results in flaccid paralysis with loss of tendon reflexes.
- **Muscle spasm** (muscle pull) is a painful contraction of the muscle. It occurs in tetanus, epilepsy, high temperature, excessive exercise, and so on.
- **Muscle atrophy:** It is a reduction in the fleshy part of the muscle due to the loss of contractile proteins. It occurs in used muscle for a long time and is called disuse atrophy.
- **Hypertrophy:** It is an increase in the size of muscle fibers. It occurs in mechanical stress such as exercise.
- **Hyperplasia:** It is an increase in the number of smooth muscle cells. For example, hyperplasia of myometrium of uterus during pregnancy.
- **Muscle injury and healing:** Skeletal muscles have limited capacity for regeneration. If a large portion of the muscle is damaged, it may be replaced by connective tissue during healing.

Some Interesting Facts

- Total number of muscles in the body are about 400.
- Gluteus maximus is the largest muscle of the body.
- Sartorius is the longest muscle of the body.
- Stapedius is the smallest muscle of the body.
- Plantaris muscle has the longest tendon. ^{MCQ}
- Achilles tendon or tendocalcaneus is the largest tendon in the body. ^{MCQ}
- It is the most commonly ruptured tendon in the body.
- **Motor unit** is the functional contractile unit of muscle. Extraocular muscle has the smallest motor unit. Muscles of lower limb have the largest motor unit. ^{MCQ}
- Red muscle or slow twitch fibers are well developed in marathon participants.
- Skeletal muscle has a few satellite cells: Hence they can repair small damage to skeletal muscle.
- In cardiac muscle, satellite cells are absent. Hence, cardiac muscle does not regenerate.
- Vestigial muscles of body: Palmaris brevis, auricle muscles.
- The most variable muscle of the body is palmaris longus muscle.
- Soleus is called *peripheral heart* as it helps in venous return. ^{MCQ}
- Muscles used for intramuscular injections: deltoid, gluteus medius, vastus lateralis.
- **Hybrid muscles** are supplied by two different nerves. For example, flexor digitorum profundus (supplied by median and ulnar nerves), adductor magnus, pectineus, and digastric.
- Smooth muscles have the highest regenerative capacity.
- Cardiac muscles can contract without nerve supply.
- Most of the muscles are supplied from their deeper aspect except sartorius, which is supplied from superficial aspect.

Cardiovascular System



Competencies:

- AN5.1** Differentiate between blood vascular and lymphatic system.
- AN5.2** Differentiate between pulmonary and systemic circulation.
- AN5.3** List general differences between arteries and veins.
- AN5.4** Explain functions and differences between elastic, muscular arteries, and arterioles.
- AN5.5** Describe portal system giving examples.
- AN5.6** Describe the concept of anastomoses and collateral circulation with significance of end arteries.
- AN5.7** Explain function of meta-arterioles, precapillary sphincters, arterio-venous anastomosis.
- AN5.8** Define thrombosis, infarction, and aneurysm.

INTRODUCTION

- The cardiovascular system consists of heart and blood vessels. The heart collects the blood and pumps it into the blood vessels.
- The *blood vessels* are tubular channels that provide passage for blood circulation. There are various types of blood vessels that includes:
 - *Arteries*: They carry blood away from the heart.
 - *Veins*: They carry blood toward the heart.
 - *Capillaries*: They connect arteries and veins and act as a metabolic and gaseous exchange site.

Functions of Cardiovascular System

Q. List the functions of circulatory system.

- The cardiovascular system performs the following functions:
 1. Carries blood
 2. Exchange of nutrients, waste products, and gases with tissue
 3. Transports substances
 4. Regulates blood pressure
 5. Directs blood flow to the tissues.

Some Interesting Facts

1. The circulatory system carries the blood from the heart to all the tissues of the body and back to the heart.

2. Exchange of nutrients and oxygen from blood to the tissue and carbon dioxide and other waste products from the tissue to the blood occurs at capillaries and sinusoids.
3. Blood acts as a vehicle for transporting substances such as hormones, enzymes, nutrients, gases, coagulation factors, waste products, etc.
4. Heart and blood vessels play an essential role in maintaining blood pressure.
5. Heart and blood vessels help in homeostasis by directing blood flow to specific tissues as needed.
6. There are several types of circuits in the body that distribute blood—for example, systematic circulation, pulmonary circulation, portal circulation, and so on.
7. Pulmonary and systemic circulation has only single plexus of capillaries. In *portal circulation*, the portal vein forms another (second) set of capillaries—for example, hepatic portal system and hypothalamo-hypophyseal portal system.
8. All the blood vessels, irrespective of their size and type are lined by *endothelium*.
9. Heart is the first organ of the body to start functioning.
10. Aorta is the largest artery in the body. Inferior vena cava is the largest vein in the body.
11. Great saphenous vein is the longest vein in the body.

COMPONENTS OF CARDIOVASCULAR SYSTEM

Q. List and describe in brief the components of cardiovascular system.

Q. Why the blood is specialized connective tissue?

- The cardiovascular system consists of the following components.
 1. Blood
 2. Heart
 3. Blood vessels.

BLOOD

- Blood is a specialized body fluid that circulates through the heart and blood vessels.

- As the blood has similar characteristics to other connective tissue, the blood is classified as specialized connective tissue. These characteristics include:
 - Blood contains *cells* – RBCs, WBCs, and platelets.
 - Extracellular *matrix* in the form of plasma.
 - Instead of connective tissue *fibers* such as collagen, the blood contains soluble proteins such as *fibrinogen* (which get converted into insoluble fibers – *fibrin*).
- The blood makes up to 8% of the total body weight.

Composition of the Blood

Q. Enlist the components of blood.

- The blood consists of (Fig. 7.1)
 - Plasma* which has proteins (albumin, globulin, and fibrinogen), water, and minerals.
 - Blood cells
 - Erythrocytes
 - White blood cells – neutrophils, lymphocytes, monocytes, eosinophils, basophils
 - Platelets
- Erythrocytes** (red blood cells, RBCs)
These are disc-shaped cells. They do not have nuclei and mitochondria.
They carry hemoglobin that helps in carrying oxygen.
- White blood cells** (WBCs, leukocytes)
These are further subdivided into (Table 7.1)
 - Granulocytes*: They have numerous cytoplasmic granules. For example, neutrophils, eosinophils, basophils.
 - Agranulocytes*: They do not have specific cytoplasmic granules—for example, lymphocytes and monocytes.

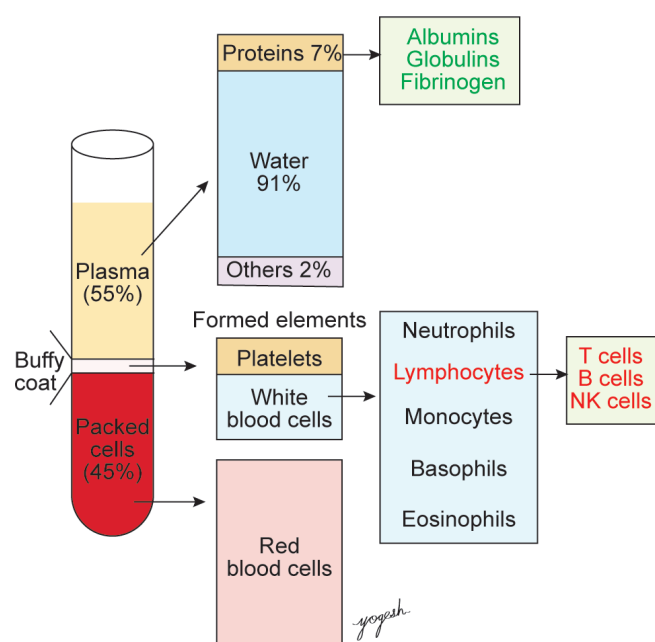


Fig. 7.1: Composition of blood

TABLE 7.1: White blood cells (For details, refer to Chapter 11, *Textbook of Human Histology*, Yogesh Sontakke, 2nd edition).

White blood cell	Description	Functions
Neutrophil (10–12 μ m)	Nucleus: 3–5 lobes Cytoplasm: Shows pink or reddish-purple granules	Phagocytosis of microorganism
Basophils (10–12 μ m)	Nucleus: Segmented Cytoplasm: Dark, basophilic granules (contain histamine)	Release histamine, promote inflammation
Eosinophil (10–14 μ m)	Nucleus: Bilobed Cytoplasm: Dark eosinophilic granules	Phagocytose antigen–antibody complexes, induces allergic reactions, and asthma, attack parasites
Lymphocytes (6–14 μ m)	Round nucleus, thin rim of cytoplasm	T lymphocytes: Cell-mediated immunity B lymphocytes: Antibody-mediated immunity NK cells: Destroy cancer cells
Monocytes (12–20 μ m)	Kidney-shaped nucleus	Phagocytosis differentiates into mononuclear phagocytic cells (e.g. macrophages)

- Lymphocytes* are further grouped into three types based on the presence of cluster of differentiation (CD) molecules:
 - T cells, B cells and natural killer (NK) cells*:
 - T cells maintain cell-mediated immunity
 - B cells maintain humoral immunity by secreting antibodies.
 - Natural killer cells destroy antibody-bound cells
 - T cells* mature in the thymus. B cells differentiate in bone marrow and mature to form *plasma cells* that secrete antibodies.
- Platelets* are minute fragments of cell, each consisting of small amount of cytoplasm surrounded by cell membrane. In bone marrow, *megakaryocytes* give rise to platelets. Platelets stop bleeding as it is involved in the formation of blood clot at the site of injury.

Functions of platelets:

- Platelets secrete serotonin and thromboxane A₂, that causes vasoconstriction and reduces blood loss.
 - Platelet-derived growth factors (PDGF) promote cell growth at the site of injury.
 - Fibrinogen that is converted into fibrin at the site of injury.
- Plasma**
 - Plasma constitutes 55% amount of the blood. It is a yellow fluid.
 - It comprises 91% water, 7% proteins, and 2% other solutes.

- Plasma proteins include albumin, globulins, and fibrinogen.
- *Albumins*: These are mainly produced in liver. They maintain osmotic pressure of the blood, which is essential for water balance between blood and tissue.
- *Globulins*: They are antibodies and complement. These are mainly part of immune system.
- Fibrinogen is a clotting factor, and its activation from thread-like protein – *fibrin*.
- Some albumins and globulins are carriers of hormones and other molecules.
- *Note*: Serum = Plasma – clotting factors.

Clinical Integration

- **Immunization**: During vaccination/immunization inactivated microorganism or its part is injected/given orally and nasally. It activates B cells to form mature memory B cells that remain in dormant phase in spleen, lymph nodes, and other places. On exposure to microorganism or its antigen, these cells get activated to form plasma cells. They produce antibodies that protect the body through humoral immunity.
- Blood acts as a route for spread of microorganisms, toxins, cancer cells, and so on.

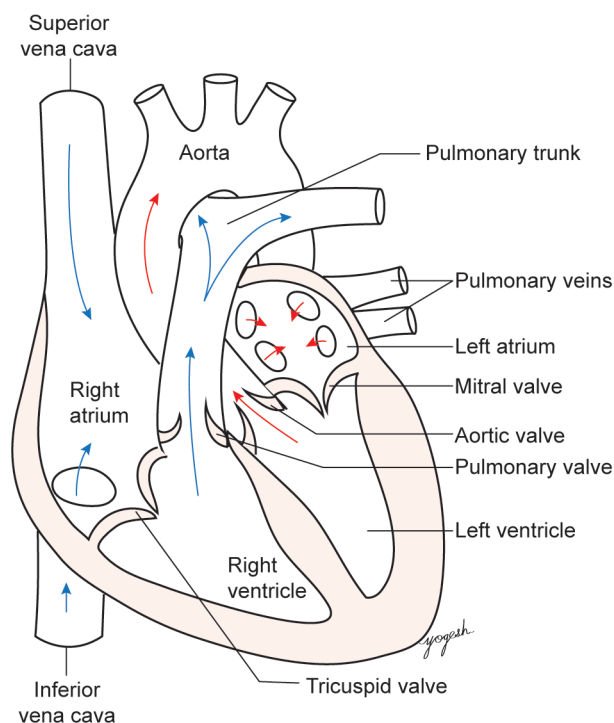
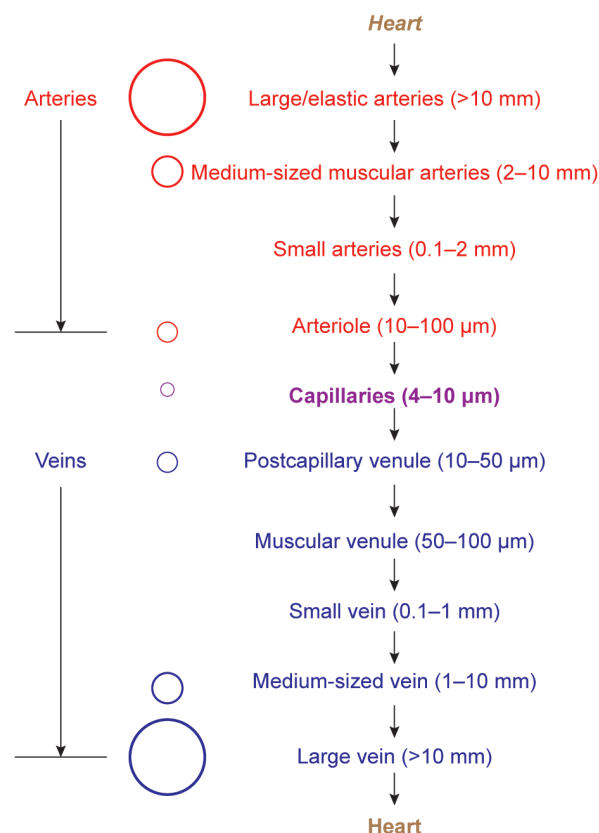


Fig. 7.2: Chambers of heart

Flowchart 7.1: Blood circulation through vessels



Note: Values given in bracket are diameters of corresponding vessels.

HEART

Q. Draw a well-labelled diagram of heart.

- Heart is a conical hollow muscular organ enclosed within the pericardium. It is about the size of the clenched fist of the individual.
- The heart consists of four chambers: Right atrium, right ventricle, left atrium, and left ventricle (Fig. 7.2).
 1. Right atrium receives deoxygenated blood from superior and inferior venae cavae and transfers to the right ventricle.
 2. Right ventricle passes the blood to the lungs through pulmonary trunk and later pulmonary arteries.
 3. Left atrium receives oxygenated blood from lungs through four pulmonary veins and later passes it to the left ventricle.
 4. Left ventricle supplies blood to the entire body through aorta.

(For details, refer to Chapter 12).

BLOOD VESSELS

Classification of Blood Vessels

- Arteries carry blood away from heart, capillaries nourish the tissue, whereas veins carry blood toward heart.
- Blood vessels are classified as follows (Flowchart 7.1):
 - A. Arteries
 1. Elastic or large arteries (conducting arteries).

2. Muscular arteries (medium-sized or distributing arteries).
3. Arterioles: Terminal arterioles and meta-arterioles.

B. Capillaries

1. Continuous capillaries
2. Fenestrated (visceral) capillaries
3. Sinusoid or sinusoidal capillaries.

C. Veins

1. Venules: Post-capillary venules, muscular venules
2. Small veins
3. Medium-sized veins
4. Large veins.

- Functionally, the blood vessels are classified as:

1. Distributing vessels: Arteries
2. Resistance vessels: Arterioles with precapillary sphincter
3. Exchange vessels: Capillaries, sinusoids, precapillary venules
4. Reservoir or capacitance vessels: Larger venules and veins
5. Shunts: Anastomoses.

Basic Structure of Blood Vessels

- The blood vessels show three basic layers in their transverse section: Tunica intima, tunica media and tunica adventitia (*tunica* = coat). ^{Viva} Presence and thickness of these layers depend on size and type of the blood vessel (Fig. 7.3, Flowchart 7.2).

1. **Tunica intima:** It is the innermost layer of blood vessel. Tunica intima consists of endothelium, subendothelial connective tissue, and internal elastic lamina (inside outwards). **Endothelium** consists of *simple squamous epithelium*. **Internal elastic membrane** consists of many fenestrated elastic sheets. These fenestrations permit transmission of nutrients to the outer wall of blood vessels from its lumen.

2. **Tunica media:** It is *middle* layer of blood vessels. It consists of concentric layers of spirally oriented *smooth muscles*. Tunica media of arteries are thicker and contains more smooth muscles than that of veins. External elastic lamina separates tunica media from tunica adventitia. Smooth muscle cells of tunica media can produce contraction or relaxation under autonomic neuronal control.
3. **Tunica adventitia:** It is the *outermost connective tissue* layer of blood vessels.

Some Interesting Facts

- **Vasa vasorum** consists of fine network of small blood vessels that supply wall of blood vessel.
- **Nervi vasorum** or **nervi vascularis** consists of unmyelinated postganglionic sympathetic nerve fibers that release norepinephrine and produce vasoconstriction.
- Inner part (one-third) of blood vessel is supplied by diffusion from luminal blood. In thicker vessels (>0.5 mm), outer portion (two-thirds) of vessel wall is supplied by vasa vasorum.
- Coronary arteries are analogous to vasa vasorum for myocardium of heart.

Endothelium

- Vascular endothelium is a lining epithelium of internal surface of cardiovascular system.
- It is a *simple squamous epithelium*. Endothelial cells are flattened, elongated and polygonal cells. These cells show small quantity of cytoplasm and elongated, flat, densely stained nucleus. Adjacent endothelial cells are connected with each other by *tight junctions* (Fig. 7.4).

Functions of Endothelium

1. **Smooth surface:** Endothelium provides a smooth nonadherent surface for flowing blood columns.

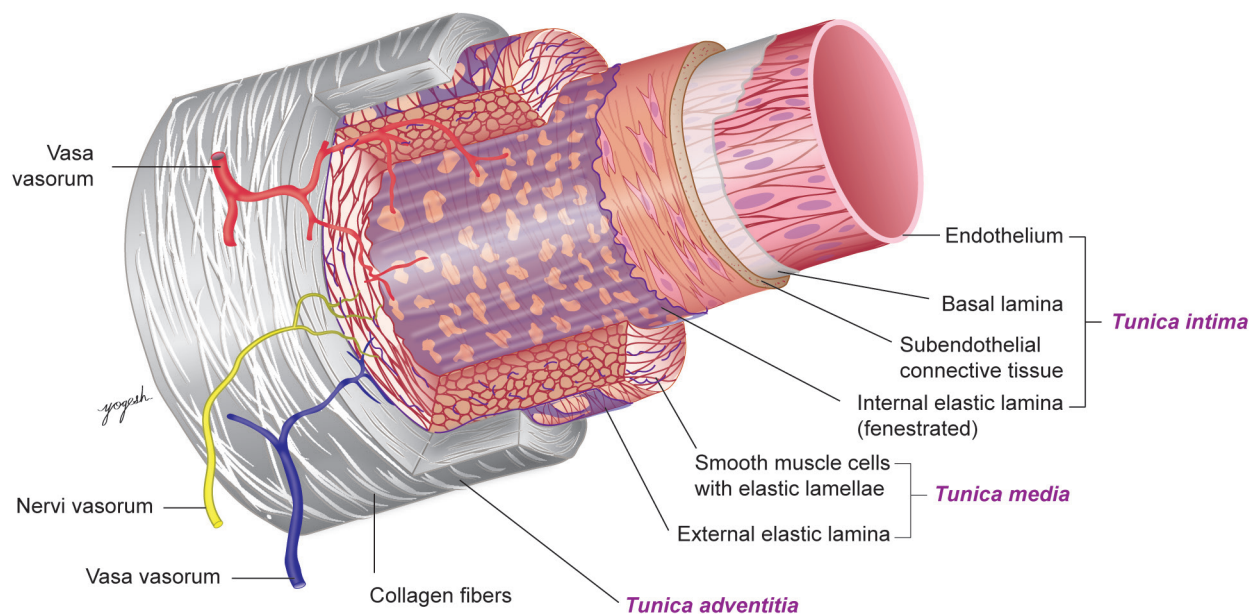


Fig. 7.3: General structure of blood vessel

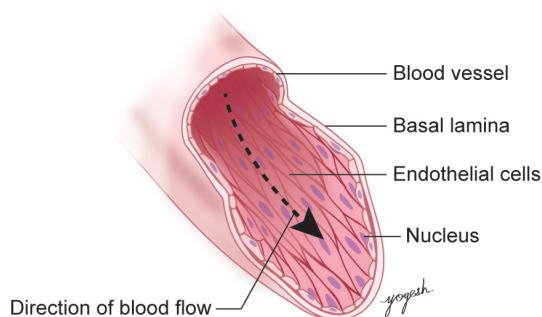
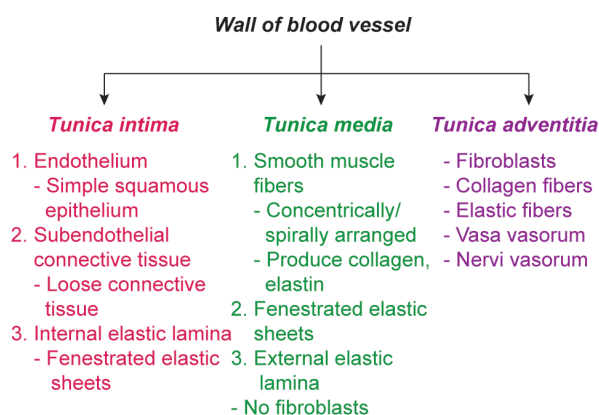


Fig. 7.4: Endothelial cells. Note: The long axis of endothelial cells lies parallel to the direction of blood flow

Flowchart 7.2: Structure of blood vessel



2. **Selective permeability barrier:** Endothelium allows movement of selected substances across it through simple diffusion, pinocytosis, and receptor-mediated endocytosis. Transport of substance mainly depends on its size and charge.
3. **Release of von Willebrand factor** (plasminogen activator inhibitor): Damaged endothelium release von Willebrand factor that induces platelet aggregation and clot formation [Erik Adolf von Willebrand, 1870–1949, Finnish physician].
4. **Release of nitric oxide (NO) and prostacyclin:** These are vasodilator agents.
5. **Release of endothelin, angiotensin-converting enzyme (ACE):** These are vasoconstrictor agents. With the help of vasodilator and vasoconstrictor agents, endothelium controls blood flow through the vessels.
6. **Hormone synthesis:** Endothelium synthesizes and secretes many growth factors such as colony stimulating factors, fibroblast growth factors, platelet-derived growth factors.
7. **Release of endothelial-derived relaxing factor (EDRF):** EDRF produces vasodilatation with the help of nitric oxide (NO).
8. **Synthesis of type IV collagen fibers** that are responsible for the formation of basal lamina.

Arteries

Features

1. Arteries carry the blood away from the heart.
2. Arteries are thick-walled vessels.

3. They have smaller and regular/round lumen as compared to veins.
4. Arteries do not have valves.
5. Neurovascular bundle: Artery along with accompanying vein and nerve form neurovascular bundle.

Classification

- Arteries are classified based on characteristics of tunica media as follows:

1. Elastic or large arteries (conducting arteries):

They have multiple layers of vascular smooth muscles and elastic lamellae in tunica media.

Their diameter is more than 10 mm.

Examples: Aorta, pulmonary trunk, brachiocephalic artery, common carotid artery, subclavian artery, common iliac artery, pulmonary artery.

2. Muscular arteries (medium-sized or distributing arteries) (Fig. 7.5):

They have more smooth muscles and less elastic lamellae and diameter of 2–10 mm.

The prominent feature of muscular arteries is presence of a greater number of *smooth muscles* and less amount of elastic material in tunica media.

Because of less amount of elastic material in tunica media, internal elastic lamina (part of tunica intima) can be easily identified.

Examples: Brachial artery, femoral artery, and other arteries of limbs.

3. Arterioles:

They are the smallest divisions of the arteries. They have only a single layer of smooth muscles and 10–100 μ m diameter.

They are called resistance vessels as they are the main source of peripheral resistance to blood flow due to their narrow lumen and surrounding smooth muscles. They regulate diastolic pressure.

Terminal arterioles have diameter less than 50 μ m.

In meta-arterioles, the smooth muscles are replaced by discontinuous noncontractile cells called pericytes or Rouget cells. Distally, meta-arterioles form capillary plexuses.

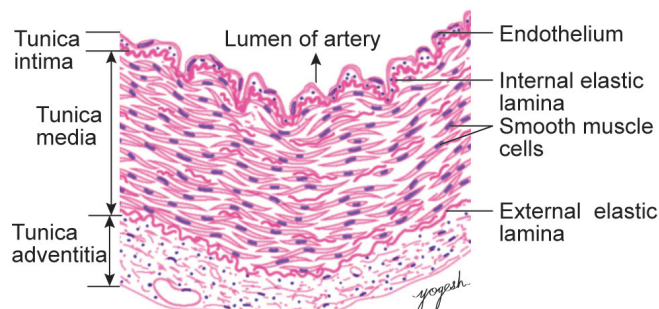


Fig. 7.5: Muscular or medium-sized artery

Arterial Pulse

- The arterial pulse is rhythmic expansion and contraction of arterial wall as blood is ejected from the heart into arteries during each heartbeat.
- Palpation of arteries:* Some arteries can be palpated (felt) through the skin.
- It is an important part of clinical examination. It gives valuable information about the overall cardiovascular health.
 1. Presence or absence
 2. Rhythm
 3. Rate
 4. Strength or amplitude.
- Table 7.2 includes the routinely palpated arteries (Fig. 7.6).

TABLE 7.2: Arteries and locations of their palpation

Arterial pulse	Site of palpation
Radial	Radial side of front of forearm at wrist lateral to the tendon of flexor carpi radialis
Branchial	In front of elbow, medial to the tendon of biceps
Carotid	In the neck, along the anterior border of sternocleidomastoid muscle, at the level of cricoid cartilage
Dorsalis pedis	Over the dorsum of the foot, just medial to the tendon of extensor hallucis longus
Posterior tibial	On the medial side of the ankle, midway between medial malleolus and tendo-calcaneus
Popliteal	Behind the knee, in the middle of the popliteal fossa

Capillaries

Q. Write a short note on capillaries.

Q. Write a short note on sinusoids.

- Capillaries form a network of vessels in tissue and are sites for exchange of nutrients. Capillary has an average diameter of $8\ \mu\text{m}$ ($4\text{--}10\ \mu\text{m}$). Human body has ~50,000 miles of capillaries.
- Capillaries consist of endothelium and its basal lamina. There is *no tunica media and tunica adventitia* in capillaries. In some capillaries, *pericytes* are present. Pericytes lie embedded in basal lamina of endothelium.

Classification

- Capillaries are classified into three groups based on continuity of wall and basal lamina as follows (Figs 7.7 and 7.8, Flowchart 7.3):
 1. *Continuous capillaries* have continuous endothelial cells and basal lamina.
Locations: Continuous capillaries are found in connective tissue, muscles, skin, lungs, and central nervous system.

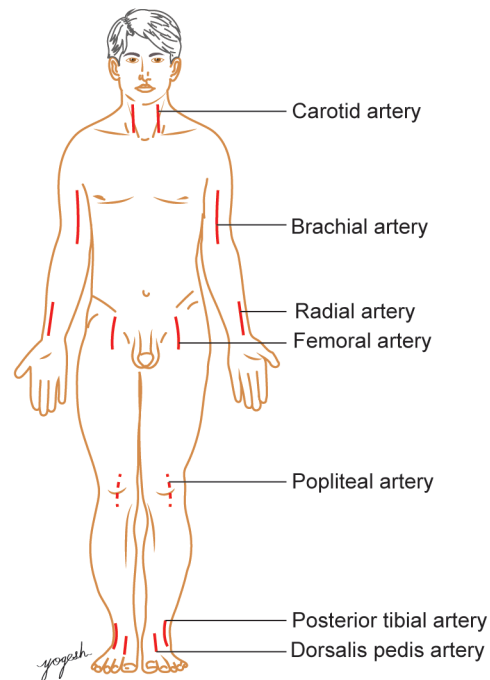


Fig. 7.6: Common sites of routinely palpated for arterial pulse

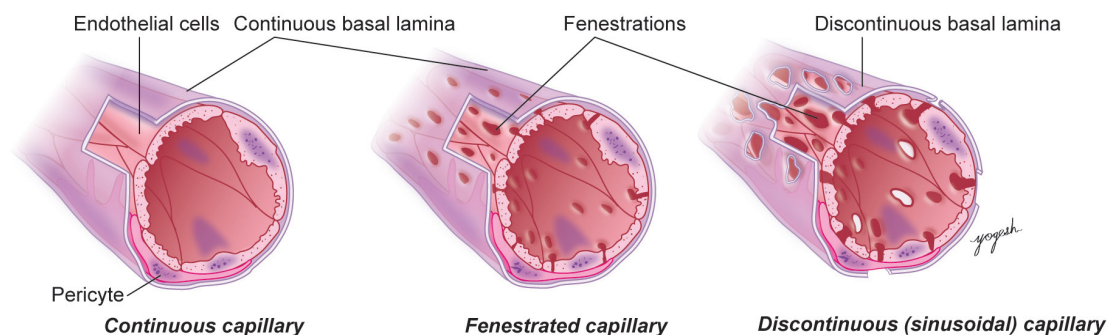


Fig. 7.7: Classification of capillaries

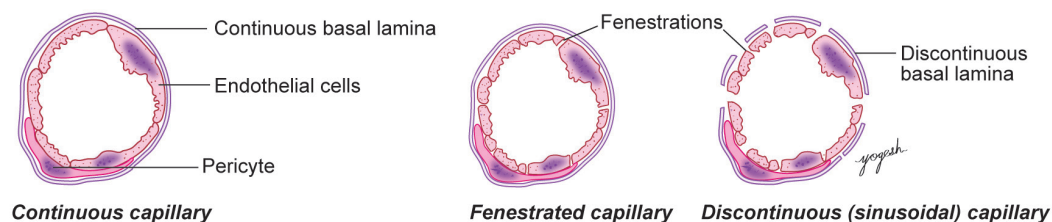
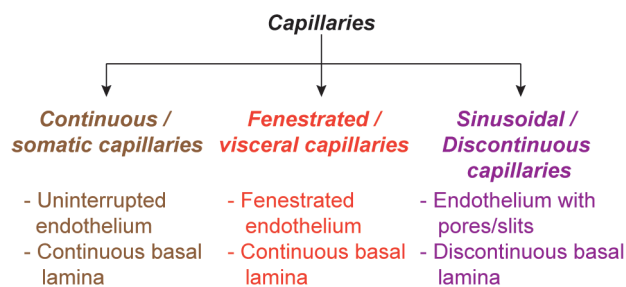


Fig. 7.8: Classification of capillaries (practice Fig.)

Flowchart 7.3: Classification of capillaries

2. *Fenestrated (visceral) capillaries* have endothelial cells have numerous circular openings called fenestrations (*fenestrations* = aperture or pores) (size of fenestrations: 50–80 nm). Basal lamina is continuous and covers the entire capillary.

Locations: Fenestrated capillaries are present in renal glomeruli, pancreas, endocrine glands, intestinal villi, choroid plexus, ciliary process of eye, and gallbladder.

3. *Sinusoid or sinusoidal capillaries* have fenestrated endothelial cells and discontinuous basal lamina. In liver, sinusoidal wall shows two special cells: Kupffer cells (phagocytic macrophages), and Ito cells (vitamin A storing cells).

Functions: The blood flow through the sinusoids is sluggish that provide sufficient time for exchange of large molecules between the blood and tissue fluid.

Locations: Liver, spleen, lymph nodes, bone marrow, endocrine glands (adrenal cortex, hypophysis cerebri, parathyroid gland), and carotid bodies.

- *Note:* Some authors consider sinusoid as a separate group of vessels.

Some Interesting Facts

For the differences between artery and vein, refer to Table 7.3. For the differences between elastic artery and muscular artery, refer to Table 7.4. For the differences between capillaries and sinusoids, refer to Table 7.5. For the differences between large-sized vein, medium-sized vein and venule, refer to Table 7.6.

BOX 7.1: Arteriovenous (AV) Shunts/Anastomosis

Q. Write a short note on AV shunts.

- Arteriovenous shunt connects arteriole to venule and *bypasses capillary network*. It helps to divert blood from capillaries (short-circuit).
- *Locations:* Skin of fingertips, nose, lips, erectile tissue of penis and clitoris.

Structure

- AV shunts may be straight or coiled. Wall of AV shunt is lined by endothelium and several layers of smooth muscle cells. Contraction of these smooth muscle cells closes AV shunt and enhances blood supply to capillary plexus (Fig. 7.9).

Functions of AV Shunts

- *Thermoregulation:* In skin, opening of AV shunts helps to bypass capillary plexus and helps to conserve heat.
- *Erectile function:* In erectile tissue, AV shunts divert the blood to cavernous spaces and initiate erection.
- AV shunts of newborn are not well formed and in old age, number of AV shunt decreases. Hence, thermoregulation is not good in newborns and old.
- *Glomus* is a specialized form of AV shunt that is formed by rounded bunch of vessels. It is found in skin, at the tip of finger and toes, lips, and tip of the tongue and nose. Smooth muscle cells lining connecting vessels in glomus are epithelioid cells because they appear as epithelial cells.

Some Interesting Facts

- *Precapillary sphincter:* It consists of vascular smooth muscle cells that surround terminal arterioles at their junction with capillaries. Pre-capillary sphincter regulates entry of blood into capillary plexus (Fig. 7.9).
- *Vascular resistance:* Smooth muscles of arterioles generate peripheral resistance to blood flow and regulate blood pressure. Hence arterioles are called resistance vessels. Arterioles generate the maximum peripheral vascular resistance.
- *Thoroughfare channel:* It connects the arteriole with venule in some places. Through this channel, blood can bypass the capillary bed (Fig. 7.9).
- Refer to Tables 7.3 to 7.6 for the differences between
 1. Artery and vein,
 2. Elastic artery, muscular artery, and arteriole
 3. Capillary and sinusoids
 4. Large-sized vein, medium-sized vein, and venule.

Veins

- Veins carry blood toward the heart.

Features of Veins (Fig. 7.10)

1. The veins are thin walled.
2. They are formed by union of capillaries or small veins.
3. They have larger and irregular lumen than arteries.
4. They have valves that provide the unidirectional blood flow.
5. Large veins are surrounded by dead space that permits their expansion during increased venous return.

Classification

- Veins are grouped into four groups based on their size as follows:
 1. Venules (diameter 10–100 μm): They receive blood from capillaries. Venules are of two types (Fig. 7.11):
 - a. *Post-capillary venules* (10–50 μm diameter): They receive blood from capillaries. They are lined by endothelium and pericytes.

TABLE 7.3: Differences between artery and vein*Q. List the differences between artery and vein*

Feature	Artery	Vein
Wall	Thicker than vein	Thinner than artery
Lumen	Oval, circular, patent (open)	Collapsed, irregular
Internal elastic lamina	Well-defined in medium and small arteries	Absent or not well defined
Tunica media	Thicker than veins Thicker than adventitia of arteries Consists of many layers of smooth muscle cells and elastic fibers	Thinner than arteries Thinner than adventitia of veins Consists of a few layers of smooth muscle cells, collagen fibers, and fibroblasts
Tunica adventitia	Consists of connective tissue	Consists of longitudinal smooth muscle cells and elastic fibers (especially in large veins)
Layers	All three layers of vessel are well defined	In small and medium-sized veins, all three layers of vessel are not clearly identified

TABLE 7.4: Differences between elastic artery and muscular artery*Q. List the differences between elastic artery, muscular artery, and arteriole.*

Layer	Elastic artery	Muscular artery	Arteriole
Tunica intima	Significant amount of subendothelial connective tissue is present. Internal elastic lamina is not clearly identifiable	Subendothelial connective tissue is scanty. Internal elastic lamina is clearly visible	Subendothelial connective tissue is thin or absent. Internal elastic lamina is present only in large arterioles.
Tunica media	Many thick fenestrated elastic laminae are present. Smooth muscles (up to 50 layers) are present intermittently between elastic laminae	Very less amount of elastic fibers present. Up to 40 layers of smooth muscles are present	Elastic fibers absent. 2–3 layers of smooth muscle are present.
Tunica adventitia	It is relatively thin layer of connective tissue	It is relatively thick layer of fibroelastic connective tissue	It is thin
Examples	Aorta, carotids, and subclavian arteries	Brachial artery, femoral artery	

Note: In capillaries, subendothelial connective tissue, internal elastic lamina, smooth muscles, and tunica adventitia are absent.

TABLE 7.5: Differences between capillaries and sinusoids*Q. List the differences between capillaries and sinusoids.*

Feature	Capillaries	Sinusoids
Size	Smaller (5–8 μm)	Larger (5–30 μm)
Lumen	Circular (regular)	Irregular
Lining epithelium	Endothelium	Endothelial cells with a few phagocytic cells
Basal lamina	Continuous	Discontinuous
Locations	Continuous capillaries are found in muscles, skin, lungs. Fenestrated capillaries are present in renal glomeruli, pancreas, endocrine glands.	In liver, spleen, lymph nodes, bone marrow.

TABLE 7.6: Differences between large-sized vein, medium-sized vein and venule*Q. List the differences between large-sized vein, medium-sized vein and venule.*

Feature	Large-sized vein	Medium-sized vein	Venule
Diameter	Larger (>10 mm)	Smaller (1–10 mm)	10–100 μm
Tunica intima	Subendothelial connective tissue is thin.	Subendothelial connective tissue is thin or absent.	Subendothelial connective tissue is absent.
Tunica media	Longitudinal smooth muscles, difficult to differentiate from adventitia.	A few collagen fibers and smooth muscle cells are present.	1–2 layers of smooth muscle cells.
Tunica adventitia	Thick. Longitudinally oriented smooth muscle cells.	Thick. Longitudinally oriented bundles of collagen fibers fibroblasts.	Thin layer of collagen fibers and a few fibroblasts.

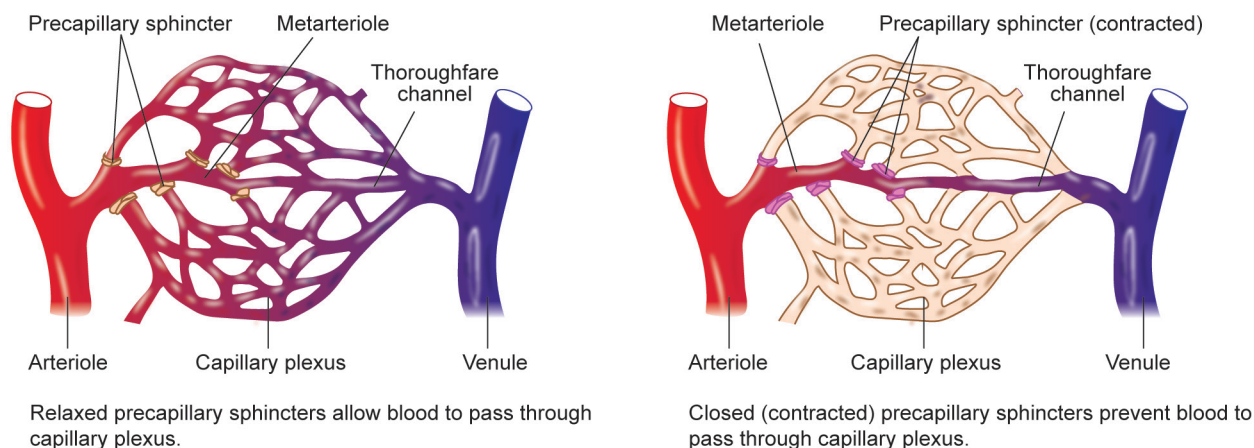


Fig. 7.9: Microcirculation and role of precapillary sphincter and metarteriole

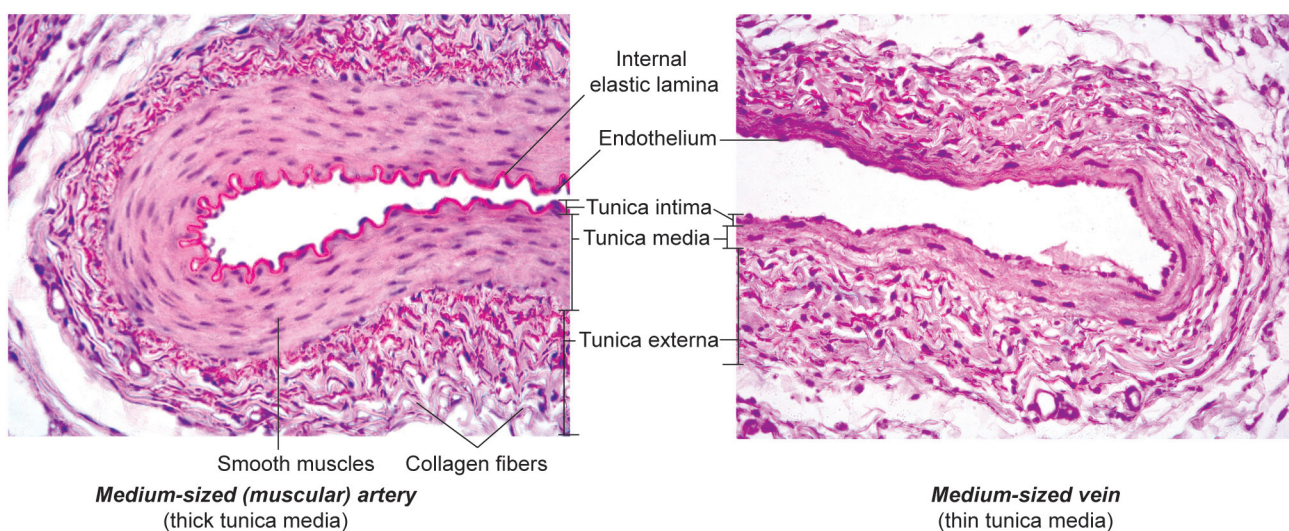


Fig. 7.10: Photomicrograph. Layers of medium-sized artery (muscular artery) and medium-sized vein (H&E stain, high magnification)

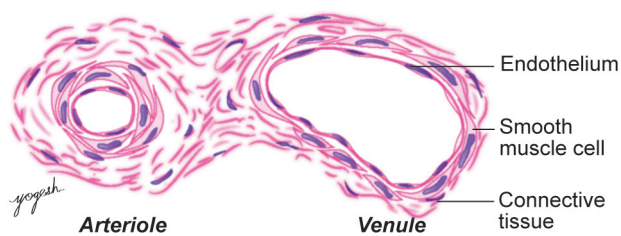


Fig. 7.11: Arteriole and venule (practice Fig.)

b. *Muscular venules* (50–100 μm diameter): They are lined by endothelium, 1–2 layers of smooth muscles and surrounded by thick layer of connective tissue.

- Small veins (diameter 0.1–1 mm) drain blood from muscular venules.
- Medium-sized veins (diameter 1–10 mm): They accompany medium-sized arteries. For example, radial vein, tibial vein, popliteal vein, and so on (Fig. 7.10).
- Large veins (diameter >10 mm): Tunica adventitia is the thickest layer of large vein. It consists of *longitudinally* arranged smooth muscle cells. Examples: Superior vena cava, inferior vena cava.

Clinical Integration

- Function of elastic arteries as a *diastolic pump*: During ventricular systole, elastic arteries dilate to acquire a sudden rush of blood from ventricles (accommodate blood). During ventricular diastole (relaxation), because of *elastic recoil*, these arteries push the blood into medium-sized arteries and maintain continuous blood flow. Thus, elastic arteries pump blood during diastole of ventricles.
- Hypertension**: Hypertension is the sustained diastolic pressure above 90 mm Hg or sustained systolic blood pressure above 140 mm Hg. It affects most of the elderly people because of increased vascular resistance, atherosclerotic changes, increased vascular smooth muscle cells, decreased amount of elastic fibers, and increased amount of collagen fibers in vessel walls.
- Varicose veins**: These are abnormally dilated veins. It is especially seen in the veins of lower limbs in older people because of failure of valves, decreased vascular smooth muscle tone, and prolonged standing.
- Brachial artery is the commonly used for measurement of blood pressure.

- Radial artery is the commonly palpated in clinical examination.
- Carotid pulse is the most reliable pulse.
- Median cubital vein is the most used for intravenous injections.
- All the arteries in the body contain oxygenated blood except pulmonary arteries and umbilical arteries in fetus, which contain deoxygenated blood. All the veins in the body contain deoxygenated blood except pulmonary veins and umbilical veins in fetus, which contain oxygenated blood.

Venous Valves

- To maintain unidirectional blood flow towards the heart veins have valves. These valves also help to maintain the blood flow against the gravity and from superficial to deep veins.
- Each venous valve has *cusps* that make the valve to open only in one direction.
- Valves are more numerous in the veins of lower to maintain blood flow against gravity.
- Valves near the termination of internal jugular, subclavian and femoral veins prevent the venous blood backflow during increased intrathoracic pressure (during inspiration and coughing) and during increased intra-abdominal pressure (during defecation).
- The following veins do not have valves in their lumen: ^{MCQ}
 1. Superior and inferior vena cava
 2. Hepatic veins and portal veins
 3. Renal veins
 4. Uterine and ovarian veins
 5. Pulmonary veins
 6. Facial veins
- The following veins do not have muscular tissue in their wall: ^{MCQ}
 1. Dural venous sinuses
 2. Pial veins
 3. Retinal veins
 4. Veins of erectile tissue of penis
 5. Veins of spongy bone.

Factors Helping Venous Return

Q. List the factors helping venous return.

- The following factors help in venous return to the heart:
 1. *Vis-a-tergo*: It is a forward push of blood from behind by the blood pumped by heart.
 2. *Negative intrathoracic pressure* sucks the blood into the heart from all major veins of body.
 3. *Gravity* helps in venous return from upper part of the body.
 4. *Muscle contractions* help to press the veins passing deep or through the substance of the muscles. It

helps in venous return. Contraction calf muscle (soleus) helps venous return from lower limb; hence, it is called *peripheral heart*. ^{Viva}

5. *Arterial pulsations*: Most of the veins are accompanied by arteries. These artery pulsations drive the venous blood toward heart.
6. *Venous valves* prevent backflow of blood and maintain unidirectional blood flow.

Clinical Integration

Site of venipuncture

- It is useful for collection of blood samples. The superficial veins are commonly used for venipuncture.

Varicose veins

- These are dilated *tortuous* veins. Continuous standing for a long period may induce varicose veins. It is caused by weakness of venous valves, and weakness of walls of veins (Fig. 7.12).
- It results in pooling blood in veins. It may occur commonly in veins of lower limb (especially great saphenous vein). It may occur at the lower end of esophagus or in the anal canal.

ANASTOMOSIS

Q. Write a short note on anastomosis.

- *Definition*: Anastomosis is communication between neighboring vessels through a collateral channel. The circulation through anastomosis is collateral circulation.

Types of Anastomoses

- There are three types of anastomoses: Arterial, venous, and arteriovenous (Fig. 7.13, Flowchart 7.4).

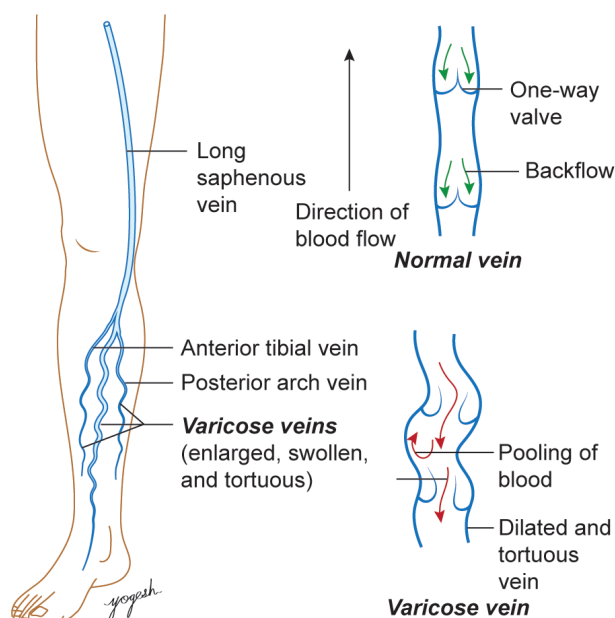


Fig. 7.12: Varicose veins and valve insufficiency in varicose veins

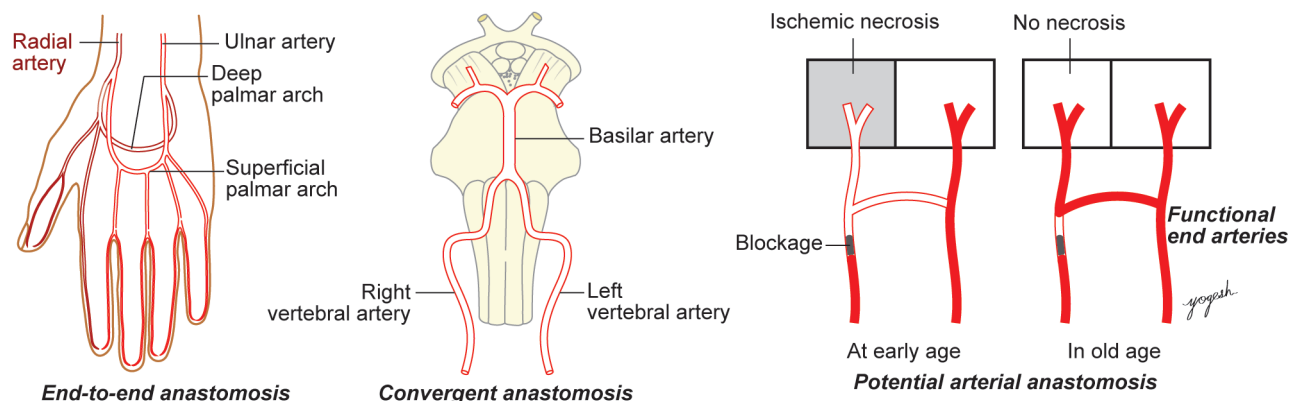
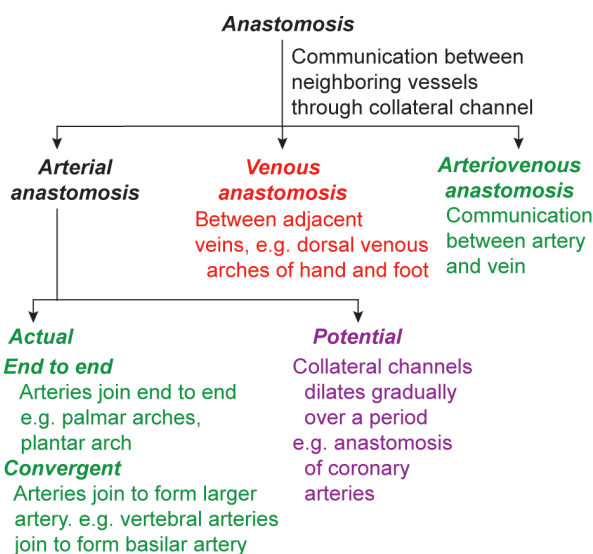


Fig. 7.13: Types of arterial anastomosis

Flowchart 7.4: Anastomoses



Arteriovenous Anastomosis (Shunt)

- It is the communication between artery and vein. It helps to supply the blood to the organ as per the need. The shunt vessel prevents/permits entry of blood as per requirement.
- For example (sites): Skin of nose, lips, external ear, mucous membrane of nose, erectile tissue of sexual organ, tongue, tip of fingers and nail bed.

End Arteries

Q. Write a short note on end arteries.

- **Definition:** The arteries or their branches that do not anastomose with the adjacent arteries are called end arteries (Fig. 7.15). ^{Viva}
- **Examples** ^{MCQ}
 1. Central artery of retina
 2. Labyrinthine artery of ear

Arterial Anastomosis

- Is the communication between two arteries. It may be actual or potential anastomosis.
 - Actual anastomosis** may be of two types: End-to-end anastomosis and convergent anastomosis.
 - End-to-end anastomosis:** In this anastomosis, arteries join end to end. For example, palmar arches, plantar arch, circle of Willis, labial branches of facial arteries.
 - Convergent anastomosis:** In this type, two arteries join to form a larger artery. For example, vertebral arteries join to form a larger basilar artery.
 - Potential arterial anastomosis:** It takes place between terminal arterioles. In such anastomosis, the collateral channel dilates gradually over a period. Sudden occlusion of the main artery, the potential anastomosis may fail to compensate for the loss of blood supply. For example, anastomosis of coronary arteries.

Venous Anastomosis

- It is the communication between adjacent veins. For example, dorsal venous arches of hand and foot (Fig. 7.14).

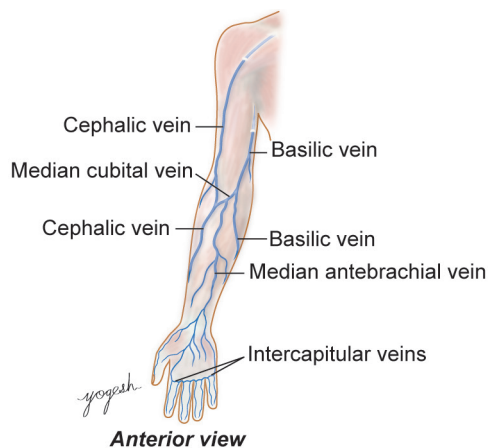


Fig. 7.14: Venous anastomosis

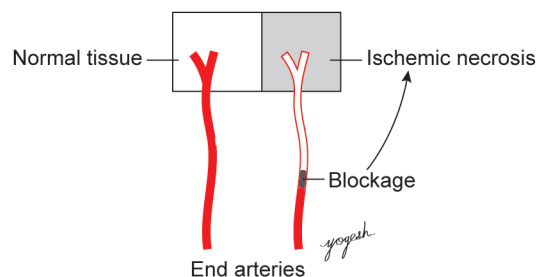


Fig. 7.15: End arteries

3. Central branches of cerebral arteries
 4. Vasa recta of mesenteric arteries
 5. Arteries of spleen, kidney, lung, metaphysis of long bones
- If the end artery is blocked, the area supplied by such artery undergoes ischemia and necrosis.
 - *Functional end arteries*: In case of coronary arteries and central branches of cerebral arteries, there is potential anastomosis. Here, sudden blockage of these arteries is not capable of development of collateral circulation. Such arteries are called functional end arteries. *Viva*

TYPES OF CIRCULATION

- There are various types of circulation in human body. These include the following:
 1. Systemic circulation
 2. Pulmonary circulation
 3. Portal circulation
 4. Fetal circulation (during embryonic life).

Systemic Circulation

- *Definition*: Systemic circulation involves the circulation of the blood ejected from the left ventricle through the body which has only one set of capillaries (Fig. 7.16).
- *Pathway*:
Left ventricle → aorta → artery → capillaries → veins → vena cava → right atrium.
- In the systemic circulation, there is only one set of capillaries in the tissue.
- Systemic circulation carries oxygenated blood from heart to the tissue.

Pulmonary Circulation

- *Definition*: Pulmonary circulation involves the transport of the deoxygenated blood from the right ventricle to the lungs and to bring back oxygenated blood from lungs to the left atrium (Fig. 7.16).
- *Pathway*: Right ventricle → Pulmonary trunk and arteries → Capillaries in lungs → Oxygenated blood → 4 pulmonary veins → Left atrium.
- Pulmonary circulation carries deoxygenated blood.

Portal Circulation

Q. Write a short note on portal circulation.

- *Definition*: Portal circulation is the circulation in which the blood flows through two consecutive capillary networks before returning to the heart.
- *Pathway*: Heart → Artery → 1st capillary network → Portal vein → 2nd capillary network → Vein → Heart.

Examples

Hepatic portal circulation:

- It is present in the liver.
- *Pathway*: Arteries supplying intestine → 1st set of capillaries in the wall of intestine → portal vein → sinusoids in liver → hepatic veins → inferior vena cava.

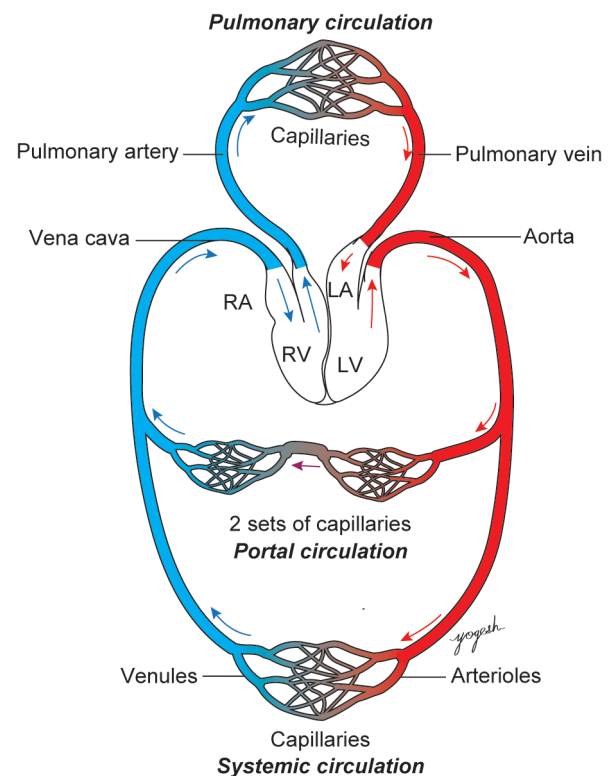


Fig. 7.16: Type of circulations

- *Functions*: Nutrients absorbed in the intestine are modified and stored in the liver using this circulation.

Hypothalamo–hypophyseal portal circulation (Fig. 7.17)

- It is present in pituitary gland.
- *Pathway*: Arteries → 1st capillary plexus in hypothalamus → portal vessels → 2nd capillary plexus in pituitary gland → systemic veins.
- *Functions*: It helps to transfer stimulatory/inhibitory hormones of hypothalamus to pituitary for controlling its hormone secretion

Renal portal circulation

- It is present in kidney.
- *Pathway*: Renal artery → Capillaries in glomerulus → efferent arteriole → capillary plexus around the renal tubules (peritubular capillary plexus) → renal vein.
- *Function*: It helps to maintain required electrolyte balance and to eliminate waste products.

Fetal Circulation

Q. Write a short note on fetal circulation.

- The developing fetus receives nutrition from placenta. The fetus is dependent on mother for:
 1. Nutrients and oxygen intake
 2. Carbon dioxide and waste product excretion

Special structures in fetal circulation (Fig. 7.18)

1. Placenta: It is a site of exchange of substances between mother and fetus.
2. Umbilical vein: Carries nutrients and oxygen to fetus.

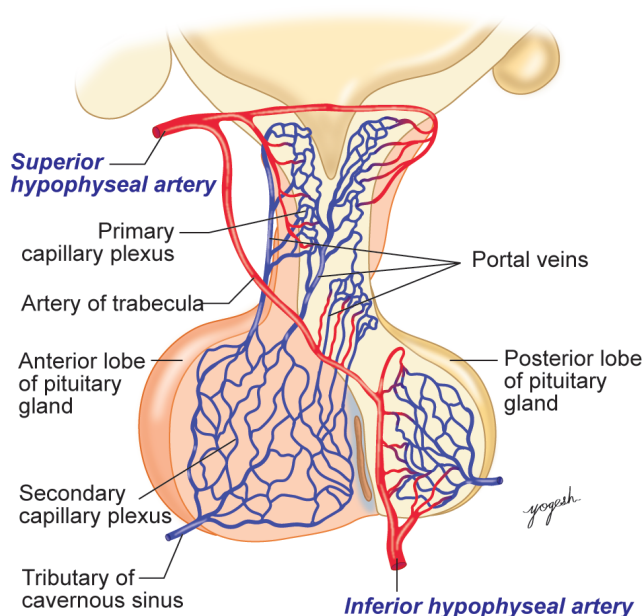


Fig. 7.17: Hypothalamo-hypophyseal portal circulation

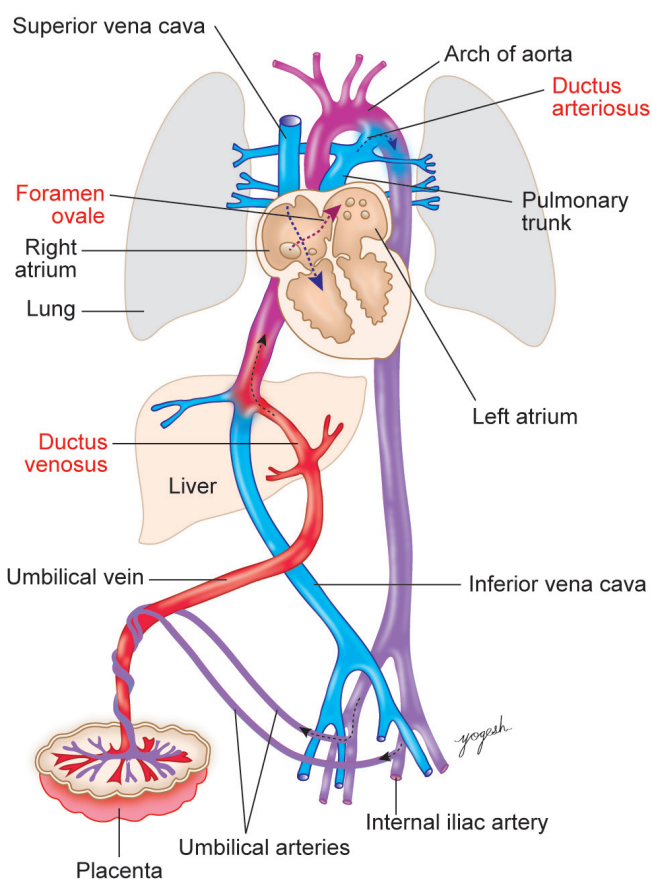


Fig. 7.18: Fetal circulation

3. Umbilical arteries: Carry waste products and carbon dioxide away from fetus.
4. Foramen ovale: Helps blood to bypass lungs. It transmits most of the blood from right atrium to left atrium.
5. Ductus venosus: Transmits oxygenated blood from umbilical vein and left branch of portal vein to inferior vena cava and thus blood bypasses liver.

6. Ductus arteriosus: Helps blood to bypass fetal lungs. It transmits the blood from left pulmonary artery to aorta.

Peculiarities of fetal circulation

Following are the peculiarities of the fetal circulation:

1. Blood shunts three times in fetus at the following places: Ductus arteriosus, foramen ovale and ductus venosus to bypass lungs and liver.
2. Regulation of oxygenated blood in fetal circulation: Sphincter at junction of left umbilical vein and ductus venosus regulates flow of oxygenated blood to the fetus.
3. Mixing of oxygenated and venous blood takes place at the following places: Liver, both atria, distal part of arch of aorta and terminal part of inferior vena cava.
4. Trans-septal blood circulation: Through foramen ovale blood enters from right atria into left atria.

Some Interesting Facts

For the differences between systemic and pulmonary circulation, refer to Table 7.7. For the differences between blood vascular and lymphatic systems, refer to Table 7.8.

TABLE 7.7: Differences between systemic and pulmonary circulation

Systemic circulation	Pulmonary circulation
Carry oxygenated blood away from heart to body tissues	Carry deoxygenated blood away from heart to lungs
Carry deoxygenated blood towards heart from tissues	Carry oxygenated blood towards heart from lungs
Starting point: Left ventricles	Starting point: Right ventricle
End point: Right atrium	End point: Left atrium
Destination: All organs except lungs	Destination: Lungs
Gaseous exchange at capillary network: CO ₂ is picked up	Gaseous exchange at capillary network: CO ₂ is expelled and O ₂ is absorbed

TABLE 7.8: Differences between blood vascular and lymphatic systems

Feature	Blood vascular system	Lymphatic system
Circulatory fluid	Blood	Lymph
Function	Transport of gases, nutrients, waste products	Carry excess interstitial fluid
Vessels	Arteries, veins, capillaries	Lymphatic capillaries, lymphatic vessels, trunk, and duct
Pumping mechanism	Heart pump the blood	Capillary action and muscle contraction helps in lymphatic drainage
Circulation	Blood moves away and back to the heart	Lymph moves towards heart only

THROMBOSIS, INFARCTION, ANEURYSM

Thrombosis

- **Definition:** Thrombosis is a medical condition characterized by the formation of a blood clot, known as a thrombus, inside a blood vessel (Fig. 7.19).
- This clot can obstruct or partially block the affected blood vessel, disrupting normal blood flow.
- Thrombosis can occur in arteries or veins.
- When a thrombus dislodges from its original site and travels through the bloodstream, it is called an *embolus*, which can potentially block smaller blood vessels elsewhere in the body, causing serious complications such as a *pulmonary embolism* or *stroke*.

Causes of Thrombosis

1. **Endothelial damage** by injury, trauma, surgery, or inflammation.
2. **Stasis or blood flow disturbance** by prolonged immobility (e.g. during long periods of bed rest or air travel), congestive heart failure, and venous insufficiency.
3. **Hypercoagulability** (increased tendency to clot).
4. Vessel wall injury in atherosclerosis.

Infarction

- **Definition:** Infarction is tissue death due to inadequate blood supply to the affected area.
- It may be caused by artery blockages, rupture, mechanical compression, or vasoconstriction.
- The resulting dead tissue or lesion is called *infarct*.

Causes of Infarction

1. Atherosclerosis
2. Thrombosis
3. Embolism
4. Vasospasm
5. Inflammation
6. Trauma

Aneurysm

- **Definition:** It is a sac-like dilatation of arterial wall (tunica media) because of its weakness (aneurysm means dilatation, in Greek) (Fig. 7.20).
- Aneurysm is associated with replacement of elastic fibers with collagen fibers.
- Aneurysm is usually seen in old age because of atherosclerosis, syphilis, and Marfan syndrome.

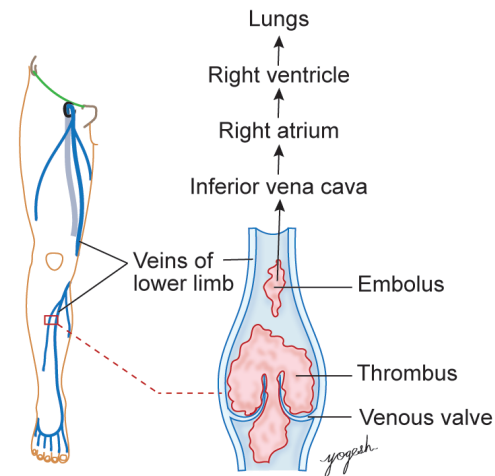


Fig. 7.19: Deep venous thrombosis and pulmonary embolism

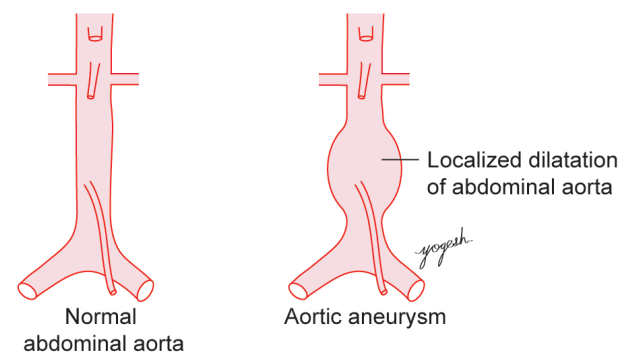


Fig. 7.20: Aortic aneurysm

Clinical Integration

- **Deep venous thrombosis (DVT):** In medium-sized veins, especially of lower limb, thrombus may form. This condition is called deep venous thrombosis. It is especially seen in patients with prolonged bed rest and in orthopedic cases with casts for treatment of fractures. Part of such clots may get separated, enter pulmonary circulation and form blockage (pulmonary embolism).
- **Thromboangiitis obliterans (Buerger disease)** is a recurring progressive inflammation and thrombosis (clotting) of small and medium arteries and veins of the hands and feet. It is commonly found in tobacco users and smokers. The main symptom is pain in the affected areas. (Leo Buerger, Austrian American surgeon, 1879–1943).

Lymphatic System



Competencies:

AN6.1 List the components and functions of lymphatic system.

AN6.2 Describe structure of lymph capillaries and mechanism of lymph circulation.

AN6.3 Explain the concept of lymphoedema and spread of tumors via lymphatics and venous system.

INTRODUCTION

- The lymphatic system consists of an extensive network of lymph vessels that drain excess extracellular fluid and act as accessory to the venous system (Fig. 8.1).
- Functions of lymphatic system
 - To drain excess extracellular fluid to the venous system.
 - To filter absorbed fluid and material.
 - To absorb fat from intestine and transport it to blood.
 - To provide defense mechanism against disease-causing microorganism.

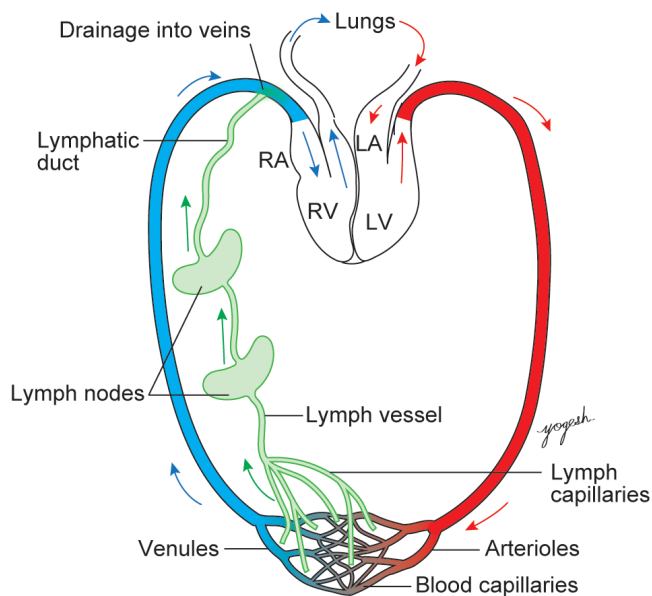


Fig. 8.1: Relationship between circulatory and lymphatic system

Components of Lymphatic System

Q. List the components of lymphatic system.

- The lymphatic system is made up of: ^{Viva}
 - Lymph
 - Lymph capillaries and lymph vessels
 - Lymphoid organs
 - Epithelio-lymphoid system
 - Bone marrow.

LYMPH

Q. What is lymph?

- Lymph is the fluid that flows through lymphatic vessels and lymph nodes.
- It is a pale, clear, watery fluid that is generated from transudate (extracellular fluid) and contains plasma proteins.
- Lymph also contains white blood cells, predominantly lymphocytes.
- Lymph also contains large fat molecules called chylomicrons that are absorbed from intestine. Such lymph containing large amounts of fat molecules looks similar to milk; hence, it is also called *chyle*. Lymph may also contain cancerous cells, viruses, bacteria, and foreign material (dyes).

Clinical Integration

- Lymphoedema:** It is an accumulation of excess lymphatic fluid in the tissue, leading to swelling. It typically occurs in limbs. It occurs due to failure of lymphatic drainage. The common causes of lymphoedema are filariasis (infection by parasite that grows and blocks lymphatic vessels), infections, trauma, cancer cells, and surgeries.

LYMPH VESSELS

Lymph Capillaries

- Lymph capillaries begin in tissue as blind-ended sacs (Fig. 8.2).

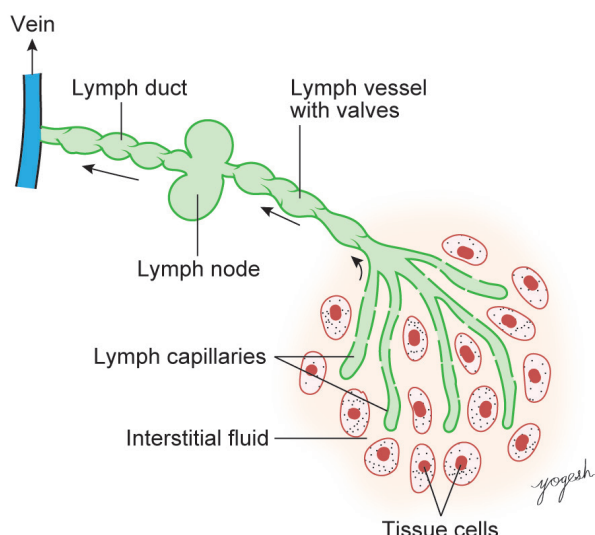


Fig. 8.2: Concept of lymphatic drainage

- Similar to the endothelium of blood capillaries, lymphatic capillaries are lined by *lymphatic endothelium*.
- Lymphatic capillaries are more permeable than blood capillaries; thus they permit entry to absorbed larger lipid molecules in intestine.
- Most of the tissues have lymph capillaries.
- Lymph capillaries are **absent** in the following structures:^{NExT}
 1. Epidermis
 2. Cornea
 3. Cartilage
 4. Hairs
 5. Nails
 6. Splenic pulp
 7. Bone marrow
 8. Choroid
 9. Internal ear
 10. Meninges
 11. Nervous tissue
- Differences between lymph capillaries and blood capillaries are as follows:
 1. Lymph capillaries begin blindly in the intercellular spaces.
 2. They have larger and irregular lumen.
 3. They can absorb larger molecules and even microorganisms.
- Most lymph capillaries carry lymph toward lymph nodes through *afferent lymph vessels*. Lymph leaves the lymph nodes through *efferent lymph vessels*.

Larger Lymph Vessels

- Lymph capillaries join to form lymph vessels. They are thin-walled vessels with diameter of 0.5 to 1.0 mm.
- They have a beaded appearance due to numerous valves within their lumen, which maintains unidirectional flow.

- The lymphatic vessels bring the lymph to series of lymph nodes. These nodes filter the fluid to remove foreign particles and microorganisms.
- Smaller lymph vessels merge to form larger lymph vessels.
- The larger lymph vessels include (Fig. 8.3):
 1. Thoracic duct (Fig. 8.4)
 2. Right lymphatic duct

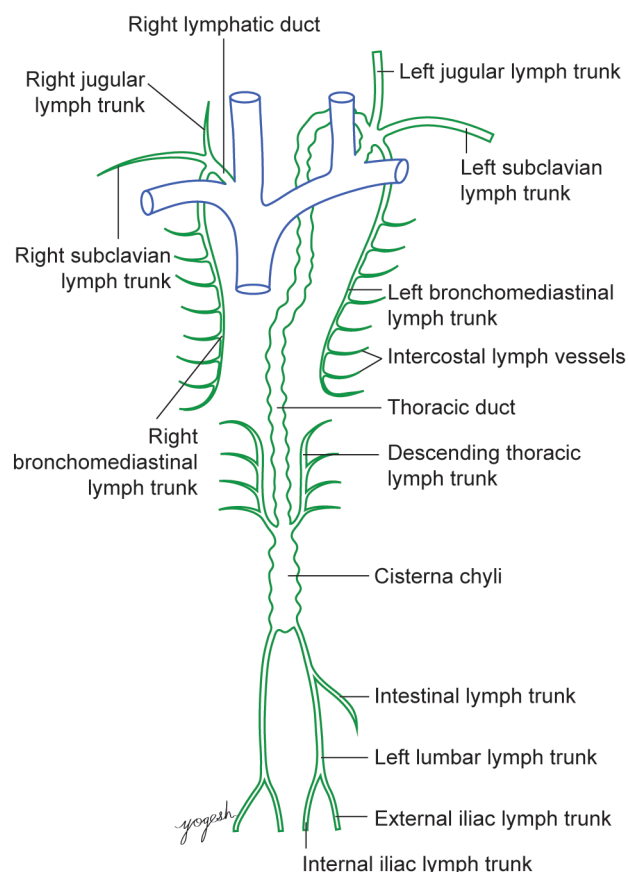


Fig. 8.3: Larger lymph vessels of the body

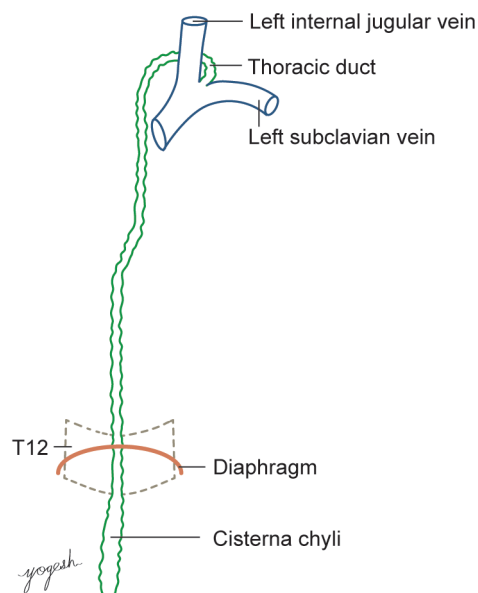


Fig. 8.4: Thoracic duct

3. Jugular lymph trunk
 4. Subclavian trunk
 5. Broncho-mediastinal trunk
 6. Intestinal lymph trunks
 7. Lumbar lymph trunks.
- Larger lymph vessels show tunica intima, media, and adventitia (similar to veins).
 - Differences of lymphatic vessels from veins are as follows:
 - Elastic fibers are present in all layers of lymphatic vessel.
 - Circular smooth muscles are present in both tunica media and adventitia of lymphatic vessels.
 - In thoracic duct, smooth muscles are arranged longitudinally.

Thoracic Duct

- The thoracic duct is the largest lymphatic vessel in the body. It is about 45 cm long and 5 mm wide. It has a *beaded appearance* due to the presence of numerous valves (Fig. 8.4).
- **Formation:** The thoracic duct begins as a continuation of upper end of *cisterna chyli* at the lower border of 12th thoracic vertebra. It enters the thoracic cavity and ascends upward.
- **Termination:** In the neck, it opens at the left jugulo-subclavian angle (junction of left internal jugular vein and left subclavian vein).
- **Area of drainage:** The thoracic duct drains the lymph from all parts of the body except the right of head and neck, right upper limb, right chest wall, right lung and right of heart, and right surface of liver (Fig. 8.5).

Right Lymphatic Duct

- It is a large lymphatic duct present on the right at the root of the neck. It is about 1 cm long (Fig. 8.3).
- It is formed by a union of
 1. Right jugular trunk
 2. Right subclavian trunk
 3. Right broncho-mediastinal trunk.

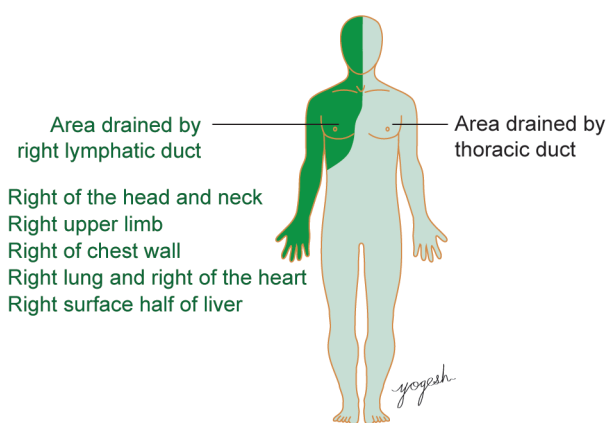


Fig. 8.5: Area of drainage of thoracic duct and right lymphatic duct

- **Termination:** In the neck, it opens at the right jugulosubclavian angle (junction of right internal jugular vein and right subclavian vein).
- **Area of Drainage:** The right lymphatic duct drains the lymph from (Fig. 8.5): *Viva, MCQ*
 1. Right of the head and neck
 2. Right upper limb
 3. Right of chest wall
 4. Right lung and right of heart
 5. Right surface of liver.

Superficial and Deep Lymph Vessels

- The lymph vessels are further subdivided into superficial and deep vessels according to their locations.
 1. Superficial lymph vessels are present in superficial fascia.
 2. Deep lymph vessels are present deep to the deep fascia. These are mostly accompanying the blood vessels.

Factors Helping Lymph Drainage

The following factors help in the lymphatic drainage:

1. Skeletal muscle contractions create pressure on the lymph vessels.
2. Valves in the lymph vessels maintain unidirectional lymph flow.
3. Contraction of smooth muscles in the wall of lymph vessels.
4. Pulsation of adjacent arteries.
5. Negative intrathoracic pressure creating during the respiration.
6. Movement of diaphragm during respiration.
7. Elevating limb (gravity).

LYMPHOID ORGANS

Q. List the primary and secondary lymphoid organs.

- Lymphoid organs are made up of lymphoid tissue.
- *Lymphatic tissue* is a specialized form of connective tissue that consists of:
 1. Immune cells (lymphocytes and plasma cells)
 2. Meshwork of reticular fibers and cells.
- Lymphoid organs are classified as primary and secondary lymphoid organs (Flowchart 8.1).

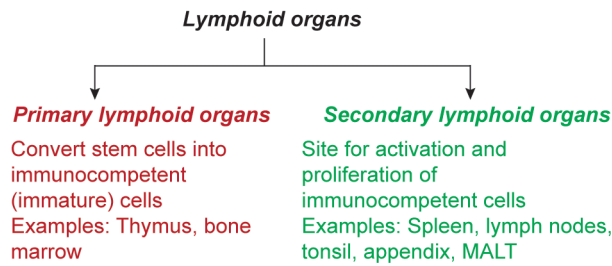
A. Primary lymphoid organs

- These are also called *central lymphoid organs*.
- These organs produce immature lymphocytes from stem cells or immature cells.
- For example, thymus and bone marrow.

B. Secondary lymphoid organs

- These organs provide exposure to foreign antigen and convert immature lymphocytes into active lymphocytes.
- For example, spleen, lymph nodes, tonsils, appendix, and Peyer's patches.

Flowchart 8.1: Lymphoid organs



DIFFUSE AND DENSE LYMPHOID TISSUES

- Lymphoid tissues are grouped as diffuse and dense lymphoid tissues (Flowchart 8.2).

A. Diffuse lymphoid tissue

- Lymphocytes are distributed throughout mucosa of gastrointestinal tract, respiratory, urinary, and reproductive tracts. This type of lymphoid tissue is called *diffuse lymphoid tissue*. Diffuse lymphoid tissue is not enclosed within capsule.
- As this lymphoid tissue is associated with mucosa, it is also called *mucosa-associated lymphoid tissue* (MALT). Ileum is the most common site of MALT. Some authors consider MALT as a dense lymphoid tissue.
- It protects and provides immunity against micro-organisms coming in contact with mucosa.

B. Dense lymphoid tissue

- Dense lymphoid tissue is enclosed by a well-defined capsule.
- It includes discrete lymphoid organs such as lymph nodes, spleen, thymus, and tonsils.

LYMPHATIC NODULE/FOLLICLE

Q. What is lymphatic follicle?

- Lymphatic nodule/follicle is a well-circumscribed concentration of lymphatic cells. The lymphatic nodule is **not surrounded by capsule**.
- Lymphatic nodule is a spherical or ovoid mass. They are present in all dense lymphoid tissues **except thymus**.
- There are two types of lymphatic nodules: Primary and secondary.

A. Primary nodules

- It shows uniform type of cells. Primary nodules are present before birth and get converted into secondary nodules on antigen exposure.

Flowchart 8.2: Lymphoid tissue

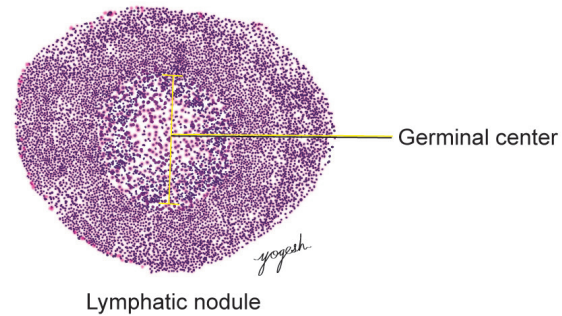
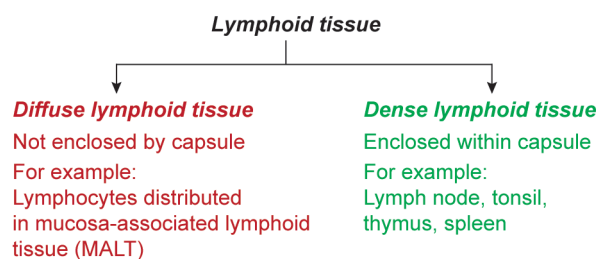


Fig. 8.6: Lymphatic nodule with germinal center

B. Secondary nodules

- Secondary nodules do not show uniform type of cells. Secondary nodules show germinal center (Fig. 8.6).
- Germinal center** lies at center of lymphatic nodule. It contains large immature lymphocytes called *lymphoblasts* and *plasmoblasts*. Cells of germinal center are **lightly stained** and have larger nuclei.
- Germinal center is surrounded by small cells with dense nucleus (mature lymphocytes); this zone is called **corona** or mature zone. Germinal center also possesses *follicular dendritic cells* (FDCs) that help in proliferation of lymphocytes.

LYMPH NODE

- The lymph node is a small kidney-shaped structure that filters the lymph.
- There are about 450 lymph nodes in the body, out of which 60–70 nodes are in the head, neck and upper limb region, 100 in thoracic region, and 250 in abdomen, pelvis, and lower limb.
- The main lymph nodes of the body are named regions, and they are as follows (Fig. 8.7):
 1. Axillary nodes in the upper limb
 2. Inguinal nodes in lower limb
 3. Cervical nodes in head and neck
 4. Mediastinal nodes in thorax
 5. Aortic nodes in abdomen
 6. Iliac nodes in pelvis.
- The superficial lymph nodes lie in the superficial fascia and are arranged along the veins. The deep nodes are located deep to the deep fascia and lie along the arteries. The superficial nodes drain into the deep nodes.

Functions of Lymph Node

1. Filtration of lymph
2. Presentation of antigens to T cells
3. Activation and proliferation of B cells
4. Conversion of B cells into plasma cells and production of antibodies. Thus, removal of bacteria, and support of humoral and cell-mediated immunity are the major functions of lymph nodes.

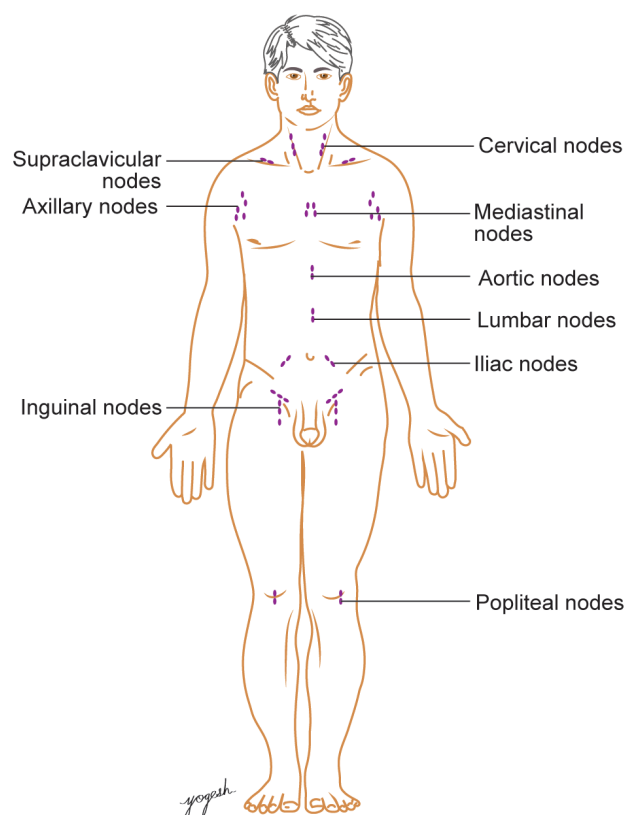


Fig. 8.7: Main lymph nodes of the body

Structure of Lymph Node

- Lymph node has convex surface and concave area (hilum) (Fig. 8.8, Flowchart 8.3). Each lymph node receives lymph through many *afferent lymphatic vessels*. Each lymph node has *efferent lymphatic vessels* through which filtered lymph leave through hilum. Lymph node receives blood vessels through hilum.
- Section of a lymph node shows capsule, subcapsular sinus, outer cortex, paracortex, and medulla (Fig. 8.9).

Capsule

- Lymph node is covered by connective tissue capsule. Trabeculae extend from capsule in the substance of lymph node. The capsule is separated from the substance of the lymph node by a space called *subcapsular sinus*.

Parenchyma of Lymph Node

- Parenchyma of lymph node shows:
 - A. Outer darkly stained cortex
 - B. Inner lightly stained medulla.
- **Cortex:** It is darkly stained outer part of parenchyma. It consists of
 1. **Superficial nodular cortex** that shows presence of numerous lymphatic follicles.
 2. **Deep cortex or paracortex** that lies between nodular cortex and medulla. Paracortex mainly consists of T cells; hence, it is also called **thymus-dependent cortex**.

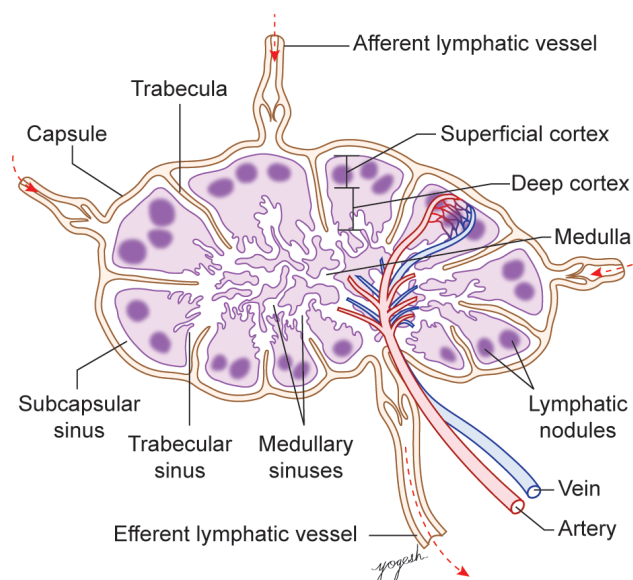


Fig. 8.8: Structure of the lymph node (sectional view)

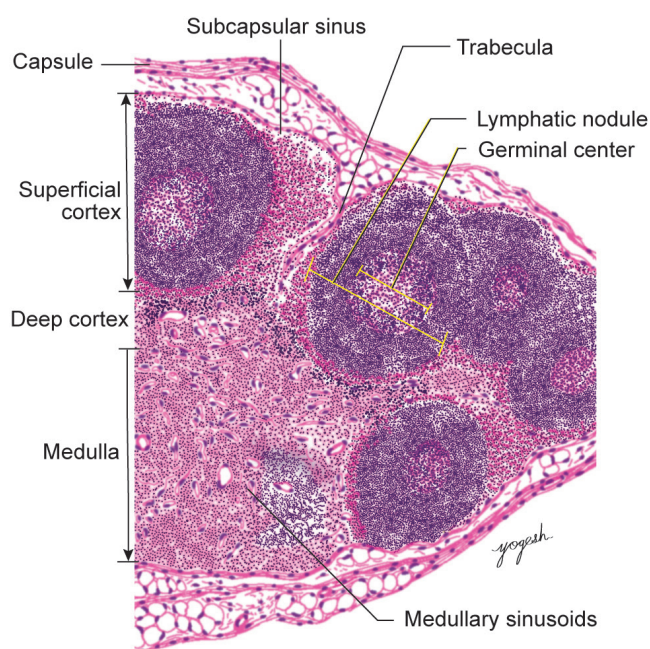


Fig. 8.9: Histology of lymph node (low magnification, practice Fig.)

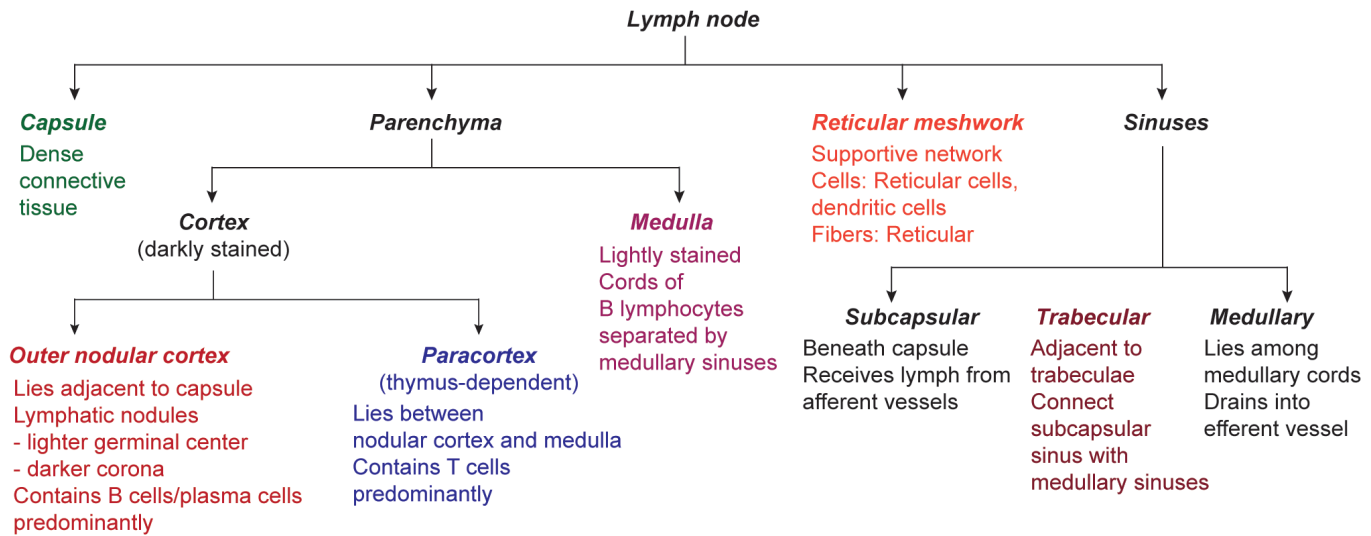
Medulla

- It is an inner part of the lymph node. It consists of
 - **Medullary cords** that are anastomosing cords of lymphocytes, macrophages, and plasma cells. Medullary cords mainly consist of *B cells*, in addition to plasma cells and macrophages.
 - **Medullary sinuses** that are spaces that separate adjacent medullary cords. They converge at hilum and form efferent lymphatic vessels.

Sinuses of Lymph Node

- There are the following three types of sinuses in lymph node:
 1. **Subcapsular sinus/cortical sinus:** Just beneath the capsule, a zone called subcapsular sinus is

Flowchart 8.3: Structure of lymph node



present. It receives lymph from afferent lymphatic vessels.

2. Intermediate/trabecular sinuses: Trabecular sinuses are present adjacent to trabeculae. They connect subcapsular sinus with medullary sinuses.
 3. Medullary sinuses: They lie among the anastomosing medullary cords. They receive lymph from trabecular sinus and drain it into efferent lymph vessels.
- Sinuses are filled with reticular meshwork that helps for filtration of lymph, trapping of cellular debris and microorganisms, and antigen presentation to immune cells.

Some Interesting Facts

- **Circulation through lymph node**
 - Lymph node receives lymph through afferent vessels (Fig. 8.10). Afferent vessels pour lymph into subcapsular sinus. This lymph enters trabecular sinus and finally medullary sinus. All medullary sinuses converge towards hilum and drain into efferent vessel that exits the lymph node through hilum. These sinuses are lined by endothelium and reticular cells.
 - Arteries enter lymph node through hilum and form a capillary network in cortex and medulla. Veins leave lymph node through hilum.
- Lymphocytes enter lymph node from two sources:
 1. Through afferent lymphatic vessels
 2. High endothelial venules
- **High endothelial venules** are present in deep cortex (paracortex) of lymph node. These are postcapillary venules that are lined by cuboidal or columnar epithelium.
- Functions of high endothelial venules:
 1. Provide channel for entry of T and B lymphocyte into lymph node
 2. Reabsorption of water from lymph.

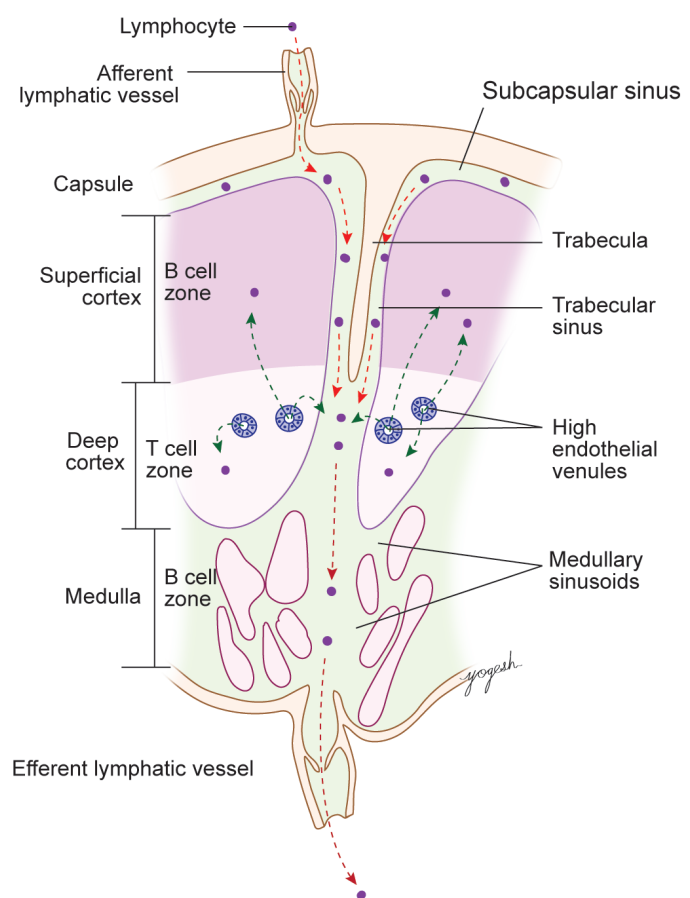


Fig. 8.10: Circulation of lymphocytes through lymph node and specific lymphocytes-dependent zones of lymph node

- **Reticular meshwork** of the lymph node forms supporting meshwork. It consists of reticular cells, follicular dendritic cells, macrophages, and reticular fibers.
- **Dendritic cells** are antigen-presenting cells that present antigens to T-cells.
- Abdomen and pelvis have the highest number of lymph nodes.

- **Lymphadenitis:** Inflammation of lymph node is called lymphadenitis. In lymphadenitis, lymph node becomes enlarged due to proliferation of lymphocytes. Causes: Infection, spread of cancer cells to lymph nodes (metastasis). Symptoms: Swollen, painful lymph nodes, and fever.
- Lymph nodes become palpable only after they enlarge in infection or cancerous conditions.
- **Metastasis to lymph nodes:** Loose cancer cells from primary cancer lesion get trapped in lymph nodes. These cancer cells multiply in lymph node and form secondary cancer lesion.
- The most common route for spread of cancer (metastasis) is through the lymph vessels.

THYMUS (THYMIC GLAND)

- Thymus and bone marrow are primary lymphoid organs.
- Thymus or thymic gland is a bilobed structure located in the anterior part of superior mediastinum. Embryologically, thymus develops from **third pharyngeal pouch** and mesoderm contributes thymocytes and connective tissue (Fig. 8.11).
- Thymus continues to grow from birth till puberty and then undergoes gradual *atrophy* called **thymic involution**.

Functions of Thymus

- The structure of the thymus is designed to perform the following functions:
 1. Education and maturation of T lymphocytes.
 2. To provide isolated environment for T lymphocyte maturation.
 3. Secretion of thymopoietin by epithelioreticular cells. Thymopoietin stimulates T-cell production.
 4. Thymus is essential for development of immunity in early life. After puberty, thymus gets atrophied.

Structure of Thymus

- Thymus has capsule, cortex, and medulla (Figs 8.12 and 8.13, Flowchart 8.4).

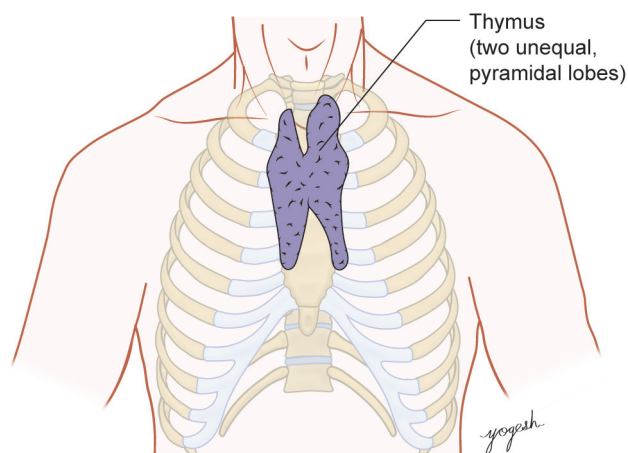


Fig. 8.11: Location of thymus

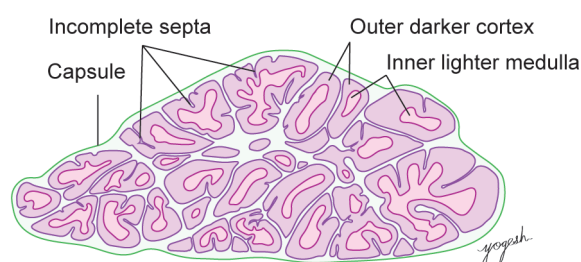


Fig. 8.12: Architecture of thymus

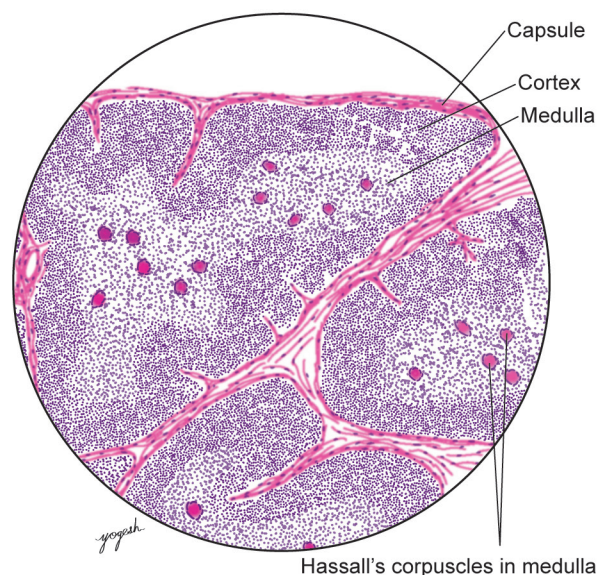
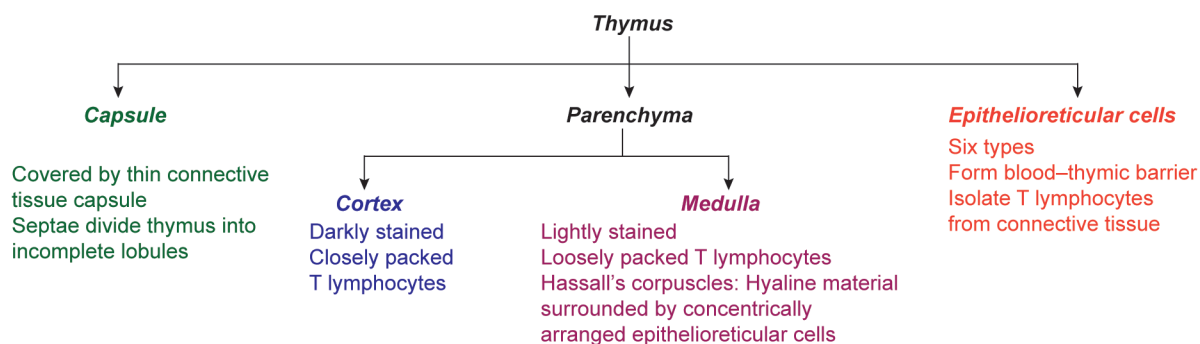


Fig. 8.13: Microscopic structure of thymus

Flowchart 8.4: Histology of thymus



Function: Production of mature T lymphocytes, secretion of thymosin and thymopoietin.

Capsule and Septa

- Thymus is covered by a thin connective tissue capsule. Trabeculae/septa extend into parenchyma of thymus and divide it into incomplete thymic lobules. Each lobule consists of outer darker cortex and inner lighter medulla. As septa are shorter (do not traverse through entire parenchyma), medulla of adjacent thymic lobules is continuous with each other.

Cortex

- Cortex is a peripheral darker/basophilic zone of thymus. It contains closely packed T lymphocytes (thymocytes).

Medulla

- Medulla is an inner lighter zone of thymus. Medulla of each thymic lobule is continuous with medulla of adjacent lobules. Medulla has less density of thymocytes; hence it is lightly stained. Medulla also contains epithelioreticulocytes in addition to thymocytes.

Hassall's/Thymic Corpuscles

- It is a unique feature of thymic medulla. These are small rounded or ovoid structures present in medulla. It consists of eosinophilic hyaline mass at the center surrounded by concentrically arranged type VI epithelioreticular cells (Fig. 8.14). Hassall's corpuscle represents degenerating thymocytes, and their number increases with age.

Epithelioreticular Cells

- Epithelioreticular cells/*epitheliocytes* form supporting meshwork in thymus. These cells are derived from third pharyngeal pouch. These cells are also called *nurse cells* as they provide required microenvironment for the differentiation and maturation of T cells.
- There are six types of epithelioreticular cells in thymus (types I–VI).

Blood–Thymic Barrier

Q. Write a short note on blood–thymic barrier.

- Immature T lymphocytes mature in thymus in an isolated environment. They are prevented from exposure to antigens by blood–thymic barrier.
- Components: Blood–thymic barrier has the following components:^{Viva}
 - Capillary endothelium with basal lamina and a few pericytes.

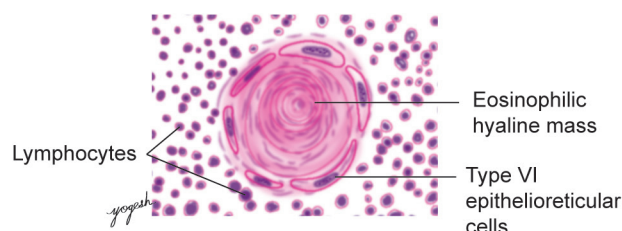


Fig. 8.14: Hassall's corpuscle

- Perivascular connective tissue with a few macrophages.
- Type I epithelioreticular cells.

Clinical Integration

Myasthenia gravis: It is a rare autoimmune disease. It is associated in 70% cases of *thymoma* (tumor of epithelioreticular cells). In myasthenia gravis, antibodies slowly destroy cholinergic receptors from skeletal muscle and cause weakness of muscles. It results in double vision (eye muscles), drooping of eyelid, dysarthria (muscles of throat), and so on.

SPLEEN

- Spleen is the largest lymphoid organ.^{MCQ} It is located in upper part of abdomen, along the 9th to 11th left ribs. It has a hilum through which splenic vessels enter (Figs 8.15 and 8.16).

Functions of Spleen

- Spleen performs immune system functions as well as hematopoietic functions as follows:
 - Activates lymphocytes by using antigen-presenting cells and induces immune response.
 - Is the site for proliferation of T and B lymphocytes.
 - Helps in the destruction of old and damaged RBCs and platelets.

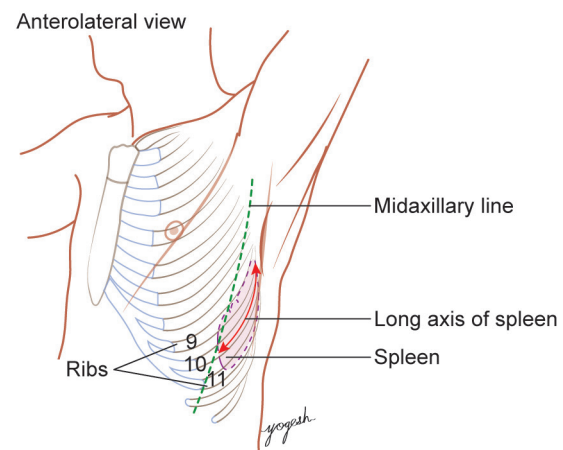


Fig. 8.15: Location of spleen

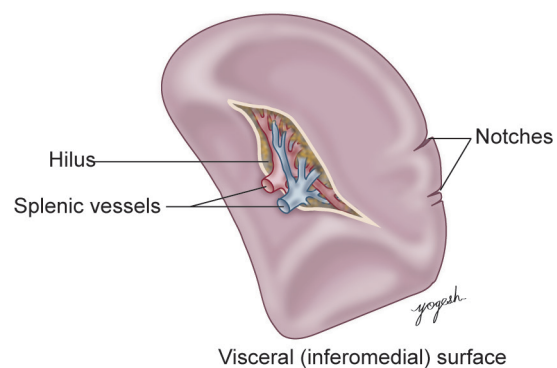


Fig. 8.16: Spleen

4. In embryonic life, spleen acts as the hematopoietic organ.
5. Stores small quantity of blood.

Features and Structure of Spleen

- A slice of fresh spleen specimen shows white pulp and red pulp. **White pulp** is grayish white areas that are scattered throughout substance of the spleen. **Red pulp** surrounds the white pulp.
- Structurally, spleen shows capsule, white pulp and red pulp (Fig. 8.17, Flowchart 8.5). Spleen does not have afferent lymphatics.

Capsule and Trabeculae

- Spleen is covered by a dense connective tissue **capsule**. **Trabeculae** arise from capsule and enter into the parenchyma of spleen.
- Connective tissue of spleen also contains **myofibroblasts** that contract the capsule and trabeculae and helps to discharge stored blood from the spleen.

White Pulp

- White pulp forms sheaths of lymphoid tissue surrounding central arterioles. These are called **periarterial lymphatic sheaths (PALS)**. PALS looks like a mass of lymphoid tissue surrounding central artery.
- **Splenic nodule/Malpighian corpuscles**: At some places, B cells proliferate in PALS on exposure to antigen and develop a germinal center. Such nodules are called splenic nodules or Malpighian corpuscles. They have **eccentric arteriole** (central arteriole pushed to one side) because of formation of germinal centers.

Red Pulp

- White pulp is surrounded by red pulp.
- Red pulp consists of two components
 1. **Cords of Billroth**: These are irregular anastomosing cords made up of reticular cells, reticular fibers,

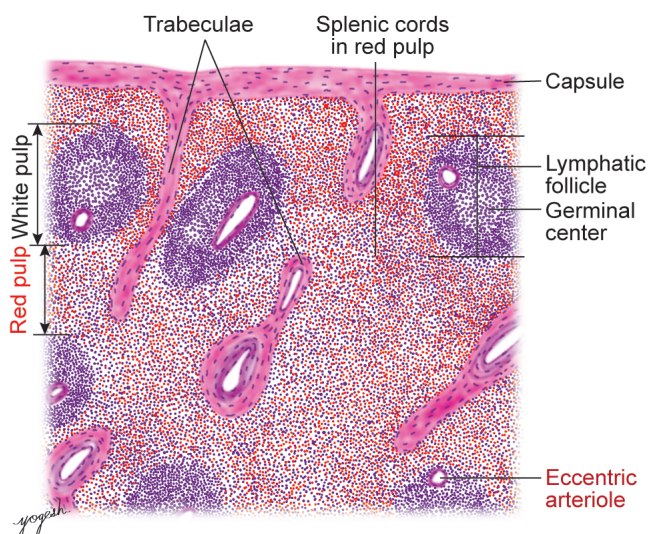


Fig. 8.17: Structure of spleen

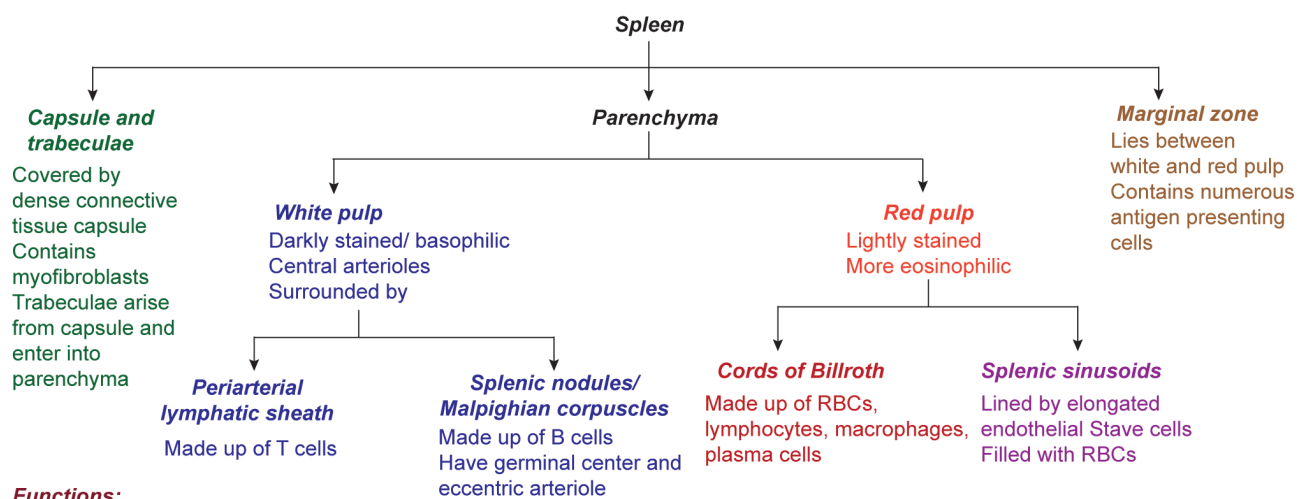
lymphocytes, macrophages, plasma cells, and large number of RBCs.

2. **Splenic sinusoids**: Cords of Billroth are separated by splenic sinusoids which are lined by elongated endothelial cells. Adjacent endothelial cells are separated by larger intercellular space that allows blood cells to pass through.

Some Interesting Facts

- **Splenic Circulation**: There are two concepts of splenic circulation (Fig. 8.18):
 1. **Open circulation**: Sheathed capillaries open into red pulp and blood passes through cords of red pulp and finally enter splenic sinusoids.
 2. **Closed circulation**: Capillaries open directly into splenic sinusoids.
- **Note**: In humans, only open circulation is present in spleen; whereas in dogs and rats, closed circulation is present. *Viva*

Flowchart 8.5: Structure of spleen



Functions:

1. Multiplication and activation of lymphocytes,
2. Phagocytosis of old or damaged RBCs/graveyard of RBCs,
3. Hematopoietic function in fetal life

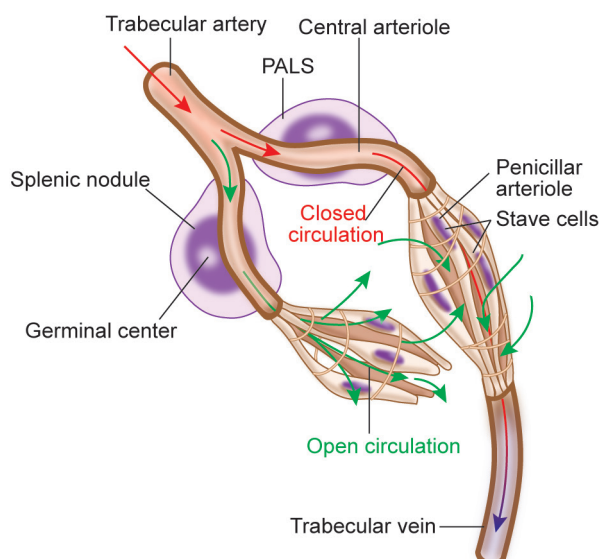


Fig. 8.18: Splenic circulation

Clinical Integration

- **Splenomegaly:** It is the enlargement of spleen. It occurs because of immunological or hematological causes such as: Abnormal RBCs (thalassemia, sickle cell anemia), immune disorders and infections (malarial infection, splenic abscess, typhoid fever, rheumatoid arthritis), cancerous conditions (leukemia), and obstruction to venous blood (cirrhosis of liver, obstruction of portal vein).
- **Splenectomy:** It is surgical removal of spleen. Indications: Injury to spleen, cancerous conditions (leukemia), severe hemolytic anemias, and so on. Patients after splenectomy do not respond properly to the infections.

EPITHELIO-LYMPHOID SYSTEM

- Epithelio-lymphoid system consists of *mucosa-associated lymphoid tissue* (MALT). It is lymphoid tissue associated with mucosa.
- It consists of two types:
 1. Gut-associated lymphoid tissue (GALT)
 2. Bronchus-associated lymphoid tissue (BALT)
- Well-defined MALT aggregates include the following (Fig. 8.19):
 1. Palatine tonsil
 2. Pharyngeal tonsil
 3. Tubal tonsil
 4. Lingual tonsil
 5. Peyer's patches in ileum.

Palatine Tonsil (Fig. 8.20)

- It is the largest tonsil in the group of tonsils. They are located on either side of oropharyngeal isthmus.
- Oral surface of the palatine tonsil is covered by *non-keratinized stratified squamous epithelium*.
- **Tonsillar crypts:** The epithelium invaginates internal surface of tonsil and forms tonsillar crypts. Tonsillar

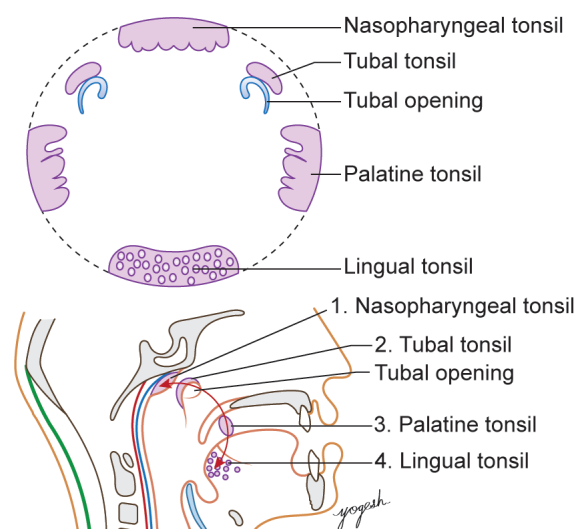


Fig. 8.19: Location of Waldeyer's ring

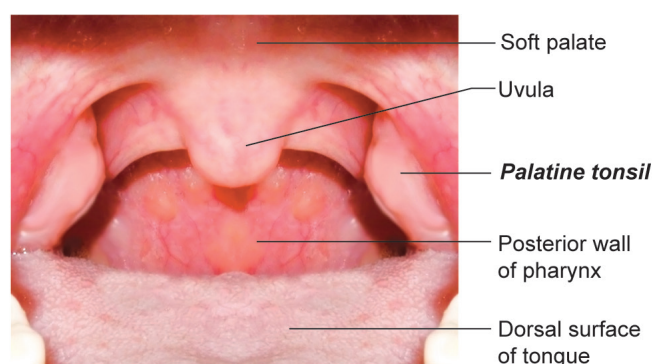


Fig. 8.20: Palatine tonsil (on oral examination)

crypts are lined by nonkeratinized stratified squamous epithelium.

- Laterally, tonsil is bounded by connective tissue *capsule* and has some efferent lymphatic vessels.
- Just beneath epithelium, palatine tonsil shows dense aggregation of lymphatic follicles.
- **Functions**
 1. Production of lymphocytes.
 2. Antigen presentation and development of immune response.

Pharyngeal Tonsil

- It is the aggregation of lymphoid tissue deep to the mucous lining of the roof and posterior wall of the pharynx.

Tubal Tonsil

- It is the aggregation of lymphoid tissue around the opening of the pharyngo-tympanic or auditory tube in the nasopharynx.

Lingual Tonsil

- These are numerous lymphoid follicles deep to the mucosa of the dorsal surface of posterior one-third of tongue.

Peyer's Patches

- These are aggregated lymphoid follicles deep the mucous membrane of small intestine (2 to 10 cm in length).
- They are more numerous in the ileum.

Clinical Integration

- Aggregation of tonsils around the naso- and oropharynx forms Waldeyer tonsillar ring which includes pharyngeal tonsil, tubal tonsil, palatine tonsil, and lingual tonsil.
- **Tonsillitis**: It is an inflammation of tonsil. It is caused by viral or bacterial infections.
- **Tonsillectomy**: Surgical removal of palatine tonsil is tonsillectomy. It is usually required in children who have recurrent tonsillitis (repeated infections).
- The Peyer's patches are ulcerated in typhoid fever forming ulcers (typhoid ulcers).
- **Adenoid**: It is an enlarged pharyngeal tonsil due to infection. It may obstruct nasal respiration and make breathing through mouth obligatory.

Some Interesting Facts

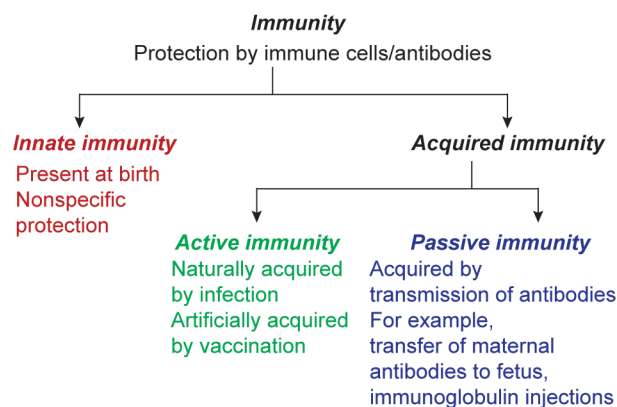
Reticuloendothelial System

- It consists of the phagocytic cells. They pick up, ingest and store foreign substances. Thus, it plays an important role in general and local defense mechanisms.
- Different types of cells in reticuloendothelial system are as follows:
 1. Macrophages in connective tissue and bone marrow,
 2. Pericytes (Rouget cells) in capillaries
 3. Monocytes in blood
 4. Dust cells (alveolar macrophages) in lungs
 5. Reticular cells in spleen and lymphoid tissue
 6. Kupffer cells in liver
 7. Microglia in central nervous system.

IMMUNITY

- **Immunity** is ability of organism to resist a particular infection or toxic substance with the help of antibodies or activated white blood cells. There are two types of immunity: Innate and acquired immunity (Flowchart 8.6).
 1. **Innate/native immunity** is present at birth. Innate immunity provides nonspecific protection against all type of infections.
 2. **Acquired or adaptive immunity** is acquired by an individual throughout the life. Acquired immunity is of two types:
 - a. **Active immunity**: It is acquired by an individual on exposure of antigenic agents, toxins or microorganisms. During exposure, immune cells get activated and impart acquired immunity.
 - b. **Passive immunity**: It is acquired by an individual by the transfer of readymade antibodies (immunoglobulin injections).

Flowchart 8.6: Immunity



LYMPHOCYTES

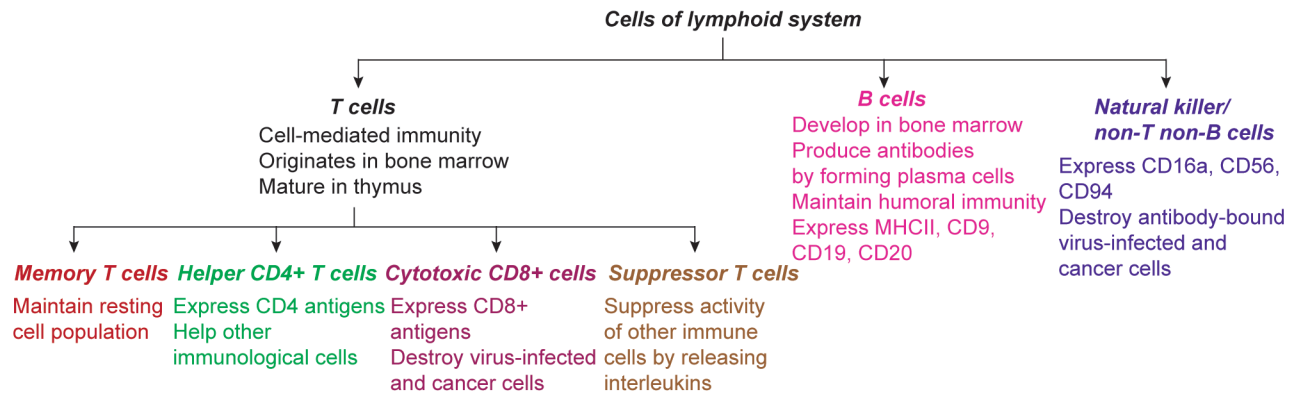
- Lymphocyte is a subtype of white blood cells that forms a major component of lymphoid tissue.
- Size: Small lymphocytes: 5–8 μm and large lymphocytes: 9–15 μm .
- Based on the presence of specific CD molecules, lymphocytes are grouped into three types: T lymphocytes, B lymphocytes, and natural killer (NK) cells.

T Lymphocytes (T Cells)

- Undifferentiated lymphocytes originate from bone marrow and enter thymus. In thymus, they get differentiated into mature T lymphocytes. They maintain **cell-mediated immunity**.
- Exposure of T cells to specific MHC molecules converts T cells into effector or memory T cells.
 1. **Memory T cell** maintains population of T cells that get easily activated on reinfection by the same microorganism. These cells persist for a long time.
 2. Effector T cells are grouped into three subtypes as follows (based on presence of specific CD antigen):
 - a. **Helper T cell (T4 cells)/CD4+ T lymphocytes**: These cells activate other immunological cells by secreting interleukins.
 - b. **Cytotoxic T cells/CD8+ lymphocytes**: They kill virus-infected cells, cancer cells, other cells infected with parasite, and transplanted cells.
 - c. **Suppressor/regulatory T cells**: They suppress immune response against foreign and self-antigens.

B Lymphocytes (B Cells)/Plasma Cells

- B lymphocytes were first recognized in the bursa of Fabricius in birds; hence, called B cells. In human, B cells originate from bone marrow (Flowchart 8.7). They maintain **humoral immunity**.
- On activation, B cell differentiates into **plasma cells** or memory B cell. Plasma cell continues secretion of antibodies against specific antigens. **Antibodies** are immunoglobulins.

Flowchart 8.7: Cells of lymphoid system

Natural Killer Cells

- They are the variety of lymphocytes that are neither T nor B cells. They constitute 5–10% of circulating lymphocytes. They kill cancer cells and virus-infected cells and destroy antibody-bound cells. This is called *antibody-dependent cellular cytotoxicity* (ADCC).



Some Interesting Facts

- Antigen-presenting cells* (APC) present antigens with the help of MHCII molecules to helper CD4+ T cells. APC include macrophages, perisinusoidal Kupffer cells in liver, Langerhans' cells in epidermis, dendritic cells in spleen and lymph nodes, epithelioreticular cells (type II or III) in thymus, and B lymphocytes. ^{MCQ}

Nervous System



Competencies:

AN7.1 Describe general plan of nervous system with components of central, peripheral, and autonomic nervous systems.

AN7.2 List components of nervous tissue and their functions.

AN7.3 Describe parts of a neuron and classify them based on number of neurites, size, and function.

AN7.4 Describe structure of a typical spinal nerve.

AN7.5 Describe principles of sensory and motor innervation of muscles.

AN7.6 Describe concept of loss of innervation of a muscle with its applied anatomy.

AN7.7 Describe various types of synapses.

AN7.8 Describe differences between sympathetic and spinal ganglia.

activities, including thinking, learning, memory, and emotional responses.

These functions collectively enable the nervous system to facilitate communication within the body, adapt to changing conditions, and support overall physiological and cognitive well-being.

- The weight of brain is about 1500 to 2000 g and it contains about 100 billion neurons.
- The nervous tissue consists of
 1. Neurons
 2. Neuroglial cells (supporting cells).
- The major parts of the brain and its cavities are listed in Tables 9.1 and 9.2, respectively.

INTRODUCTION

- The nervous system is most evolved part of the human body. It integrates and controls most of the body functions, hence it is termed '*master system*' of the body.
- Some major functions of the nervous system are as follows:
 1. **Sensory reception:** It receives sensory input from both the internal and external environments, allowing the body to perceive and react to various stimuli.
 2. **Information integration:** The nervous system processes and integrates the received sensory information, enabling the brain to make sense of the surroundings and respond appropriately.
 3. **Muscle control:** It oversees the intricate control of muscles throughout the body, regulating voluntary and involuntary movements.
 4. **Glandular control:** The nervous system governs glands and their secretions, influencing the release of hormones and various physiological processes.
 5. **Homeostasis maintenance:** It plays a crucial role in maintaining the body's internal balance, ensuring that essential physiological parameters, such as temperature and blood pressure, remain within a narrow range.
 6. **Cognitive functions:** The nervous system is instrumental in establishing and sustaining mental

TABLE 9.1: Major parts of brain

Part	Subparts
Cerebral hemisphere	Cerebral cortex Frontal lobe Parietal lobe Occipital lobe Temporal lobe Basal ganglia, claustrum, insular cortex Limbic system Internal capsule
Diencephalon	Thalamus, hypothalamus, subthalamus, epithalamus, metathalamus
Brainstem	Midbrain Pons Medulla oblongata
Cerebellum	Cerebellar cortex Cerebellar nuclei

TABLE 9.2: Cavities of brain and spinal cord

Part of brain	Cavity
Cerebral hemisphere	Lateral ventricle
Diencephalon	3rd ventricle
Mesencephalon (Midbrain)	Cerebral aqueduct
Rhombencephalon (hindbrain)	4th ventricle
Spinal cord	Central canal of spinal cord Terminal ventricle

DIVISIONS OF NERVOUS SYSTEM

- The nervous system can be classified in two divisions on the anatomical or functional basis.

Anatomical (Descriptive) Divisions (Flowchart 9.1)

- Anatomically, the nervous system is divided into two parts: Central and peripheral nervous systems.

A. Central nervous system (CNS)

- It consists of the brain and spinal cord (Figs 9.1 and 9.2, Tables 9.1 and 9.2).

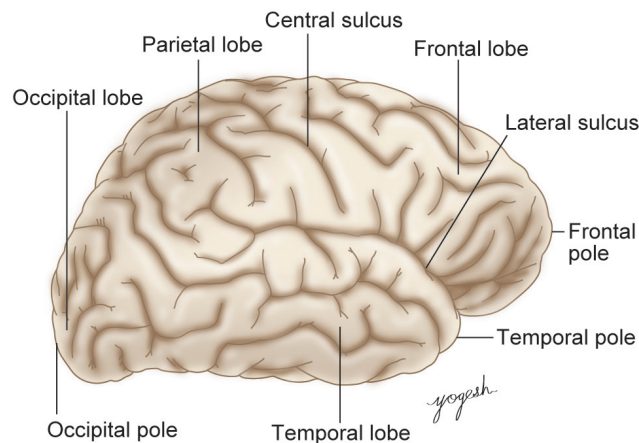


Fig. 9.1: Superolateral surface of the right cerebral hemisphere

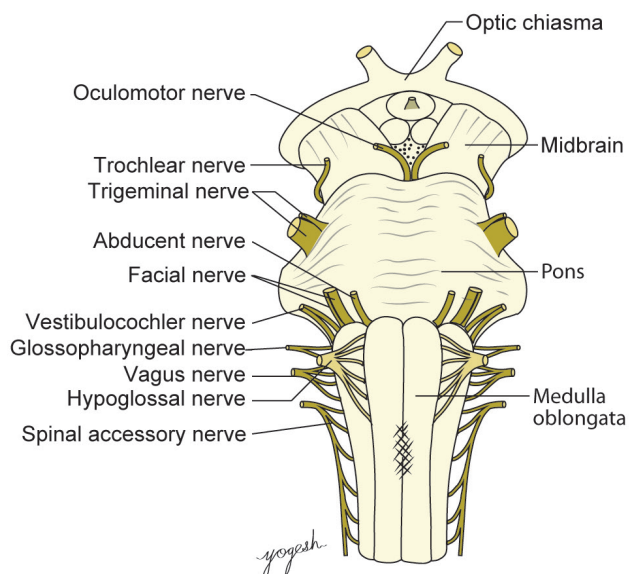


Fig. 9.2: External features of brainstem (anterior view)

- It is responsible for integration, processing and coordinating sensory inputs and generation of motor output.
- It is the seat of higher functions such as intelligence, memory, learning, and emotions.

B. Peripheral nervous system (PNS)

- Peripheral nerves: They consist of
 - 12 pairs of cranial nerves
 - 31 pairs of spinal nerves (Fig. 9.3)
 - Autonomic (splanchnic) nerves.
- Ganglia: Dorsal root ganglia of spinal nerves, cranial nerve root ganglia, and autonomic ganglia.
- It carries sensation to CNS and gives efferent fibers to muscles, glands, and blood vessels.

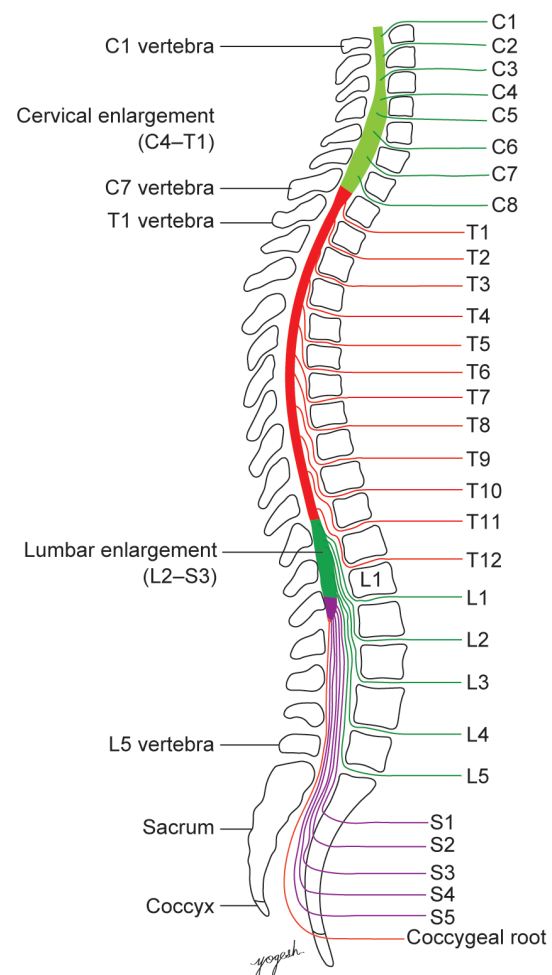
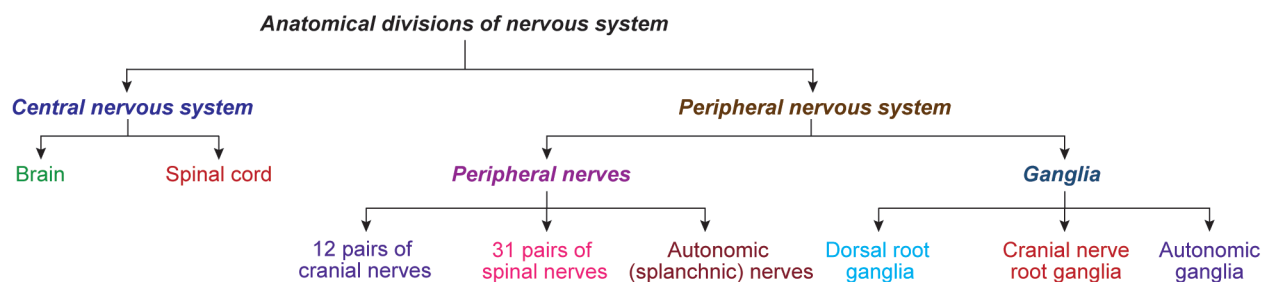


Fig. 9.3: Spinal cord with 31 pairs of spinal nerves

Flowchart 9.1: Anatomical divisions of nervous system



Functional (Physiological) Divisions (Flowchart 9.2)

- Functionally, the nervous system is divided into two divisions:
 - Afferent division:** It gives sensory input to the central nervous system.
 - Efferent division:** It carries motor signals away from the central nervous system. It is further subdivided as follows:
 - Somatic nervous system (SNS):** It has voluntary control over skeletal muscles.
 - Autonomic nervous system (ANS):** It has involuntary control over the heart, smooth muscles, glands, and blood vessels and includes sympathetic and parasympathetic nervous system.

NEURON

- Neuron is the structural and functional unit of the nervous system.
- Neurons are grouped as sensory neurons (carry information toward the nervous system), motor neurons (carry information away from the nervous system), and interneurons (communicate information from sensory to motor neurons).
- More than 99% neurons are interneurons (intercalated neurons).

Structure of Neuron

- Neuron has a body, axon, dendrites, and synaptic junctions (Fig. 9.4).

Body/Perikaryon

- Cell body of a neuron is also called perikaryon or soma. It consists of the nucleus, perinuclear cytoplasm, and cell membrane.
- Cytoplasm:** Cytoplasm contains a large central vesicular nucleus, numerous mitochondria, rough endoplasmic reticulum, and Golgi complex.
- Nucleus is euchromatic (lightly stained) with 1–2 nucleoli.
- New concept:** Neurons have centrioles, but they cannot divide. *Viva* (**Previous concept:** Neurons do not have centrioles).
- Cytoplasm shows the presence of **Nissl bodies**.
- Nissl bodies/substance/granules:** Cytoplasm of neurons shows the presence of granular **basophilic** cytoplasmic

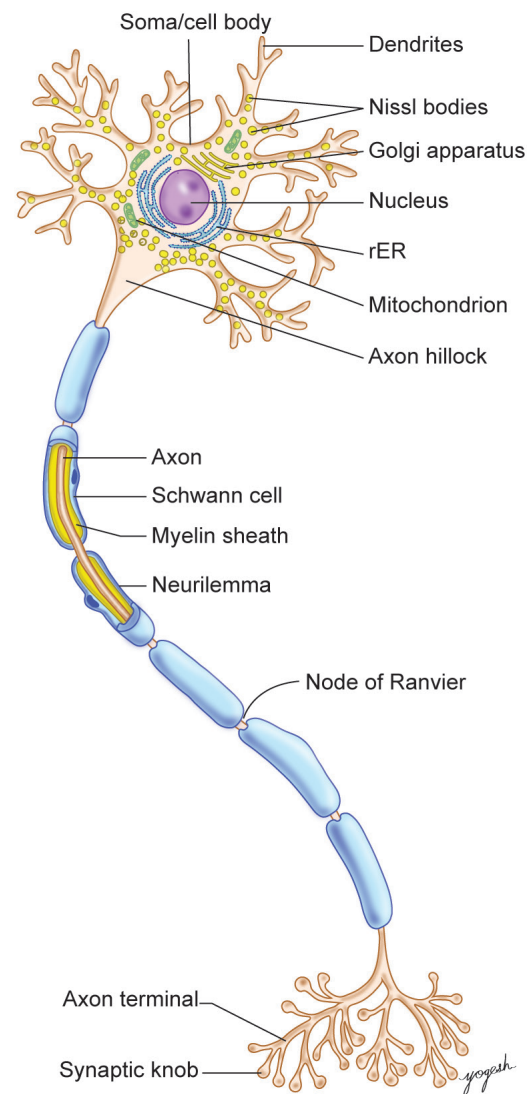


Fig. 9.4: Parts of neuron

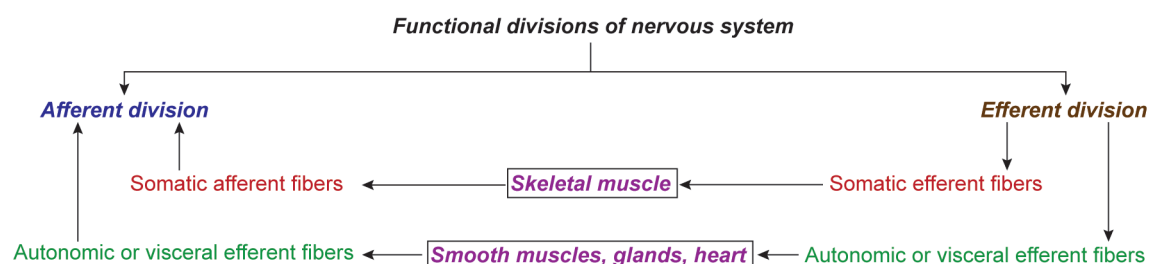
material called Nissl bodies. *NEXT, Viva* On electron microscopy, Nissl bodies are stacks of the rough endoplasmic reticulum. *Viva, MCQ*

- Neuron contains many **neurofibrils** (microtubules and microfilaments). Centrioles may help in the production of neurofibrils. *Viva*
- Some of the neurons also contain melanin pigment (substantia nigra) and lipofuscin pigments. *MCQ*

Neurites

- Processes arising from the cell body of a neuron are called **neurites**. They are axons and dendrites.

Flowchart 9.2: Functional divisions of nervous system



Dendrites

- Dendrites are multiple, short, thick, tapering processes. Nissl granules extend into the dendrites.
- Branching pattern of dendrites (*arborization*) is called *dendritic tree*. Dendrites receive information and carry it toward the body of the cell.

Axons

- Axon is a single, long, and thin process of neuron. Axons carry information away from the neuron body and have a uniform diameter. Axon is commonly termed 'nerve fiber'. Axon is devoid of Nissl granules. ^{MCQ}
- Axoplasm* is cytoplasm in axon and *axolemma* is its cell membrane.
- Axoplasmic transport* (axonal transport system): As axons do not contain rough endoplasmic reticulum, the protein synthesized in the cell body needs to be transported across axon.
- New concept:** Periaxoplasmic plaques – these are axon terminals that have protein synthesis machinery (rER). These are involved in the process of neuronal cell memory. ^{NEXT}
- Axon hillock*: It is a part of cell body that is devoid of Nissl granules and gives rise to axon.
- New concept:** Some cells of the olfactory bulb and dentate gyrus of the hippocampus are neural stem cells, and these cells can generate new neurons [*Pawlina, Histology, 7th edition*].
- Initial segment*: It is the initial *nonmyelinated* part of axon between axon hillock and myelinated part of axon. An action potential is generated at initial segment.
- Telodendria* is the terminal branching part of the axon. It has terminal *boutons* or *presynaptic knobs*.
- The gray matter consists of mainly nerve cell bodies, whereas the white matter consists of mainly nerve fibers.
- The differences between axons and dendrites are listed in Table 9.3.

CLASSIFICATION OF NEURON

Q. Classify the neurons.

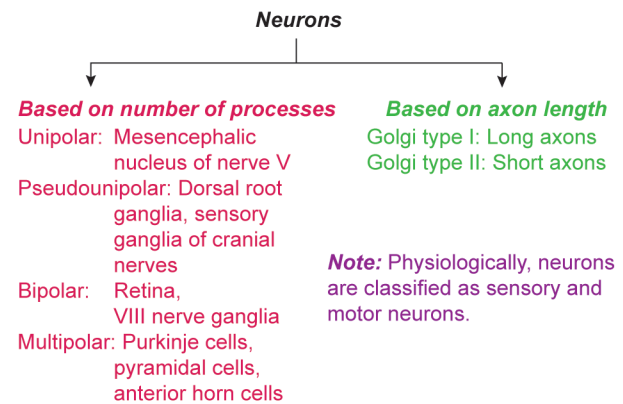
A. Based on Number of Processes/Polarity

- Neurons are classified as unipolar, pseudounipolar, bipolar, and multipolar depending on the number of processes (Fig. 9.5, Flowchart 9.3).
 - Unipolar neurons:** Unipolar neurons have only one cell process, mostly dendrite. ^{MCQ}
 - Neurons of mesencephalic nucleus of trigeminal nerve
 - Some neurons during embryonic life.
 - Pseudounipolar neurons:** These neurons have only one process (axon) that divides into two branches, peripheral and central.

TABLE 9.3: Differences between axon and dendrites
Q. List the differences between axon and dendrites.

Axon	Dendrites
It is a single, long, thin process of neuron	These are multiple, short, thick processes of neuron
It carries signal away from nerve cell body	It carries signal toward nerve cell body
Axon rarely branches. Branches of axon form axon terminals	Branches of dendrite form dendritic tree
Diameter: Uniform	Diameter: Taper toward distal end (away from neuron)
Does not contain Nissl granules	Contain Nissl granules

Flowchart 9.3: Classification of neurons ^{Viva, NEXT}



Examples: ^{NEXT}

- Dorsal root ganglia
 - Sensory ganglia of cranial nerves.
- New concept:** Unipolar and pseudounipolar neurons are under the same category [*Pawlina, Histology, 7th edition*].
- Bipolar neurons:** They have two processes: One axon and another dendrite.

Examples:

 - Olfactory epithelium
 - Retina
 - Ganglionic cells of vestibular and spiral ganglia (VIII cranial nerve).
 - Multipolar neurons:** They have multiple processes – one axon and many dendrites. These are present in the spinal cord, cerebellum, and cerebrum as *motor neurons* and *interneurons*.

Examples: ^{NEXT}

 - Stellate (star-like) cells
 - Purkinje (flask-shaped) cells
 - Pyramidal (triangular) cells.

B. Based on Length of Axon

- Based on length of the axon, neurons are grouped as Golgi type I and Golgi type II neurons.
 - Golgi type I neurons** have long axons.

Examples: ^{NEXT}

 - Pyramidal cells of motor cortex in cerebrum.

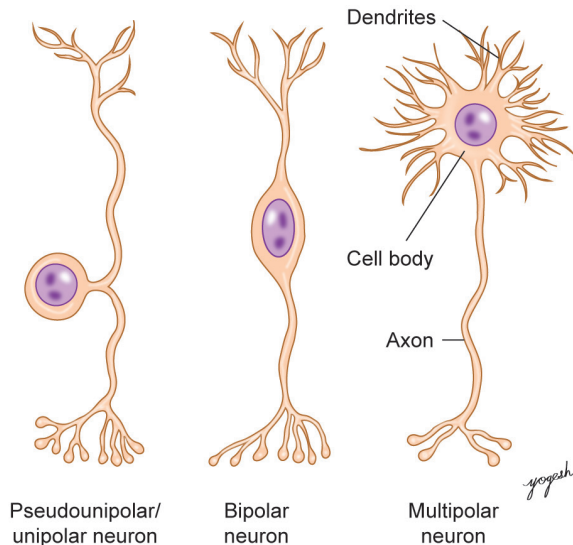


Fig. 9.5: Types of neurons

- b. Anterior horn cells of spinal cord
- c. Purkinje cells of cerebellum.
2. **Golgi type II neurons (microneurons)** have short axons. They are abundant in the cerebral and cerebellar cortex.

Example:

- a. Granule cells in the cerebellum
- b. Basket cells in the hippocampus
- c. Stellate cells in the cerebral cortex
- d. Amacrine cells in the retina
- e. Golgi cells in the cerebellum.

C. Physiological Classification

- Based on function, neurons are classified as sensory and motor neurons.
 1. **Sensory neurons:** They receive impulses and carry signals to the nervous system.
 2. **Motor neurons:** They carry impulses from the nervous system to muscles and glands.

NEUROGLIA

Q. List the types of neuroglia.

- Supporting cells of the nervous system are called *neuroglia* or *glia*.
- Functions of neuroglial cells
 1. Support and structural maintenance of nervous tissue
 2. Insulation for nerve conduction
 3. Nutrient supply to neurons
 4. Waste removal
 5. Immune defense and phagocytosis
 6. Regulation of extracellular environment
 7. Modulation of synaptic activity.
- Neuroglia are grouped as follows (Flowchart 9.4 and Fig. 9.6):
 1. Central neuroglia (neuroglia of the central nervous system)
 2. Peripheral neuroglia (neuroglia of the peripheral nervous system).

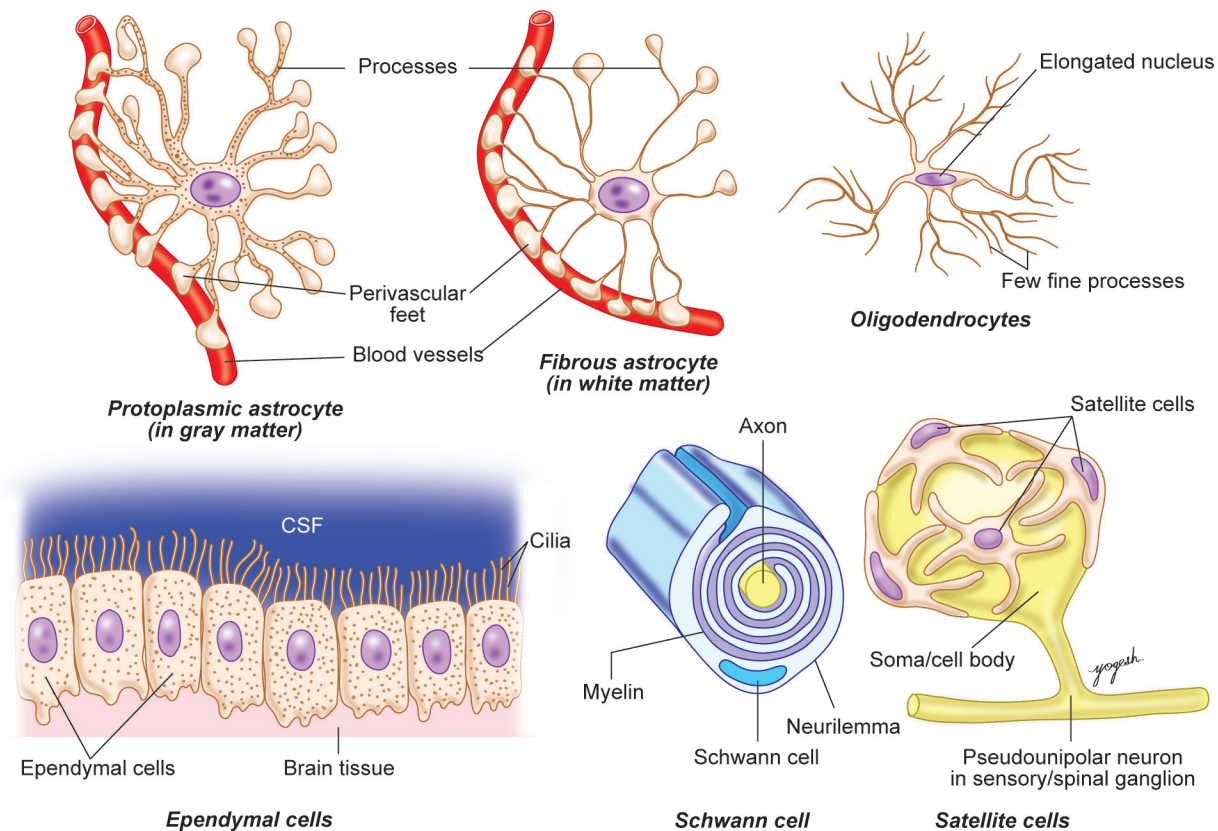
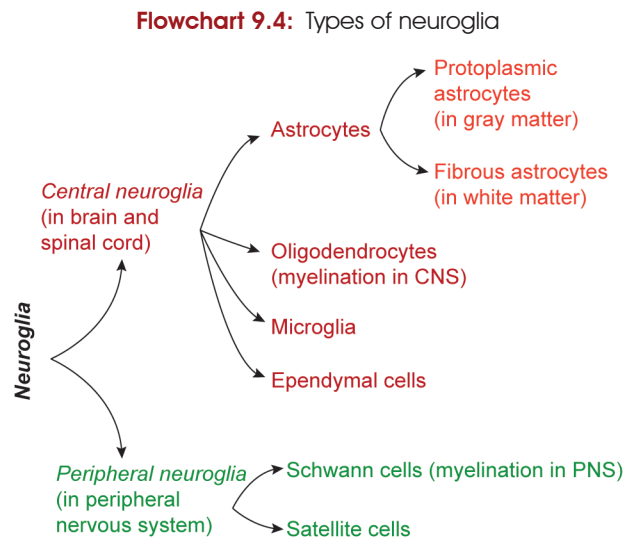


Fig. 9.6: Various neuroglial cells



CENTRAL NEUROGLIA

- These are supporting cells of the central nervous system. There are four types of central neuroglia:
 - Astrocytes
 - Oligodendrocytes
 - Microglia
 - Ependymal cells.^{MCQ}
- Neuroglial cells support embryonic (developing) neurons as well as provide physical support after development. Radial glial cells direct the migration of neurons during development.^{NEXT}

Astrocytes

- These are star-shaped cells (largest neuroglia) and they have numerous processes. There are two types of astrocytes: Fibrous and protoplasmic.
- Fibrous astrocytes*: They have fewer and thin processes and are mostly found in the white matter of the CNS.
- Protoplasmic astrocytes*: They have numerous, short, thick, branching cytoplasmic processes. They are mostly found in gray matter.
- Functions of astrocytes**
 - They provide physical support to neurons.
 - They maintain a favorable metabolic environment for neurons by removing neurotransmitters from synapses.
 - They help in the maintenance of blood–brain barrier.
 - Glia limitans* is the membrane-like barrier on external surfaces of brain and spinal cord. It is produced by protoplasmic astrocytes.
 - Astrocytes maintain K^+ ion concentration in extracellular spaces of the brain and spinal cord by potassium spatial buffering.
 - Gliosis* is the proliferation of astrocytes to heal the damaged zones of nervous tissue.^{NEXT}
 - Fibrous astrocytoma* (tumor) accounts for about 80% of brain tumors in adults.

Oligodendrocytes

- Oligodendrocytes are small, round cells and have a few cytoplasmic processes (*oligo* = scanty, in Greek).
- Function**: Oligodendrocytes produce myelin sheaths in CNS.^{Viva, MCQ} One oligodendrocyte myelinates many adjacent axons or sometimes the same axons at different places.
- Note**: Nonmyelinated neurons are not enclosed by processes of oligodendrocytes in CNS.

Microglia

- These are the smallest neuroglial cells.
- Function**: Microglia are phagocytic cells. They proliferate specifically in nervous tissue injuries and diseases. Microglia form a part of mononuclear phagocytic system in CNS.^{Viva}
- Current update**: Microglia remove bacteria, cancer (neoplastic) cells, and dead nerve cells.
- Gitter* or *Hortega cell* is a lipid-laden microglial cell observed at the edge of healing brain infarcts. It is also called compound granule cell, gitterzelle, mesoglea, or perivascular glial cell.^{NEXT}

Ependymal Cells

- The cavities of the nervous system are lined by epithelium-like *ependymal cells*. Ependymal cells are cuboidal to columnar in shape and arranged in a single layer.
- There are three types of ependymal cells: Ependymocytes, choroid epithelial cells, and tanocytes.
- Functions**
 - Exchange of substances between the brain and cerebrospinal fluid at the brain–CSF barrier.
 - Choroid plexus secretes CSF.

Peripheral Neuroglia

Schwann Cells

(Theodor Schwann, 1810–1882, German physiologist):

- Schwann cells are also called *neurolemmocytes*. These are present only in peripheral nervous system.
- Functions**: Schwann cells produce myelin in peripheral nervous system.^{NEXT}

Satellite Cells

- In ganglia (collection of neuronal cell bodies outside the CNS), neuronal bodies are surrounded by a layer of flat cuboidal cells called satellite cells.
- Satellite cell capsule* gives passage to nerve cell processes.
- In sensory ganglia, the satellite cell capsule is nearly complete as sensory neurons do not synapse in ganglia.
- In autonomic ganglia, the satellite cell capsule is not complete as autonomic neurons have synapses in the ganglia.
- Functions**: Protection and support ganglionic neurons.

SYNAPSE

- Neuron conveys messages to another cell (neuron/effector cell) through a synapse. Synapse is the junction between neurons.

Morphological Classification (Flowchart 9.5)

- Depending on components of the synapse, they are classified as follows (Fig. 9.7):
 - Axodendritic synapse:** It is the most common type of synapse. In the axodendritic synapse, the axon of one neuron synapses with the dendrite of another neuron.
 - Axosomatic synapse:** Axon conveys impulses to soma (body) of another neuron.
 - Axoaxonic synapse:** It is the synapse between two axons.
 - Dendroaxonic synapse:** It is the synapse between dendrite of presynaptic neuron and axon of postsynaptic neuron. It is seen in some parts of thalamus.
 - Dendrodendritic synapse:** It is the synapse between two dendrites.
 - Somatosomatic synapse:** It is the synapse between bodies of neurons.
 - Somatodendritic synapse:** It is the synapse between soma and dendrite of postsynaptic neurons.
- Boutons en passant:** Presynaptic neuron makes several contacts with postsynaptic neuron. These contacts are called *boutons en passant* (means *buttons in passing* in French).
- Bouton terminal:** Enlarged terminal end of axon is called bouton terminal (means *terminal button* in French).

Chemical and Electric Synapses (Flowchart 9.6)

- Based on mechanism of conduction of nerve impulses, synapses are classified as chemical or electrical.

Chemical Synapses

- Chemical synapse involves release of chemical (neurotransmitter) from preganglionic neurons for conduction of impulse.

Structure of chemical synapse (Fig. 9.8)

- Components of chemical synapse are as follows:
 - Presynaptic element (presynaptic knob):** It is the part of presynaptic neuron that releases neurotransmitter.
 - Presynaptic element stores neurotransmitter in synaptic vesicles.

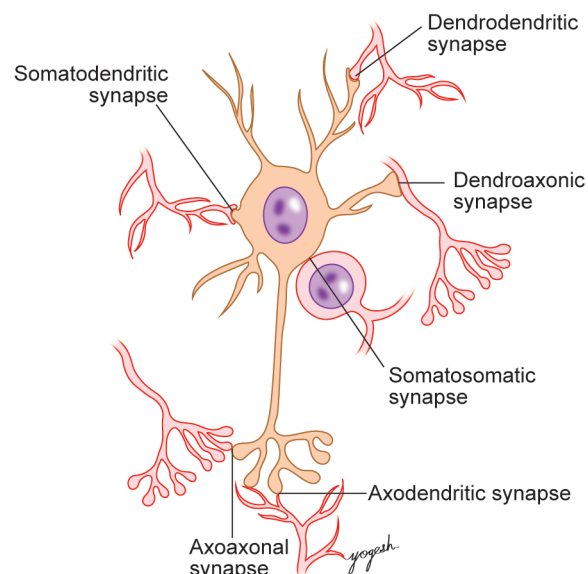


Fig. 9.7: Types of synapse

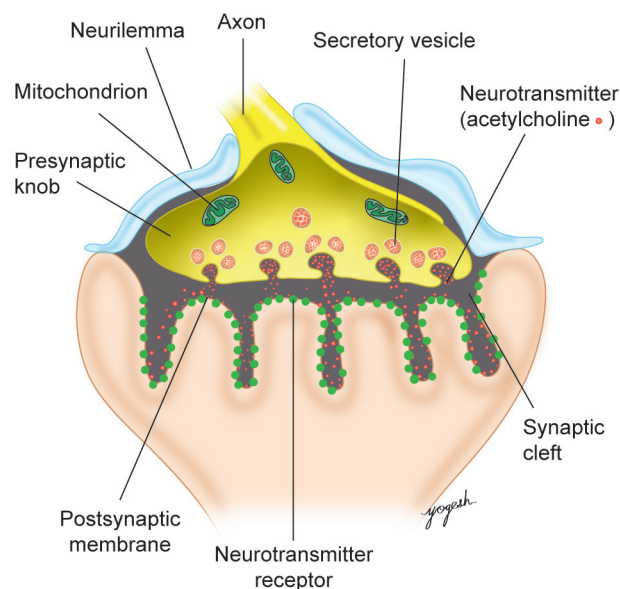


Fig. 9.8: Structure of chemical synapse

- Synaptic cleft:** It is a narrow gap (20–30 nm) between presynaptic and postsynaptic neurons. Neurotransmitter needs to cross synaptic cleft.
- Postsynaptic membrane/process:** It is a membrane of postsynaptic neuron that has receptors for neurotransmitters.

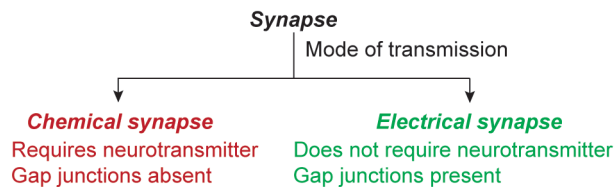
Electrical Synapses

- Electric synapse involves the passage of electric signal from one cell to another cell by gap junctions.

Flowchart 9.5: Morphological classification of synapse

Morphological classification of synapse							
Structures	Axodendritic	Axosomatic	Axoaxonal	Dendroaxonic	Dendrodendritic	Somatosomatic	Somatodendritic
Presynaptic	Axon	Axon	Axon	Dendrite	Dendrite	Soma	Soma
Postsynaptic	Dendrite	Soma	Axon	Axon	Dendrite	Soma	Dendrite

Flowchart 9.6: Classification of synapse based on the mode of transmission



- Electrical synapses do not involve neurotransmitter release.
- *Examples:* Gap junctions of cardiac and smooth muscles.

Some Interesting Facts

- Merkel epidermal cells, auditory receptors, and taste buds are epithelial receptors, whereas the olfactory epithelium is a neuroepithelial receptor. *NEXT*
- Neurotransmitters once released in synaptic cleft may be degraded by enzymes or may be taken back (uptake) by presynaptic neurons. For example, catecholamine action is terminated by their uptake.
- *Clinical fact:* Amphetamine and cocaine inhibit catecholamine uptake and prolong their actions. Acetylcholine is degraded by acetylcholine esterase.
- *Clinical fact:* Many poisons (pesticides) and other drugs inhibit the action of acetylcholine esterase and cause prolonged muscle contraction.
- Axon hillock is the most excitable part of the neuron.
- Astrocytes are the largest neuroglia, whereas microglia are the smallest.
- Axodendritic synapses are the most numerous synapses in the body.
- Pacinian corpuscles are the largest sensory receptors.

NEUROTRANSMITTERS

Q. Write a short note on neurotransmitters.

- These are the substances released from presynaptic neurons that traverse the synaptic cleft to reach the postsynaptic membrane.
- They may depolarize (activate) or hyperpolarize (inhibit) the postsynaptic membrane.
- The neurotransmitters are grouped based on their chemical nature into the following groups:
 1. Acetylcholine
 2. Amines: Noradrenaline, adrenaline, serotonin dopamine, histamine
 3. Amino acids: Gamma-aminobutyric acid (GABA), glycine, glutamate, aspartate
 4. Neuropeptide: Substance P, endorphins, enkephalins.
- Neurotransmitters bind with *receptors* to produce their desired effects such as:
 1. Acetylcholine: ACh binds with cholinergic receptors.
 2. Adrenaline and noradrenaline bind with adrenergic receptor.

- *Note:* Acetylcholine esterase (AChE) immediately hydrolyses secreted acetylcholine into acetic acid and choline. *Viva*

Clinical Integration

- *Myasthenia gravis:* It is an autoimmune disease in which antibodies destroy own acetylcholine receptors in muscle fibers. It results in muscular weakness, fatigue, ptosis (drooping of upper eyelid), and flaccid muscle paralysis.
Treatment: Anticholinesterase drugs (e.g. neostigmine) enhance acetylcholine concentration and hence, useful in treatment of myasthenia gravis.

MYELIN SHEATH

- Myelin is an insulating sheath surrounding the axons of myelinated nerve cells. *Viva* Myelin is produced by oligodendrocytes in CNS and Schwann cells in PNS. *NEXT, Viva* Myelin consists of lipids (80%), proteins, and water.

Formation of Myelin Sheath (Fig. 9.9)

- In the process of myelination, the axon initially lies in a groove of a Schwann cell.
- Sheet-like extension of mesaxon surrounds axon spirally, and cytoplasm of mesaxon gets squeezed. Thus, it results in the formation of myelin sheath (lipid layer) around axon.
- Outside the myelin sheath, thin layer of cytoplasm of Schwann cell is present along with surrounding cell membrane of Schwann cells, now called *neurilemma* or *neurilemmal sheath*.
- *Schmidt-Lanterman clefts:* These are the small pockets of cytoplasm in the inner layers of the myelin sheath. Usually, cytoplasm gets squeezed out of the myelin sheath during the wrapping of mesaxon around the axon. *NEXT*

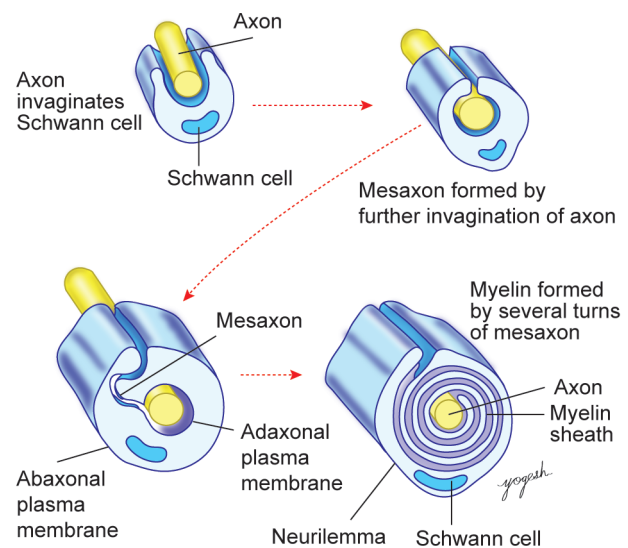


Fig. 9.9: Process of myelination

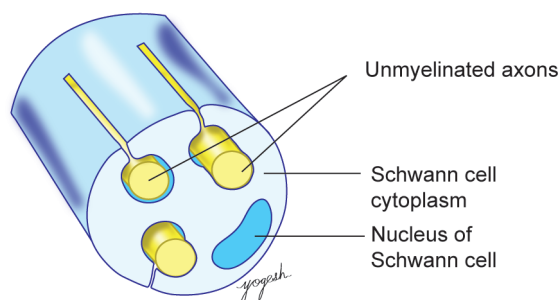


Fig. 9.10: Role of Schwann cell in the protection of nonmyelinated axon

Note: One Schwann cell surrounds multiple nonmyelinated nerve fibers.

- Nonmyelinated axons are covered by Schwann cells in PNS. Single Schwann cell is invaginated by multiple nonmyelinated axons.
- The gap between the segment of myelin and between adjacent Schwann cells is called **nodes of Ranvier** or **incisura myelini** (Louis Antoine Ranvier, French Anatomist, 1835–1922). Nodes of Ranvier increase the rate of nerve conduction by saltatory conduction.
- Internode is a segment of myelin sheath between adjacent nodes of Ranvier.
- Thickness of myelin sheath depends on axon diameter of axon and not on Schwann cell. ^{MCQ}
- A single Schwann cell protects many nonmyelinated axons (Fig. 9.10).

Functions of Myelin Sheath

1. Protection and physical support to axons
2. Insulation of axons
3. Increases nerve conduction by saltatory conduction
4. Neurilemmal sheath plays a major role in nerve regeneration.

Clinical Integration

- **Enuresis** (bed-wetting). It is observed in the first 3–6 years of life. It occurs up to the completion of myelination of corticospinal tract fibers that control the emptying of the urinary bladder.

Embryological basis: The myelination begins before birth and continues for a few years after birth. Enuresis is normal in infants.

- One Schwann cell can produce a myelin sheath around a small segment of one axon. One oligodendrocyte can produce a myelin sheath around many axons. ^{NEXT} Hence, the **neurilemmal sheath** is present only in the peripheral nervous system (cell membrane of Schwann cell) and not in CNS as a single oligodendrocyte does not cover one axon. Because of the absence of neurilemmal sheath in CNS, regeneration of neuron is not possible in CNS. ^{Viva}

Classification of Nerve Fibers

- Based on the diameter of the nerve fibers, they are grouped as follows:

Group A: Highly myelinated fibers

Group B: Thinly myelinated fibers (up to 3 μm thick)

Group C: Nonmyelinated fibers (about 0.2–1.5 μm thick).

CONDUCTION OF ACTION POTENTIAL

- Ionic concentration within the neuron and extracellular fluid creates *resting membrane potential* (RMP) across the neuronal plasma membrane. At resting membrane potential, the neuronal plasma membrane is polarized. Resting membrane potential is always negative (–70 mV). ^{MCQ}
- The resting membrane potential is negative because of the high concentration of cations (for example, Na^+ ions) outside the nerve fibers in the extracellular fluid.
- **Action potential:** It is a sequential change in membrane potential that develops on activation or stimulation of the nerve cell rise in membrane potential which soon comes back to resting membrane potential.
- It involves two phases:
 1. **Depolarization** – increase in membrane potential up to +40 mV.
 2. **Repolarization** – decrease in or restoration of membrane potential.
- Action potential is generated at one point of the neuronal plasma membrane, and it propagates across this membrane (Fig. 9.11). The speed of conduction of action potential depends on the myelination of the nerve fibers.
- Thickness of myelin is directly proportional to the conduction of action potential. ^{MCQ}
- **Saltatory conduction** (*saltare* = to leap in Latin) is jumping conduction of action potential from one node of Ranvier to other nodes of Ranvier. In thick myelinated motor fibers (alpha fibers), the speed of conduction is very high (70–120 meters per second).

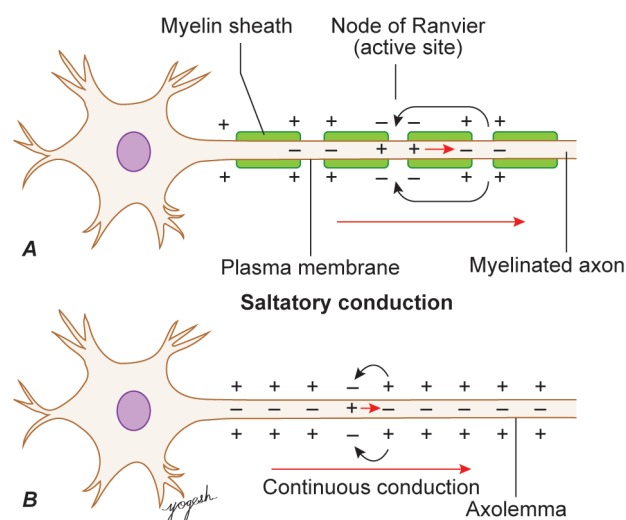


Fig. 9.11: Conduction of action potential along an axon. A. In myelinated axon, B. in nonmyelinated axon

NERVE INJURIES

- Based on the severity of the damage, nerve injuries are classified as:
 - Neurotmesis* – both axon and myelin sheath damaged
 - Axonotmesis* – only axon is damaged, myelin sheath is intact
 - Neuropraxia* – both axon and myelin sheath are preserved.
- Nerve regeneration occurs in the peripheral nerve in case of *neuropraxia* and *axonotmesis*, but in case of *neurotmesis*, nerve regeneration does not occur.

NERVE DEGENERATION AND REGENERATION

Q. Write a short note on Wallerian degeneration.

- Injury to the axon with myelin sheath follows two events:
 - Degeneration of nerve fiber
 - Regeneration of nerve fiber.

Degeneration of Nerve Fiber

- Definition:** These are the changes that occur in the nerve cell following the injury. These include changes in the nerve cell body and changes in the nerve fiber (Fig. 9.12).
- Changes in nerve fiber:** These include
 - Wallerian degeneration:* These are changes in the distal segment. It includes disintegration of myelin and degeneration of nerve fibers.
 - Degeneration of proximal segment up to the nearest node of Ranvier.
- Changes in the nerve cell body:** Due to loss of neural activity after injury, the cell body undergoes the following changes:
 - Chromatolysis – disintegration of Nissl bodies
 - Cell swelling
 - Nucleus shifts to an eccentric position.

Regeneration of Nerve Fiber

- The regeneration of nerve fibers is a very slow process. It begins after two weeks after injury. It involves (Fig. 9.12):
 - In the process of regeneration, macrophages remove the degeneration debris by phagocytosis.
 - Schwann cell proliferation: The Schwann cells proliferate and fill the empty space created by disintegration of axon and the myelin. Schwann cells also fill the gap between proximal and distal segments of axon.
 - Axonal growth: The ends of the axon give rise to multiple sprouts that enter the *endoneurial tube* of proliferated Schwann cells.
 - Elongation of axon: One of the axonal sprouts continues elongation under the guidance of Schwann cells to reach the end organ.

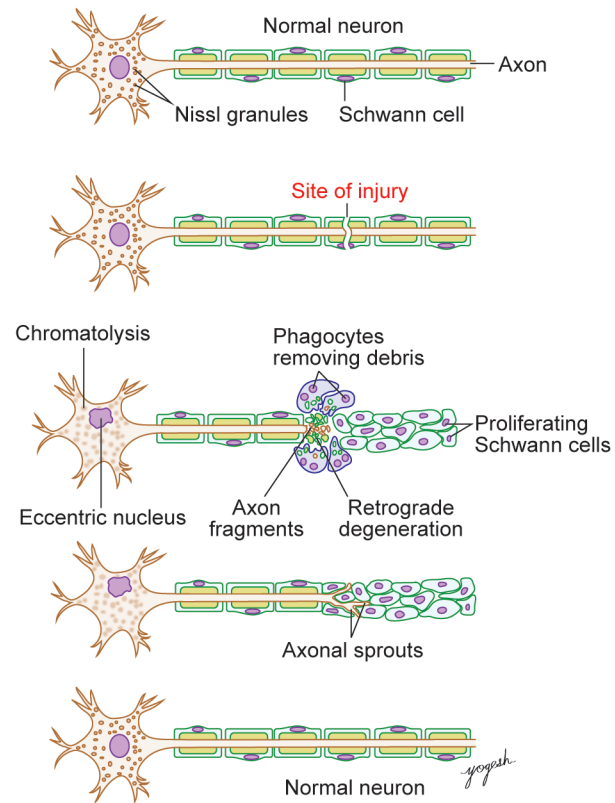


Fig. 9.12: Degeneration and regeneration of a nerve fiber (Wallerian degeneration)

- Regeneration of myelin: Surrounding Schwann cells reform the myelin sheath to restore the function completely.

Some Interesting Facts

- Rate of nerve regeneration/growth: 3.5 to 4.5 mm per day.
- Proper nutrition is essential for faster nerve regeneration.

Clinical Integration

- Neuroma:** It is a benign tumor. Sometimes, if the distance between the cut ends of nerve fibers is more, then the gap is filled with fibrous tissue which contains growing axonal sprouts. This mass forms neuroma. It is painful.

PERIPHERAL NERVES

- The peripheral nerves form a communication between the organs and the central nervous system.
- It consists of two components:
 - Somatic nerves
 - Autonomic (splanchnic or visceral) nerves.
- The peripheral nerves include
 - 12 pairs of cranial nerves
 - 31 pairs of spinal nerves
 - Autonomic (splanchnic) nerves: Sympathetic and parasympathetic nerves

- The peripheral nerve contains the following nerve fibers:
 1. *Somatic afferent (sensory) fibers* to carry sensory inputs from skin, bones, muscles, and joints to the CNS.
 2. *Somatic efferent (motor) fibers* to carry motor impulses to the skeletal muscles.
 3. *Visceral afferent (sensory) fibers* to carry input from the organ and blood vessels to the CNS.
 4. *Visceral efferent (motor) fibers* to carry impulses from CNS to glands, smooth muscle of organs and blood vessels, and cardiac muscles.

Note: The bundle of nerve fibers in CNS is called *tract*.

Structures of Peripheral Nerve or Nerve Fiber

Q. Write a short note on structure of peripheral nerve (TS).

- The peripheral nerve is a collection of many nerve fibers held together by connective tissue. The concept of nerve fiber is confusing as it does not mean a connective tissue fiber (Figs 9.13 and 9.14, Flow-chart 9.7).
- *Nerve fiber* with Schwann cells and basal lamina is the basic structural unit of the peripheral nerve.
- Each single *nerve fiber* is surrounded by a thin connective tissue called the *endoneurium*.
- *Endoneurium* consists of the loose connective tissue with collagen fibril, a few fibroblasts, occasional mast cells, and macrophages.
- A group of nerve fibers forms a *nerve fascicle* or bundle. Each *nerve fascicle* is surrounded by a layer of specialized connective tissue called *perineurium*.
- *Perineurium* is made-up of flattened (squamous) perineurial cells. Perineurial cells are connected with each other by tight junctions and hence, form a *blood-nerve barrier*.
- *Epineurium* surrounds entire peripheral nerve. It contains blood vessels that supply the nerve.
- *Note:* Blood vessels (*vasa nervorum*) are present only in epineurium and perineurium. Endoneurium does not have blood vessels. Nerve fibers receive nutrition by diffusion through endoneurium. *NEXT, Viva*

Cranial Nerves

- There are 12 pairs of cranial nerves which arise from the brain. They are designated by Roman numerals I to XII (Table 9.4).
- The cranial nerves and their main functions are listed in Table 9.4.
- Trigeminal nerve is the largest cranial nerve and vagus is the longest. Trochlear nerve is the smallest cranial nerve.
- All the cranial nerves emerge from the ventral aspect of the brainstem except trochlear nerve, which emerges from the dorsal aspect.
- All the spinal nerves supply skin except the first cervical spinal nerve. *MCQ*

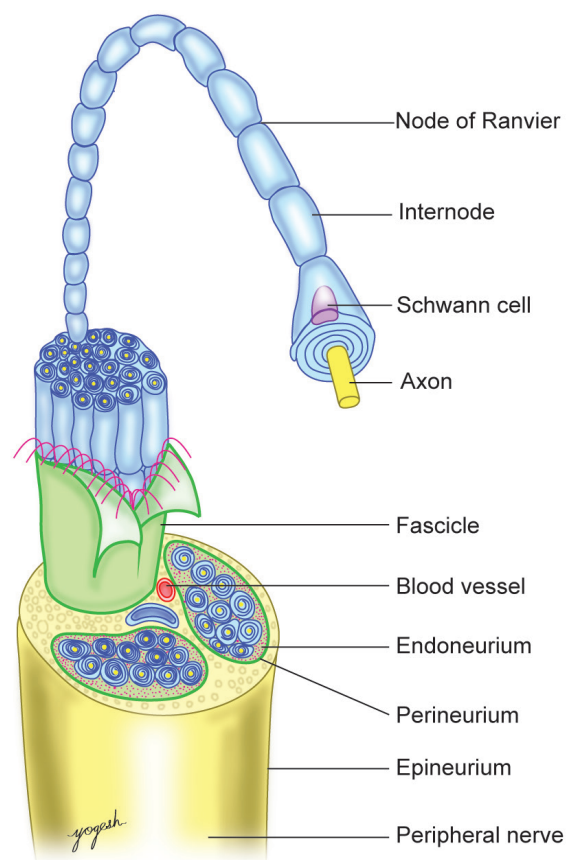


Fig. 9.13: Structure of peripheral nerve

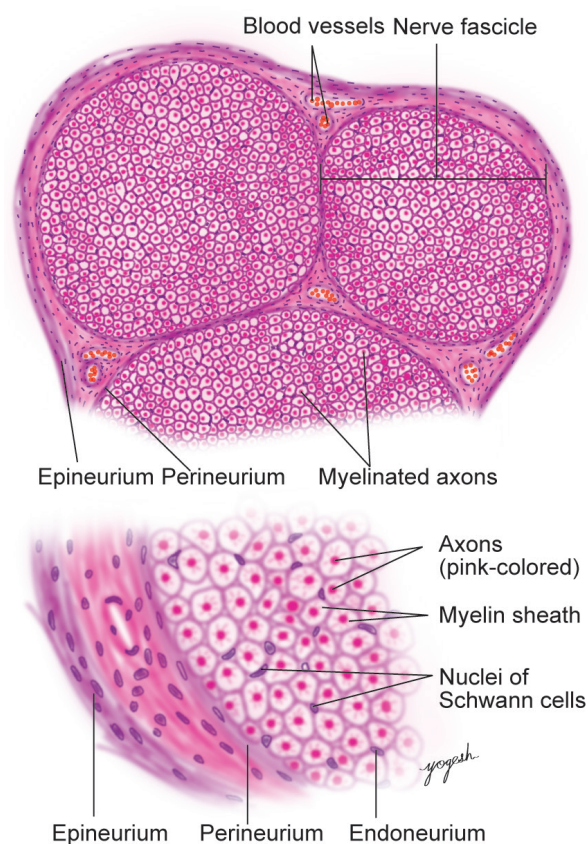
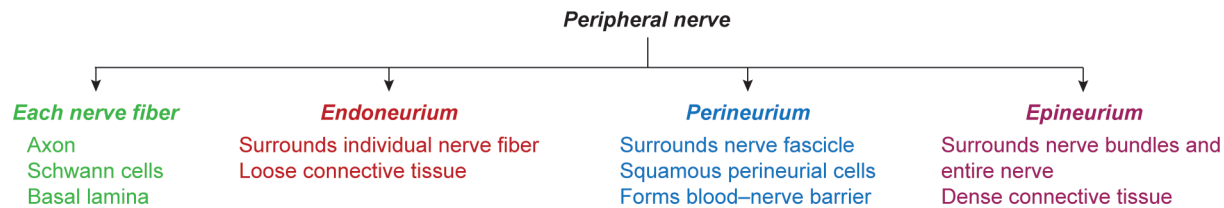


Fig. 9.14: Practice Fig.: Histology of peripheral nerve (transverse section, H&E stained, low magnification above, high magnification below)

Flowchart 9.7: Peripheral nerve

**TABLE 9.4:** Cranial nerves and their main functions

Cranial nerve	Primary functions
I Olfactory nerve	Sense of smell
II Optic nerve	Vision
III Oculomotor nerve	Eye movement (most eye muscles), pupil constriction
IV Trochlear nerve	Eye movement (superior oblique muscle)
V Trigeminal nerve	Sensations of the face, chewing movements
VI Abducent nerve	Eye movement (lateral rectus muscle)
VII Facial nerve	Facial expression, taste (anterior two-thirds of tongue), secretomotor supply to submandibular, nasal and lacrimal glands
VIII Vestibulocochlear nerve	Hearing, balance (equilibrium sensation)
IX Glossopharyngeal nerve	Swallowing, taste (posterior one-third of tongue), secretomotor supply to parotid gland
X Vagus nerve	Swallowing, talking, parasympathetic nervous system functions (heart, lungs, digestive system), taste sensation from posterior most part of tongue
XI Accessory nerve (spinal accessory nerve)	Accessory part joins vagus nerve to supply muscles of larynx, pharynx, and soft palate. Spinal part: Supply two muscles: Trapezius, sternocleidomastoid
XII Hypoglossal nerve	Muscles of tongue (speech, swallowing)

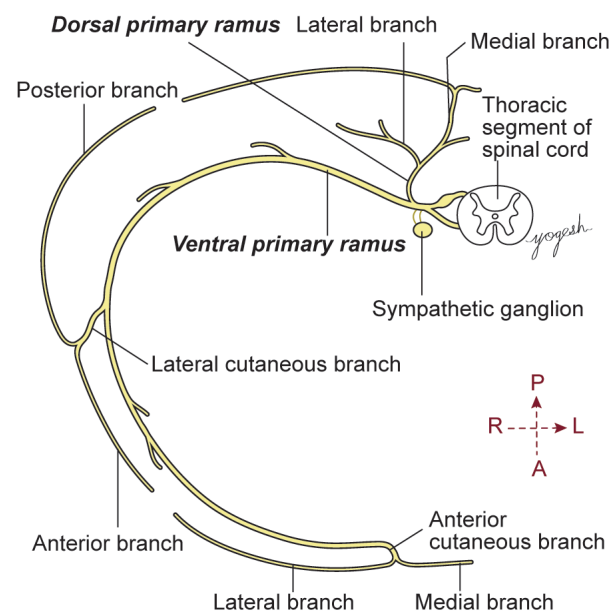
For details, refer to *Textbook of Human Anatomy*, Yogesh Sontakke, Volumes 5 and 6.

Spinal Nerves

- There are 31 pairs of spinal nerves which arise from the spinal cord. These are as follows:
 - 8 pairs of cervical nerves (C1 to C8)
 - 12 pairs of thoracic nerves (T1 to T12)
 - 5 pairs of lumbar nerves (L1 to L5)
 - 5 pairs of sacral nerves (S1 to S5)
 - 1 pair of coccygeal nerves

Typical Spinal nerve

- A typical spinal nerve arises from the spinal cord by two roots (Fig. 9.15):
 - Anterior root: It is motor and arises from anterior horn cells.
 - Posterior root: It is sensory and possesses a posterior (dorsal) root ganglion which has nerve cell bodies of sensory nerve fibers.
- The two roots come out of the vertebral canal through the intervertebral foramen and then join each other to form nerve trunk, which divides into a small posterior ramus and large anterior ramus, both containing motor and sensory fibers.
- The posterior or dorsal ramus divides into lateral and medial branches which supply the muscles. One of them sends a branch called posterior cutaneous branch which divides into lateral and medial branches.

**Fig. 9.15:** Typical thoracic spinal nerve

- The anterior or ventral ramus runs anterolaterally around the body wall to supply the muscles and skin of the anterolateral wall of the body.
- In thoracic region, large ventral ramus forms intercostal nerve that runs along the lower border of the corresponding rib and supplies intercostal muscles. It gives lateral and anterior cutaneous branches.

Distribution of Sympathetic Fibers through Spinal Nerves (Fig. 9.15)

- Lateral horn cells are present in thoracic, upper lumbar, and sacral regions of spinal cord.
- Sympathetic fibers arising from lateral horn cells enter the ventral root and then the chain of sympathetic ganglion via nonmyelinated gray rami communicantes. Postganglionic sympathetic fibers join spinal nerve through myelinated white rami communicantes (Fig. 9.15).
- These sympathetic fibers supply the smooth muscle of blood vessels and muscles associated with hair (arrectores pilorum) and sweat glands.

Dermatome

- A dermatome is the area of the skin supplied by a single spinal nerve. *Viva*
- During embryonic development in limbs, dermatomes are migrated away from the trunk. During this migration, they carry their nerves and vessels.
- Segmental overlap (Figs 9.16 and 9.17): There is varying degree of overlap of adjoining dermatomes. Hence, area of sensory loss in damage to a particular spinal nerve is always less than the area of distribution.

Plexus Formation by Spinal Nerves

- The anterior primary rami of 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 ventral primary rami of C1, C2, C3, and C4 spinal nerves. It innervates the head and neck.
 2. *Brachial plexus*: It is formed by the anterior primary rami of C5, C6, C7, C8, and T1. It innervates the upper limb.
 3. *Lumbosacral plexus*: It is formed by L1, L2, L3, L4 and S1, S2, S3. It innervates the lower limb.

REFLEX ACTION

- *Definition*: A reflex action is an automatic, rapid, and involuntary response to a stimulus without conscious thought.
- It is a fundamental protective mechanism against potentially harmful or dangerous stimuli. They occur without the involvement of the brain's conscious processing.

Reflex Arc

- A reflex arc is a neural pathway that controls a reflex action.
- Components of reflex arc include (Fig. 9.18):
 1. *Sensory receptor*: The process begins with a sensory receptor, which detects a stimulus (such as heat, pain, or pressure) in the peripheral nervous system (PNS).

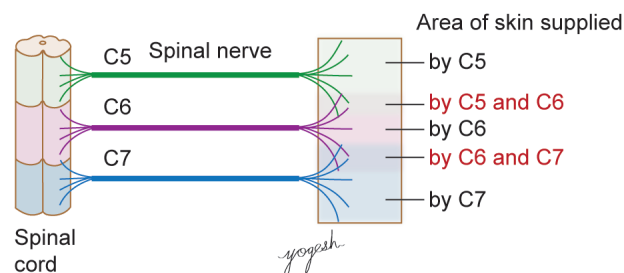


Fig. 9.16: Overlapping of the dermatome

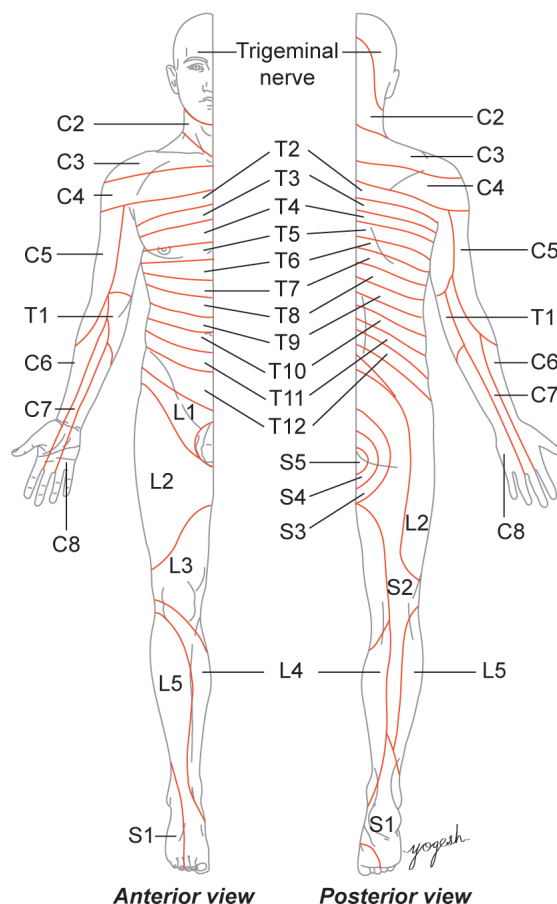


Fig. 9.17: Dermatome map or pattern of peripheral distribution of spinal nerves

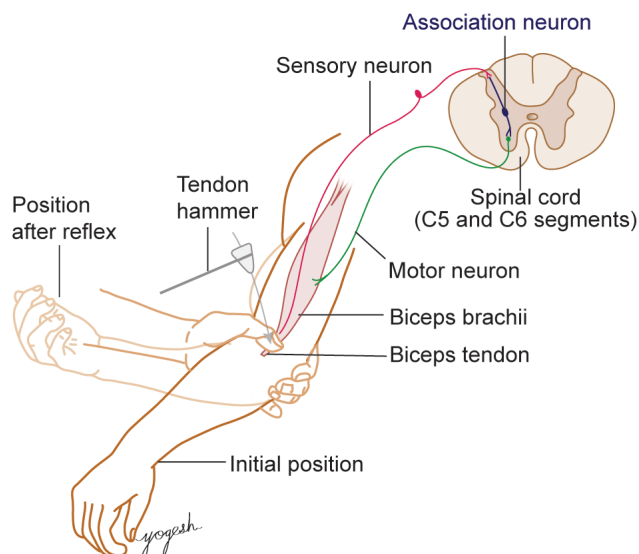


Fig. 9.18: Biceps tendon reflex (right)

2. Sensory neuron: The sensory receptor sends a signal through a sensory neuron (also known as an afferent neuron) to the spinal cord.
3. Integration center: In the spinal reflex arc, the sensory neuron synapses with an interneuron (also called an association neuron) within the spinal cord.
4. Motor neuron: The interneuron sends a signal through a motor neuron (also known as an efferent neuron) away from the integration center. The motor neuron carries the response signal to an effector organ, typically a muscle or gland.
5. Effector organ: The motor neuron stimulates the effector organ, which carries out the response, such as muscle contraction or releasing a hormone.

Examples of Reflex Actions (Table 9.5)

1. Knee-jerk reflex (*patellar reflex*)
2. Biceps reflex (Fig. 9.18)
3. Withdrawal reflex (*flexor withdrawal reflex*)
4. Crossed extensor reflex
5. Gag reflex.

AUTONOMIC NERVOUS SYSTEM

- The autonomic nervous system regulates involuntary activities of the body such as blood pressure regulation, size of pupil, digestion, peristalsis, secretions of glands, heart rate, and so on. Hence, it is also called *visceral nervous system*.

Divisions of Autonomic Nervous System

- The autonomic nervous system is divided into three divisions (Fig. 9.19):
 1. Sympathetic nervous system
 2. Parasympathetic nervous system
 3. Enteric nervous system.

Sympathetic Nervous System

- It consists of preganglionic fibers, sympathetic ganglia, and postganglionic fibers (Fig. 9.19). Its *preganglionic fibers* arise from the lateral horn cells of thoracic and upper two lumbar spinal segments (T1 to T12, L1 and L2); hence it is called *thoracolumbar system* or *outflow*. The *sympathetic ganglia* are connected with each other, and they form *sympathetic chain*. The *postganglionic*

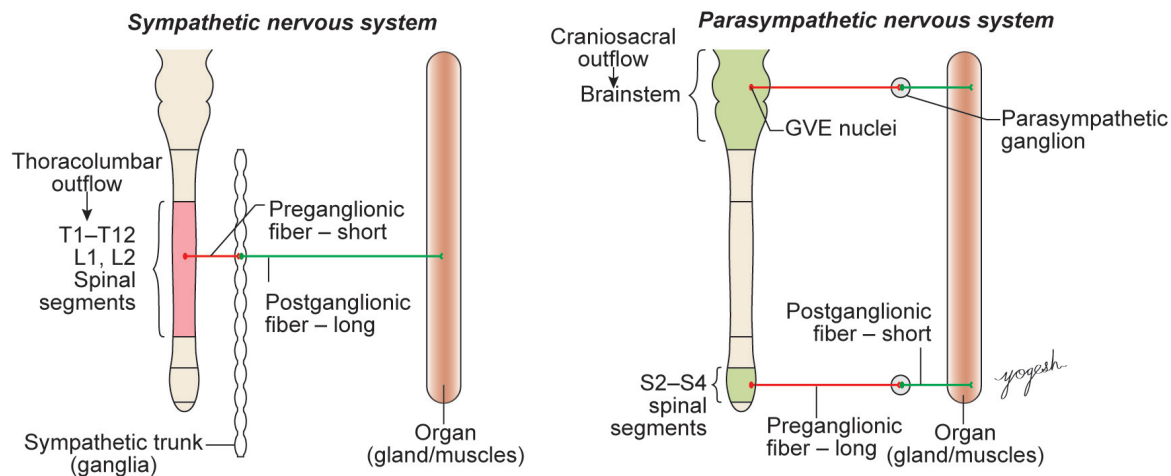


Fig. 9.19: Practice Fig.: Sympathetic and parasympathetic nervous system (schematic representation)

TABLE 9.5: Examples of reflex actions and their neuronal pathways				
Reflex action	Stimulus	Spinal segments	Efferent neuron	Response
Knee-jerk reflex	Tapping patellar tendon	Lumbar (L3, L4)	Motor neurons to quadriceps muscle	Leg kicks forward involuntarily
Biceps reflex	Tapping biceps tendon above the elbow	Cervical (C5, C6)	Motor neurons to biceps brachii	Forearm jerks upward involuntarily
Withdrawal reflex	Painful stimulus (e.g. touching hot surface)	Varies (depends on location of stimulus)	Motor neurons to flexor muscles	Body part moves away from painful stimulus
Crossed extensor reflex	Stepping on a sharp object with one foot	Lumbar (L3, L4) for injured leg; Lumbar and thoracic for opposite leg	Motor neurons to flexor (injured leg) and extensor (opposite leg) muscles	Flexor muscles contract (withdrawal reflex) in injured leg, extensor muscles contract in opposite leg to support body weight
Gag reflex	Touching back of the throat or uvula	Brainstem (medulla oblongata)	Motor neurons to pharyngeal muscles	Throat and pharynx muscles contract, preventing foreign object entry

sympathetic fibers reach the targeted viscera through adjacent spinal nerves or by forming plexuses around the adjacent arteries.

Parasympathetic Nervous System

- It also consists of preganglionic fibers, parasympathetic ganglia, and postganglionic fibers (Fig. 9.19).
- Its preganglionic fibers arise from
 - Nuclei of cranial nerves in the brainstem
 - Lateral horn cells of S1–S3 spinal segments.
- Hence, the parasympathetic nervous system is called *craniosacral system* or *outflow*.
- The parasympathetic ganglia are located near the viscera, mostly in wall of the organs. The postganglionic parasympathetic fibers are shorter.

Enteric Nervous System

- It is a network of neurons located in the wall of intestine.
- It consists of:
 1. Neuronal network
 2. Meissner's plexus in submucosa
 3. Auerbach's (myenteric) plexus in between outer longitudinal and inner circular muscle coats of muscularis externa.
- It controls movements (peristalsis) and secretions of gastrointestinal tracts. Enteric nervous system is controlled by sympathetic and parasympathetic nervous system and secretions of cells of gut.
- The differences between sympathetic and parasympathetic nervous systems are listed in Tables 9.6 and 9.7.

TABLE 9.6: Major differences between sympathetic and parasympathetic nervous system

	Sympathetic nervous system	Parasympathetic nervous system
Outflow	Thoracolumbar system or outflow	Craniosacral system or outflow
Origin	Thoracic and L1–L2 spinal cord	Brainstem S1–S3 spinal segments
Preganglionic fibers	Short Myelinated Release acetylcholine	Long Myelinated Release acetylcholine
Ganglia	Located near spinal cord	Located near viscera
Postganglionic fibers	Long Nonmyelinated	Short Myelinated
Postganglionic fiber neurotransmitter	Adrenaline, noradrenaline, acetylcholine	Acetylcholine
Major function	Fight and flight mechanism	Conservation of energy and growth

TABLE 9.7: Functional differences in sympathetic and parasympathetic nervous systems

Viscera/parameter	Sympathetic effect	Parasympathetic effect
Heart	Increases heart rate, force of contraction, and cardiac output	Decreases heart rate, force of contraction, and cardiac output
Blood pressure	Increases	Decreases
Blood vessels	In skin and gut – vasoconstriction In skeletal muscles – vasodilatation	No effect
Respiration	Increases respiratory rate	Decreases respiratory rate
Bronchial smooth muscles	Bronchodilatation	Bronchoconstriction
Gastrointestinal tract	Peristalsis – decreases Sphincters – contract Secretions – decrease	Peristalsis – increases Sphincters – relax Secretions – increase
Urinary bladder	Inhibits urination	Induces urination
Eye	Pupil – dilatation	Pupil – constriction
Lacrima and salivary glands	Thick secretion	Watery secretion
Sweat glands	Sweating	No effect
Arrector pili muscle	Contraction	No effect

Visceral Sensation

- The autonomic nervous system carries a few afferent nerve fibers as *general visceral afferent neurons*.
- The cell bodies of these neurons are located at
 - a. Dorsal root ganglion of spinal nerves
 - b. Sensory ganglia of cranial nerves.

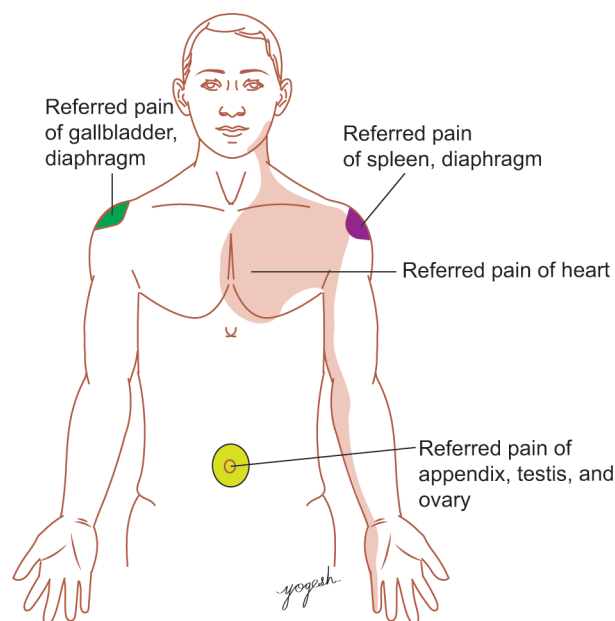


Fig. 9.20: Important sites of referred pain

- These sensations are helpful as
 1. They carry visceral pain sensation.
 2. Elicit visceral reflexes at unconscious level.
 3. Elicit the hunger, thirst, nausea, urination, and defecation sensation.

Clinical Integration

- *Visceral pain:* The autonomic nerves carry visceral pain sensation. It is dull, poorly localized sensation. *Visceral pain* is usually referred to the skin (dermatome) that is innervated by the same spinal segment.

Anatomical basis: Through the spinal cord, the visceral pain sensation reaches the area of sensory cerebral cortex, which represents the specific skin area (dermatome). Hence, the visceral origin of pain cannot be differentiated at conscious level. The sites of referred pain are as follows (Fig. 9.20):

Heart – left precordium, inner aspect of arm and forearm

Gallbladder – tip of right shoulder

Spleen – tip of left shoulder

Diaphragm – tip of corresponding shoulder

Appendix, testis, and ovary – skin around the umbilicus.

Skin and Fasciae



Competencies:

- AN4.1** Describe different types of skin and dermatomes in body.
- AN4.2** Describe structure and function of skin with its appendages.
- AN4.3** Describe superficial fascia along with fat distribution in body.
- AN4.4** Describe modifications of deep fascia with functions.
- AN4.5** Explain principles of skin incisions.

INTRODUCTION

- Integumentary system consists of skin and its appendages are as follows:
 - Skin consists of two layers — epidermis and dermis
 - Hair follicles and hairs
 - Sweat glands
 - Sebaceous glands
 - Nails
 - Mammary glands.
- Hypodermis consists of adipose tissue that lies deep into the dermis (*hypodermis* = subcutaneous fascia).

SKIN

- Skin forms the outer covering of body. It is supported by appendages or derivatives of skin such as hairs, nails, sebaceous glands, and sweat glands.
- Skin is the largest organ of the body, constituting about 16% (15–20%) of total body weight.

Functions of Skin

The skin performs the following major functions:

1. **Protection:** The skin is a physical barrier that protects the body from pathogens (bacteria, viruses, etc.), chemicals, and physical injuries.
2. **Regulation of body temperature:** The skin helps to regulate body temperature through sweating and regulating blood flow to the surface.
3. **Sensation:** The skin contains receptors that detect stimuli such as touch, pressure, temperature, and pain.
4. **Excretion:** Sweat glands in the skin help eliminate waste products.
5. **Immune defense:** The skin hosts a few immune cells.

6. **Synthesis of vitamin D:** The skin produces vitamin D when exposed to sunlight.
7. **Absorption:** The skin can absorb certain substances, including medications and chemicals, under specific conditions.

Types of Skin

- There are two types of skin depending on thickness of epidermis:
 1. **Thick skin:** Thick skin has very thick layer of epidermis. Its epidermis shows thick stratum corneum. Thick skin is also called *glabrous skin*. Thick skin does not have hairs. Locations: Skin of palm of hand and sole of feet. ^{Viva}
 2. **Thin (hairy) skin:** In thin skin, epidermis is thin. Thin skin shows hairs. Locations: Skin covering all parts of body except palm and soles. ^{Viva}
- For detailed differences between thick and thin skin, refer to Table 10.1.

Structure of Skin

- Skin consists of two layers:
 1. **Epidermis:** It is a superficial layer that consists of keratinized stratified squamous epithelium.
 2. **Dermis:** It is a deeper layer that is made up of connective tissue.

TABLE 10.1: Differences between thin and thick skin
Q. List the differences between thick and thin skin.

	Thick skin	Thin skin
Stratum lucidum	Present	Absent
Thickness of epidermis	0.07–1.5 mm	0.01–0.15 mm
Epidermal ridges	Present	Absent
Hair follicles	Absent	Present
Arrector pili muscle	Absent	Present
Sebaceous glands	Absent	Present
Sweat glands	Many	Few
Sensory receptors/ Merkel's cells	More	Less
Location	Skin of palm and sole	Skin except of palm and sole

Epidermis

- Epidermis consists of keratinized stratified squamous epithelium. *MCQ, Viva*
- Epidermis shows five layers of cells as follows (Figs. 10.1 to 10.5, Flowchart 10.1): *NEET, Viva*
 1. Stratum basale
 2. Stratum spinosum
 3. Stratum granulosum
 4. Stratum lucidum (only in thick skin)
 5. Stratum corneum.

1. Stratum basale (stratum germinativum)

- Stratum basale is the deepest layer of epidermis. It consists of a *single layer of cuboidal (low columnar) cells* that rest on basal lamina. It also contains melanocytes and mechanoreceptors. Cells show *melanin pigments*. These cells divide mitotically to give rise to keratinocytes (cells of skin) that form superficial layers of skin. Hence, stratum basale is also called stratum germinativum. *Viva*

2. Stratum Spinosum

(Malpighian Layer, Prickle Cell Layer) (Fig. 10.2)

- Above the stratum basale, several layers of thick *stratum spinosum* are present. Keratinocytes of stratum spinosum are *polygonal cells* that are connected with adjacent cells by *desmosomes*.
- *Spines are artifact*: During preparation of tissue for sectioning, cells often shrink. But these keratinocytes (*prickle cells*) remain adherent with each other at the site of desmosomes. It creates spines over the surface of these cells at the site of desmosomes. Thus, keratinocytes in this layer show small spine-like projections on their external surface.

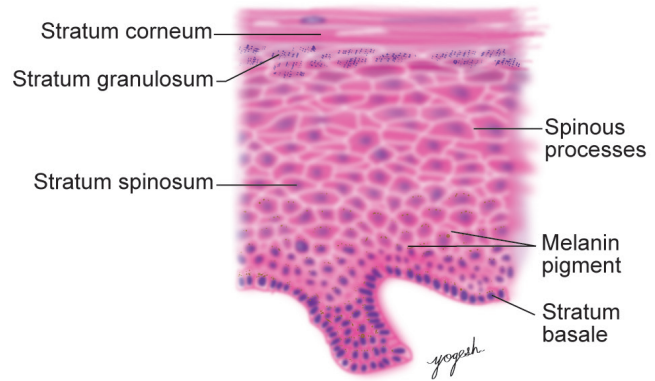


Fig. 10.1: Layers of epidermis (Note: Stratum lucidum is present only in thick skin. Stratum lucidum lies between stratum granulosum and stratum corneum)

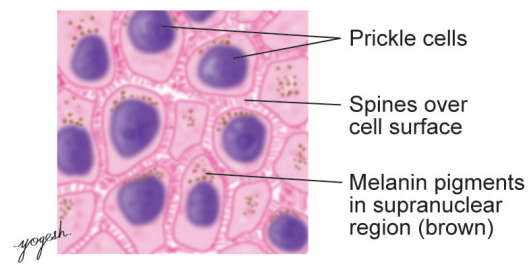


Fig. 10.2: Stratum spinosum of epidermis

3. Stratum Granulosum

- Stratum granulosum consists of 1–3 cells thick layer of keratinocytes. Cells of stratum granulosum contain granules of keratohyalin protein; hence, the name stratum granulosum. Keratohyalin is a precursor of filaggrin protein that on aggregation, forms keratin filaments.

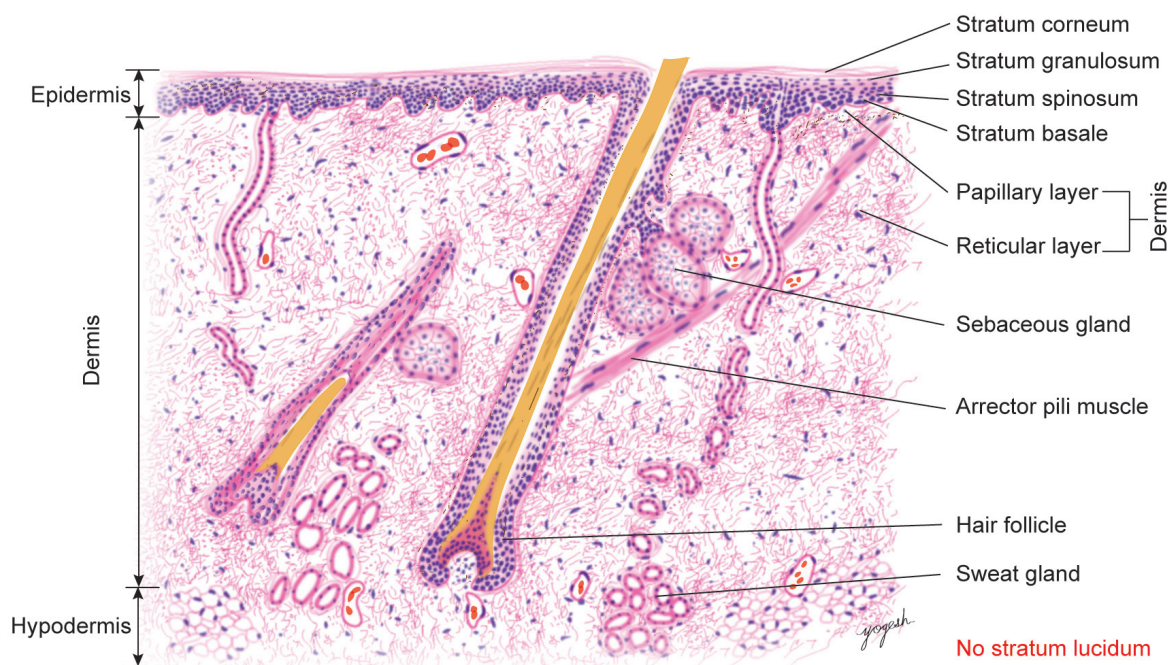


Fig. 10.3: Histology of thin skin (practice Fig.)

4. Stratum Lucidum (Lucid = Clear) (Fig. 10.4)

- Stratum lucidum is present only in thick skin. ^{MCQ}
- The cells of stratum lucidum are stained lightly with eosin and appear homogenous. Their cell boundaries are indistinct. The nuclei and cell organelles become disrupted and disappear toward superficial layer.
- Cells of stratum lucidum contain *eleidin*. It is a clear intracellular protein derived from keratohyaline. Later, eleidin gets converted to keratin in stratum corneum. ^{Viva}

5. Stratum Corneum

- This is the most superficial layer of epidermis. Cells of stratum corneum are *nonnucleated*, flat, scale-like (squamous) cells (dead cells), and they do not have cell organelles.
- Cells of stratum corneum are filled with keratin filaments. These cells are held together by extracellular lipid and carbohydrates that form a glue-like substance. Extracellular lipid makes skin impermeable to water.
- Thickness of stratum corneum depends on the amount of friction to which skin is exposed. Stratum corneum is very thick in palms and soles. Superficial cells of stratum corneum are being constantly shed off and are replaced by proliferation of stratum germinativum.

Some Interesting Facts

- Skin is the largest organ of the body.
- Only palm and sole have thick skin in the body.
- Face is the commonest site of skin cancer.
- Mole is the commonest congenital disorder of the skin.
- Thickest skin of body is present in upper part of the back. Here, thin skin covers extremely thick dermis.
- Skin of eyelid is the *thinnest skin of body*. It is devoid of fat.
- Cutaneous route for drug delivery: Lipid-soluble drugs can be absorbed by skin when applied as ointment, spray, or patches.
- Mammary gland is modified sweat gland in females.

Clinical Integration

- **Basal cell carcinoma:** It is the most common skin cancer. ^{MCQ} It arises from trichoblast or folliculosebaceous-apocrine germ. ^{Neet} It begins as painless skin elevations. It rarely metastasizes (spreads to distinct locations). Basal cell carcinoma occurs in hairy skin (mostly on face).
- **Squamous cell carcinoma** (epidermoid carcinoma): It arises from squamous cells of skin, part of respiratory tract, and gut. Squamous cell carcinoma of skin usually arises in sun-exposed parts (UV light exposed) in older people and mostly on face, ears, back of hands, scalp, and lips.

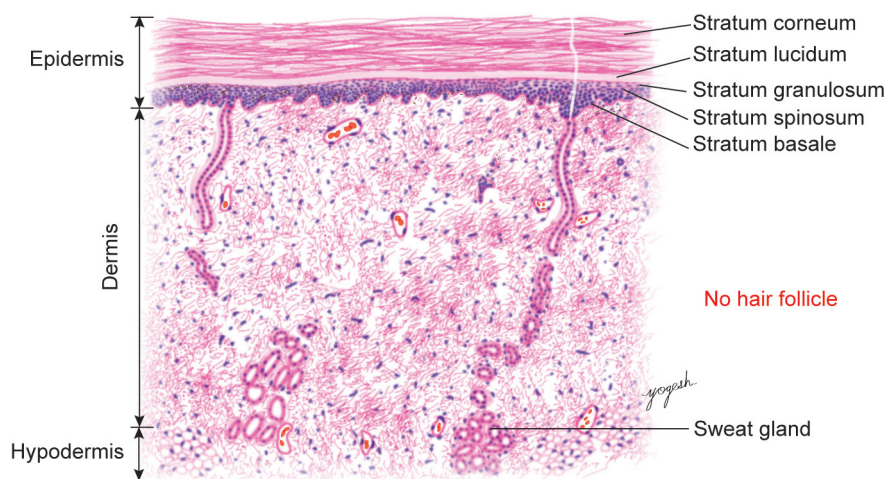
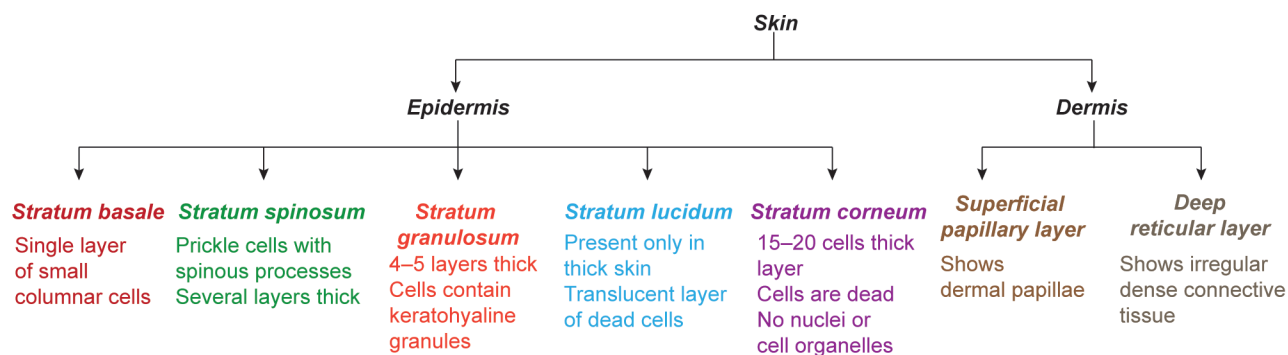


Fig. 10.4: Histology of thick skin (practice Fig.)

Flowchart 10.1: Structure of skin



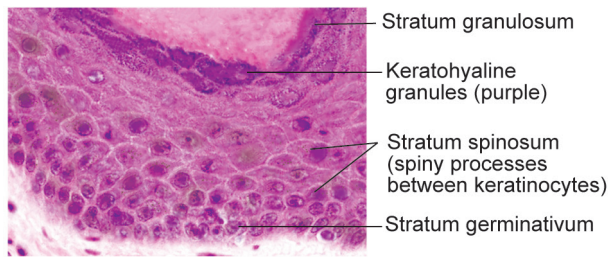


Fig. 10.5: Photomicrograph. Layers of epidermis

Dermis

- Dermis is a deep vascular layer of skin. It is made up of connective tissue containing collagen bundles, blood vessels, lymphatics, and nerve fibers. It also contains arrector pili muscle and hair follicles.
- It develops from mesoderm.
- Dermis has two layers:
 1. Superficial papillary layer
 2. Deep reticular layer.

1. Papillary Layer of Dermis

- It lies just deep to basal lamina of epidermis. It consists of loose connective tissue. It shows finger-like projections into the under surface of epidermis. These projections are called *dermal papillae*.
- Epidermis also protrudes into dermis in the form of *epidermal ridges*, *rete ridges*, or *rete pegs*.
- Dermal papillae and epidermal ridges are longer in skin where mechanical stress is more. For example, skin of palm and dorsum of hand.

2. Reticular Layer

- Reticular layer of dermis lies deep to papillary layer and it is a dense irregular connective tissue. It is thicker and less cellular than papillary layer. It consists of thick, irregular bundles of type I collagen fibers and elastic fibers.

BOX 10.1: Panniculus carnosus

- It is a part of subcutaneous connective tissue. It consists of a layer of striated muscles just deep to subcutaneous fascia or hypodermis. It is well developed in lower animals.
- In human, examples of panniculus carnosus include:
 1. Muscles of facial expression including platysma
 2. Palmaris brevis in hand
 3. Dartos muscle in scrotum.

Cells of Epidermis

- Skin has four types of cells: Keratinocytes, melanocytes, Langerhans cells, and Merkel's cells. ^{Viva}

Keratinocytes (85%)

- Keratinocytes constitute approximately 85% of cells of skin (predominant cell type). The major functions

of these cells include production of keratin and formation of epidermal water barrier.

- **Keratinization:** Keratinocyte synthesizes keratohyalin granules. Later, keratohyalin granules release keratin filaments into the cytoplasm. These filaments get aggregated with the help of filaggrin and trichohyalin protein. This process is called keratinization.

Melanocytes (Fig. 10.6)

- Melanocytes are present in stratum germinativum/basale. They have dendrite-like processes.
- Melanocyte synthesizes melanin and transfers it to other cells.

Dendritic Cells of Langerhans (Fig. 10.6)

- These are antigen-presenting *cells of epidermis*. ^{NEXT, Viva} They arise from lymphoid precursor cells of bone marrow. These cells lie in stratum spinosum of skin, oral mucosa, vagina, and thymus.
- Langerhans cells phagocytose bacteria and present bacterial antigens to T-lymphocytes.
- In AIDS patients, Langerhans cells may show presence of HIV virus and may act as reservoir of HIV virus.

Cells of Merkel (Fig. 10.6)

- These are sensory cells responsible for cutaneous sensation. These are located in stratum basale.
- Merkel cells are *mechanoreceptor* (*faithfully represents the Braille text/characters* – useful for blind people). Sensory nerve endings are present in relation to Merkel cells. These cells are more abundant in fingertips, oral mucosa, and hair follicles.

Some Interesting Facts

- **Desquamation of surface keratinocytes:** Surface keratinocytes are held together by desmosomes. Released proteolytic enzymes (Kallikrein-related serine peptidases) break desmosomes in superficial layers of epidermis and produce desquamation. There is an equilibrium in the production of keratinocytes and desquamation of keratinocytes. The total time required for formation of keratinocytes till its desquamation is approximately 47 days. ^{MCQ}
- **Psoriasis** is a skin disorder showing a patch of skin covered by silvery-white scales. It occurs because of rapid turnover of keratinocytes (~8–10 days).

Color of Skin

- The color of skin depends on the presence of three pigments:
 1. Amount of melanin in epidermal cells
 2. Carotene pigment (yellow color) of skin
 3. Vascularity of skin (hemoglobin).
- **Melanin:**
- It is a brown pigment. Melanin is present in melanocytes, keratinocytes of skin, pigmented epithelium of retina,

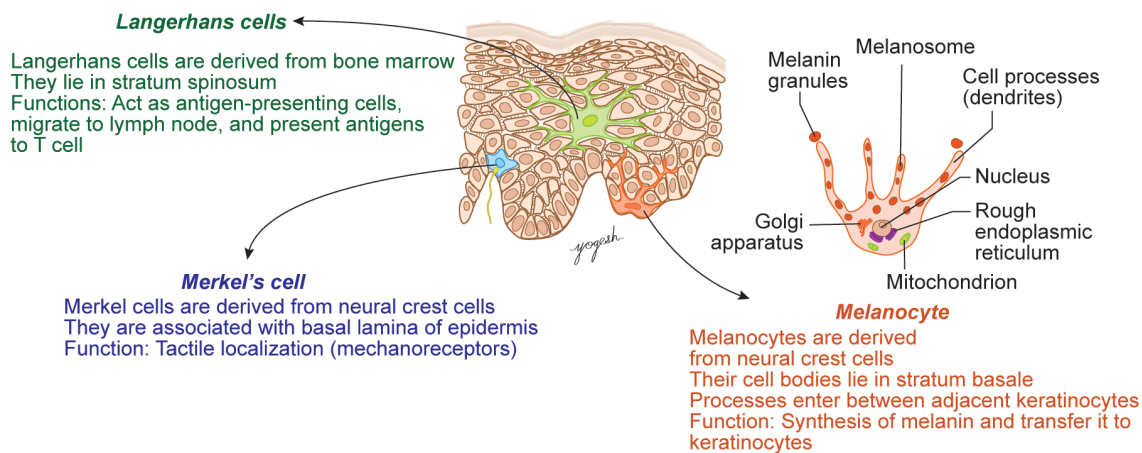


Fig. 10.6: Migrated cells in epidermis and their functions

pigmented cells of vascular zone of eyeball (choroid, ciliary body, and iris), and in some neurons of brain.

- **Synthesis:** Tyrosine amino acid is converted into dihydroxyphenylalanine (DOPA) by tyrosinase. This DOPA is converted into melanin by tyrosinase. Synthesis of melanin is under control of melanocyte-stimulating hormone (MSH) of intermediate lobe of pituitary gland.
- **Role of melanin:** *Melanosomes* acquire supranuclear position in keratinocytes and protect nuclei from ultraviolet ray-induced damage.^{MCQ}
- **Carotene** is a yellow-orange pigment. It is taken from the food and presents in stratum corneum and fat cells of dermis and superficial fascia.

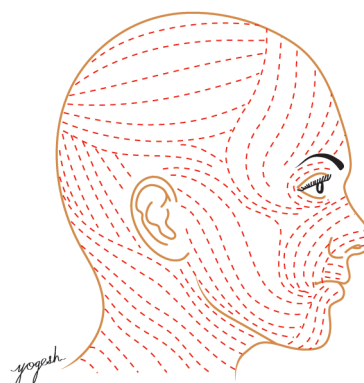


Fig. 10.7: Cleavage line or Langer lines in the skin of face

in reticular layer of skin. [Karl Langer, Austrian anatomist, 1819–1887]. Skin incisions made parallel to tension lines of Langer heal with least scarring (Fig. 10.7).

Flexor Lines and Flexor Creases

- These are acquired permanent lines and creases in the skin. The flexor creases are well-marked in the palms and soles. They are produced by habitual movements (Fig. 10.8).
- The skin along the flexor lines is thin and firmly bound to the deep fascia. The lines are prominent on the flexure aspects of the joints.

Papillary Ridges (Friction Ridges)

- They are present on the fingers, toes, palms, and soles. They form narrow ridges separated by parallel grooves and correspond to the dermal ridges.
- The pattern of papillary ridges is unique for each individual and hence, useful for identifying individuals. These patterns are genetically determined.
- **Patterns of papillary ridges:** There are four basic dermatoglyphic patterns in the digits (Fig. 10.9):
 1. Arches
 2. Whorls
 3. Loops
 4. Composite.

Clinical Integration

- **Albinism** is inborn error of metabolism that makes melanocytes incapable of melanin synthesis. It occurs because of absence of tyrosinase enzyme.^{MCQ}
- **Vitiligo** occurs on destruction of melanocytes, mostly because of autoimmune reactions. It produces patchy depigmentation of skin.
- **Moles/naevocellular naevi** are dark, slightly elevated, or flat lesions of skin. These are present almost in all individuals either at birth or in later life because of hormonal influence.
- **Malignant melanoma** is an invasive tumor arising from melanocytes. It may spread locally or throughout the body through blood or lymphatics. It may occur because of excessive exposure to sunlight.

Surface-Patterns of Skin

- There are three types of surface patterns or surface irregularities of the skin:
 1. Tension lines
 2. Flexor lines
 3. Papillary or friction ridges.

Langer's Lines or Cleavage Lines

- These are tension lines of skin. These lines correspond to natural orientation of collagen and elastic fibers

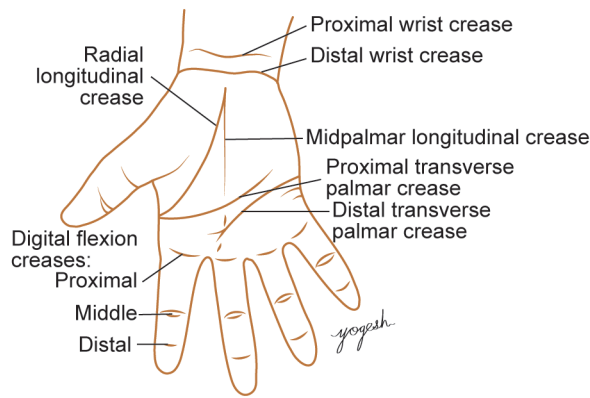


Fig. 10.8: Flexion creases of palm and hand

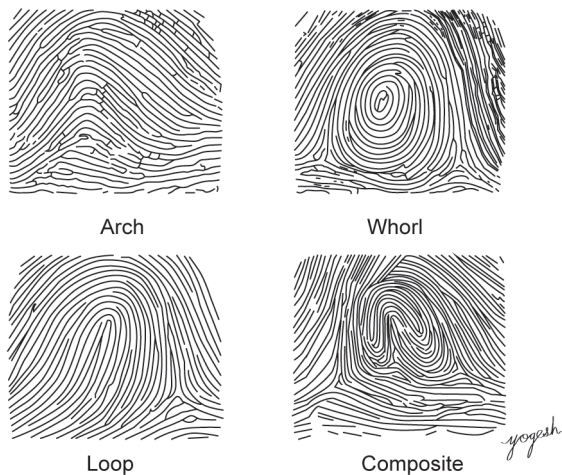


Fig. 10.9: Patterns of papillary ridges

Clinical Integration

- **Stretch marks** or *linea albicans*: These marks appear due to overstretching of the dermis. It results due to rupture of collagen fibers and repair with scar tissue. It is commonly observed in the lower part of abdomen, buttock, thighs, and breasts of multiparous females.
- Skin incisions made parallel to tension lines of Langer heal with least scarring.
- **Wrinkle lines** are produced by contraction of underlying muscles. These are usually perpendicular to the lines of the muscle pull.
- **Lines of expression**: These are the furrows or lines on the forehead and face are produced due to continuous contraction of the muscles of facial expression.
- The study of patterns of papillary ridges is termed *dermatoglyphics*.
- **Fingerprints**: Every individual has a unique fingerprint pattern. Hence, fingerprints are used for medicolegal purpose to identify criminals and identification of genetic disorders, particularly mental disorders, or for predicting disorders.

Blood Supply and Nerve Supply of Skin

Blood Supply

- The epidermis is *avascular*. It derives its nutrition by diffusion.

- Skin receives its blood supply from the following arterial plexuses:

1. *Rete subpapillare* or *papillary plexus*: It is located just below dermal papillae.
2. *Rete cutaneum* or *reticular plexus*: It lies just below dermis.
3. *Deepest plexus*: It lies over deep fascia.

- There are numerous *arteriovenous anastomoses* in skin that regulate blood flow through capillary plexuses of skin. Decreased blood flow to these capillaries conserve body temperature, whereas increased blood flow decreases body temperature. *Clinical fact*

Nerve Supply

- Skin is supplied by cutaneous nerves that carry sensation from free nerve endings, Meissner's corpuscles, Pacinian corpuscles, and Ruffini end organs.
- Blood vessels of skin receive autonomic supply. Sympathetic stimulation produces vasoconstriction and diverts the blood away from skin.
- Autonomic nerves in skin increase secretions of sweat gland (contraction of myoepithelial cells) and produce contraction of arrector pili muscles.

Clinical Integration

- *Pemphigus* is a rare blistering autoimmune disease affecting skin and mucous membranes.
- *Pemphigus vulgaris* is a blistering skin disease characterized by formation of autoantibodies directed against the desmosomes.
- *Skin cleavage levels in pemphigus and bullous pemphigoid*: In *pemphigus foliaceus* blisters form in the superficial layers of the epidermis. In *pemphigus vulgaris*, blisters can form at any epidermal level but typically form in the lower aspects of the epidermis. In *bullous pemphigoid* blisters form subepidermally (lamina lucida of the basement membrane zone).

BOX 10.2: Sensory receptors of skin

- Skin is enriched by free nerve endings, Pacinian corpuscles, Meissner's corpuscles, and Ruffini corpuscles (Fig. 10.10).
- **Free nerve endings**: They terminate in stratum granulosum of epidermis and surround most of the hair follicles. These carry fine touch, heat, cold, pain sensation, and hair-movement senses.
- **Pacinian corpuscles**: These are large, oval structures present in deeper part of dermis and in hypodermis. They carry deep pressure and vibration sense.
- **Meissner's corpuscles**: These are located within dermal papillae of hairless skin. In Meissner's corpuscle, nerve ending is surrounded by perpendicularly arranged supporting cells. They are responsible for light touch sensation.
- **Ruffini corpuscles**: These are elongated fusiform corpuscles. They carry skin stretch and torque sensation.

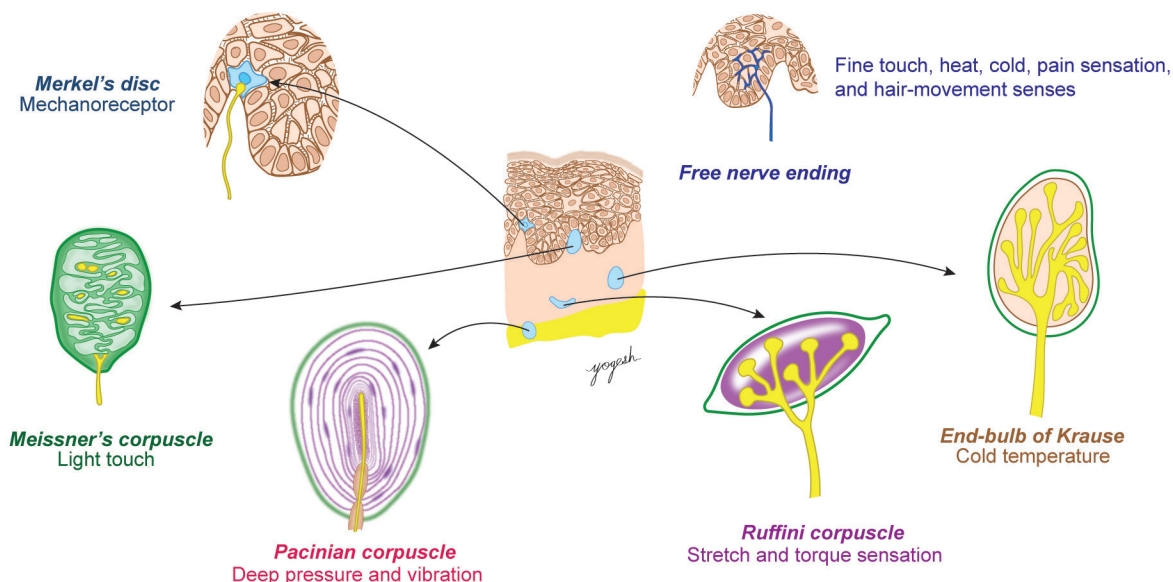


Fig. 10.10: Receptors in the skin

- **End-bulb of Krause (bulboid corpuscle):** End-bulbs of Krause are thermoreceptors, sensing cold temperatures. They are located in conjunctiva of eye, in mucous membrane of lips and tongue, and epineurium of nerve trunks, penis, and clitoris, and in synovial membranes of certain joints.
- **Merkel discs:** These are mechanoreceptors, a type of sensory receptor, that are found in basal epidermis and hair follicles.



Some Interesting Facts

- **Pacinian corpuscles** are the largest sensory receptors of the skin.
- Scalp has the longest coarse hairs of the body.
- Breast, buttocks, flanks, and anterior abdominal wall have abundant fat in the superficial fascia.

APPENDAGES OF SKIN

- Epidermis gives rise to appendages of skin that support skin. Appendages of skin include hair follicles, hair, nails, sebaceous glands, eccrine sweat glands, and apocrine sweat glands.

Nails

- Nails are modified zones of epidermis found on the dorsal surface of the tips of fingers and toes. Corneocytes are nonnucleated cornified cells that form nail plate. Nails consist of a tough protein called alpha keratin. High sulfur content of keratin is responsible for hardness of nail plate.

Parts of Nail

Nail shows the following parts (Fig. 10.11):

1. **Nail plate** (body) consists of keratinized cells. Nail plate shows a free distal end and an embedded proximal end (root or radix).

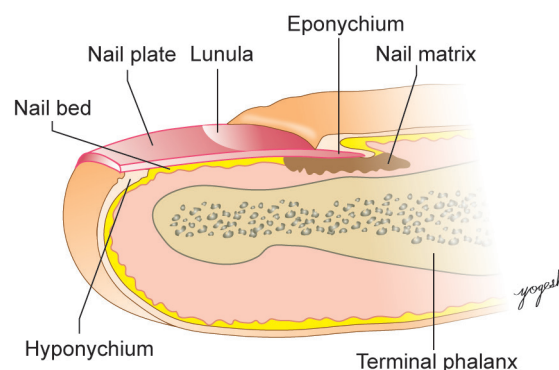


Fig. 10.11: Parts of nail (Source: Textbook of Human Embryology, Yogesh Sontakke, 2nd Edn.)

2. **Nail bed** is a highly vascular connective tissue layer that lies deep to nail plate. **Germinal matrix** is the thickened germinative zone of nail bed at root of nail plate. These cells form nail plate. Rest of the nail bed is thin and called sterile matrix.
3. **Proximal nail fold** is the fold of epidermis that covers nail root. **Lateral nail folds** (nail wall) are epidermal folds that overlap sides of nail. **Lateral nail grooves** are the grooves between lateral margin of nail plate and lateral nail folds.
4. **Lunula** is proximal soft, half-moon-shaped white part of nail plate that overlies germinal matrix.
5. **Eponychium** is an extension of base of nail plate or stratum corneum deep to proximal nail fold. **Hyponychium** is part of stratum corneum (epidermis) that lies under the free edge of nail plate (*onyx* = nail in Greek). **Perionychium** includes nail wall and cuticle area. **Cuticle** is skin that overlies the base of nail at the matrix.

Growth of Nails

- Proliferation of cells of nail matrix produces continuous nail growth. Nails grow throughout the life.

- Growth of fingernails (1 mm per week) is faster than toe nails. It takes 3 to 4 months for whole nail to grow. Hence, to remove nails infected with fungus, treatment should continue for 3 to 4 months.

Clinical Correlation

- **Onychia** is inflammation of nail folds that result in pus formation and shedding of nail.
- **Onycholysis**: Detachment of nail plate from nail bed.
- Onychocryptosis (unguis incarnatus or ingrown toe nails): It is a painful condition caused by penetration of ingrow toe nails towards the lateral nail fold.
- **Onychodystrophy** is deformation of nail.
- **Onychogryposis/ram's horn nail** is a hypertrophy of nail that produces ram's horn.
- **Paronychia** is bacterial or fungal infection of nail base.
- **Koilonychia**/spoon-shaped nails are caused by iron deficiency or vitamin B12 deficiency.

BOX 10.3: Nail clubbing

- Nail clubbing involves bulbous swelling of nail bed that results in convex curved nails and increase in the angle between cuticle and nail plate. Nail clubbing is a deformity of nails associated with number of diseases.
- **Causes**: Reduction in amount of circulating oxygen (hypoxia) causes proliferation of nail bed and results in clubbing. Any disorder causing prolonged hypoxia can result in clubbing. For example, lung diseases, heart diseases, and so on.
- **Schamroth's window test** (Fig. 10.12): On opposing distal phalanges of corresponding fingers of opposite hands, a small diamond-shaped window is usually apparent between nail plates. If this window is obliterated, Schamroth test is considered positive for clubbing.
- **Lovibond angle**: It is the angle between the proximal nail fold and the nail (Fig. 10.12). Normally it is less than 180 degrees. If it is >180 degrees, it indicates clubbing [John Locke Lovibond, English physician, 1907–1954].

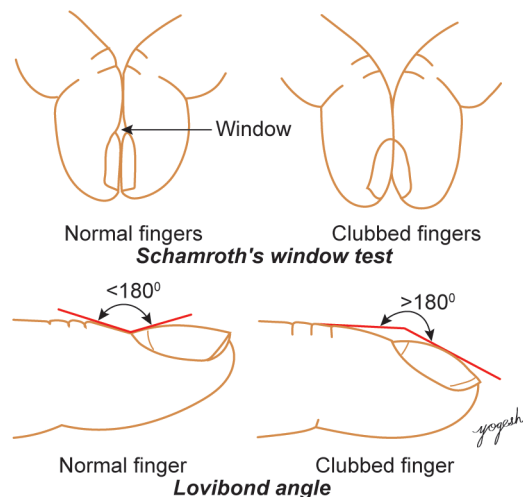


Fig. 10.12: Schamroth's window test and Lovibond angle

HAIRS

- Hairs are elongated keratinized structures. They cover the entire body except for the following sites: Palm, sole, sides of hand and feet, lips, ventral surfaces and sides of digits, and part of genitalia. Hair growth and texture are influenced by hormones.

Some Interesting Facts

- With advancing age, because of lack of estrogen and estrogen-like hormones, hairline recedes in both male and female.
- Fine hairs and less number of hairs are adaptations in humans as compared to lower animals. It helps to enhance more sensory aspects of skin.
- In humans, subcutaneous fat helps in conservation of heat (Hairs perform same function in lower animals).

Parts and Structure of Hair

- Hair has the following parts (Flowchart 10.2):
 1. **Shaft** is a visible part of hair that projects above surface of skin.
 2. **Root** is a part of hair that is embedded in skin and enclosed by hair follicle.
 3. **Bulb** is lower expanded end of root of hair.
- **Hair papilla** is a part of the dermis that invaginates base of hair bulb. **Hair follicle** is dermo-epidermal sheath that covers root of the hair.

Hair Shaft and Root

- Hair shaft and root consist of keratinized cells. Hence, hair is considered a modified part of stratum corneum of epidermis. Hair shaft has three parts: Cuticle, cortex, and medulla.
 1. **Medulla** is a central part of hair. It consists of large, keratinized cells. Medulla is a part of thick hairs, which is absent in thin hairs.
 2. **Cortex** surrounds medulla. It is made up of cornified cells containing hard keratin filaments and melanin pigments.
 3. **Cuticle** covers surface of hair. It consists of several layers of keratinized squamous cells. These cells are semitransparent, have distinct boundaries and resemble scales of fish.

Hair Follicle (Figs 10.13 and 10.14)

- The dermo-epidermal covering of hair root forms a knob-like structure called hair follicle. It produces hair.
- The wall of hair follicle consists of 3 layers: Inner root sheath, outer root sheath, and dermal connective tissue sheath.
 1. **Inner root sheath** is a multilayered cellular coat that covers deep part of hair. It consists of the following three layers from outside inwards:
 - a. **Henle's layer** consists of single layer of cuboidal cells.
 - b. **Huxley's layer** consists of double layer of flattened cells.

Flowchart 10.2: Structure of hair

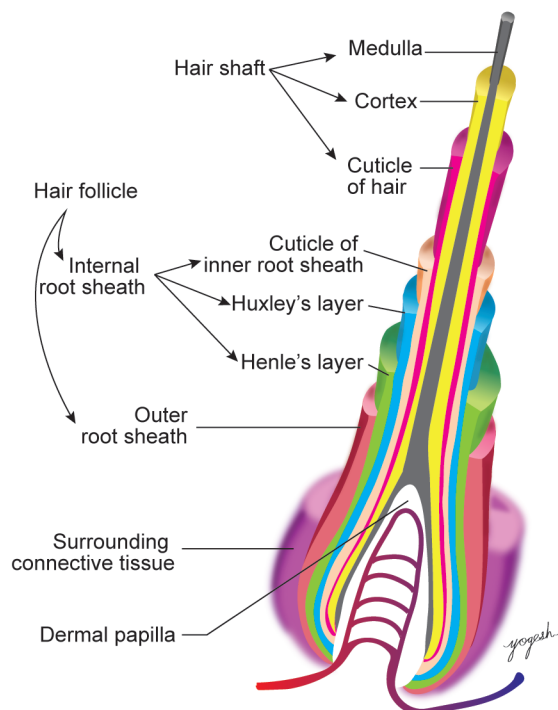
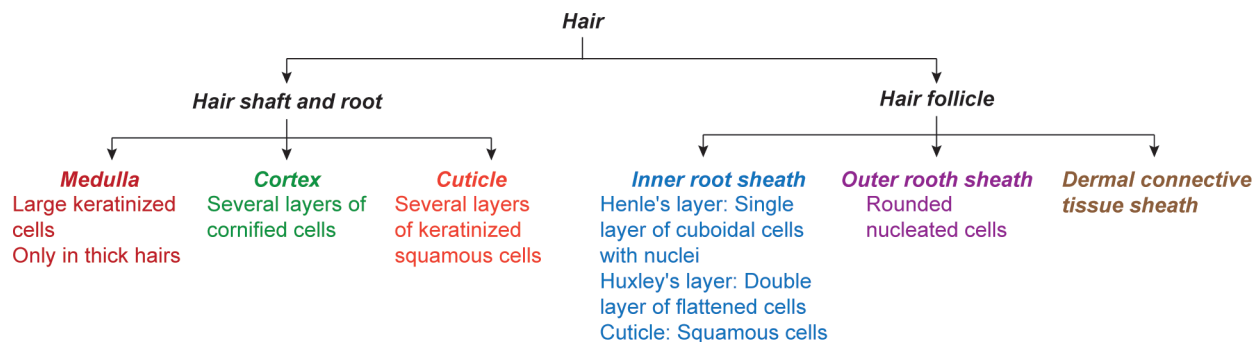


Fig. 10.13: Structure of hair

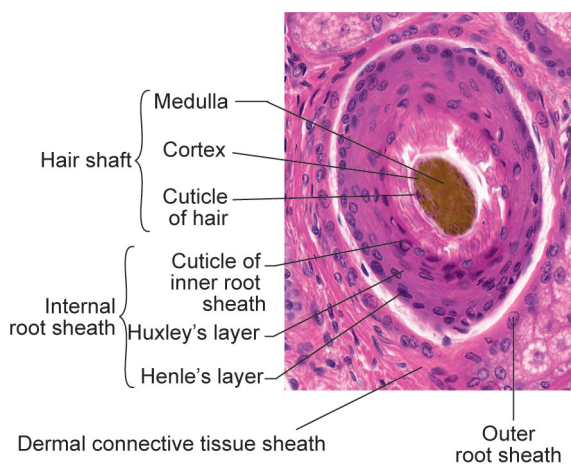


Fig. 10.14: Photomicrograph. Hair follicle (high magnification, H&E stain)

- c. **Cuticle** consists of squamous cells that cover outer free surface of hair shaft.
2. **Outer root sheath** continuous with stratum spinosum of epidermis.
3. Connective tissue sheath is derived from the dermis.

Clinical Correlation

- Cortex of the hair determines the color of the hair. Color of hair is produced by the underlying melanocytes in the germinative layer of hair bulb. The varying amounts of melanin produce hair color, ranging from blonde to brunette to black.
- Greying of hair: In old age, hairs become grey or white. It is due to lack of production of melanin due to progressive decrease of tyrosinase and increase in the number of air spaces in the cells of medullary shaft that generally accompany aging.
- Phases of hair growth:
 - *Anagen* is a time of new hair development.
 - *Catagen* is a period when hair growth stops.
 - *Telogen* is a period of hair loss because of follicular atrophy.
- *Texture of hair* is determined by its cross-sectional shape. *Straight hair* is round in cross-section, *wavy hair* is oval, and *kinky hair* is flat.
- Hair may be:
 - Lanugo are fine silky hairs that cover the fetus. They develop during the third trimester of development and are usually not evident on the baby's body at birth unless the baby is born prematurely.
 - *Terminal hairs (angora)*: These are long and coarse hairs. Examples: hair of scalp and face of male, hair in axillary and pubic regions, eyelashes, and eyebrows.
 - *Vellus hairs*: These are short and fine hairs.
- **Alopecia areata** (spot baldness): In this condition, hairs are lost in a small area of body. Area of alopecia areata does not show any scar, scale, or redness. At periphery of alopecia zone, *exclamation mark* hairs are present. It is characteristic of alopecia areata.

BOX 10.4: Arrector pili muscle

- Arrector pili muscles are small smooth muscle bundles attached at one end to dermis and another end to connective tissue sheath of a hair follicle. These muscles are attached to hair follicle that forms an obtuse angle with skin surface.
- **Nerve supply**: Sympathetic nerves.

Functions

- **Hair stands on end/goose-flesh appearance:** Contraction of arrector pili muscle, on sympathetic innervation, produces hair stand on end with slight depression at the dermal attachment of muscle. It gives goose flesh appearance.
- **Ejection of sebum:** As sebaceous glands lie between arrector pili muscle and skin, during contraction of muscle, sebaceous glands get squeezed. It results in release of sebum.

SEBACEOUS GLANDS

- The sebaceous gland is a *holocrine*, simple saccular gland present in dermis (Fig. 10.15). Usually, sebaceous gland opens into *pilosebaceous canal* at infundibulum of hair follicle by a short duct.
- Hair-independent sebaceous glands are found in lips, areolae of nipple (Montgomery's tubercles), labia minora, and inner surface of prepuce.
- Each sebaceous gland has two portions:
 1. Secretory portion (alveoli) consists of a mass of polyhedral cells. Usually, alveolus does not have lumen.
 2. Broad, short duct (lined by stratified squamous epithelium).
- **Function:** Secretory cells of sebaceous glands synthesize and accumulate sebum. During this process, these cells undergo apoptosis. In the end, entire dead cell debris and lipids get secreted into duct as sebum (oily). This mode of secretion is called *holocrine secretion*.

Clinical Correlation

- **Seborrhea** or oily skin refers to overactive sebaceous glands that produce excess sebum.
- **Acne vulgaris:** It occurs during adolescence in both sexes. In acne vulgaris, hair follicles get clogged with dead cell debris and sebum. It occurs as white head (closed by skin), black head (open, black because of oxidized melanin), pimple (trapped sebum under skin), or even scarring. In 80% of cases, acne is genetically based. Increased hormonal levels during puberty enhance acne. *Comedo* is a clogged hair follicle.

SWEAT GLANDS

- Sweat glands produce sweat or perspiration.
- There are two types of sweat glands (Fig. 10.16, Table 10.2):
 1. **Eccrine** (typical or merocrine) sweat glands: These are distributed all over the body **except** lips and external genitalia.
 2. **Apocrine** (atypical) sweat glands: These are present only in axilla, areola, nipple of mammary gland, skin around the anal opening, and external

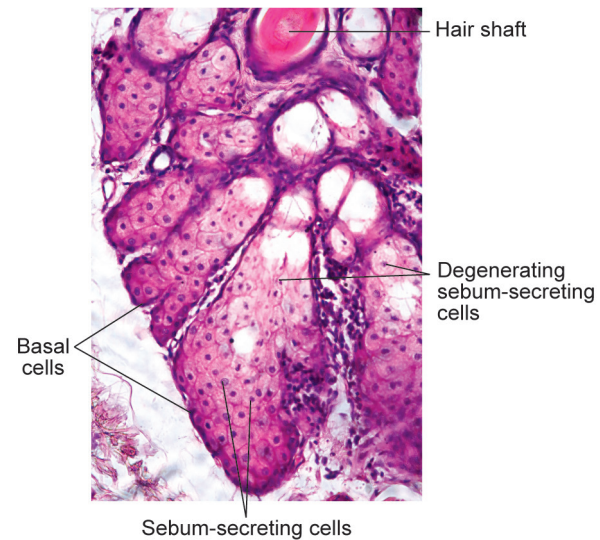


Fig. 10.15: Photomicrograph. Sebaceous gland (high magnification, H&E stain)

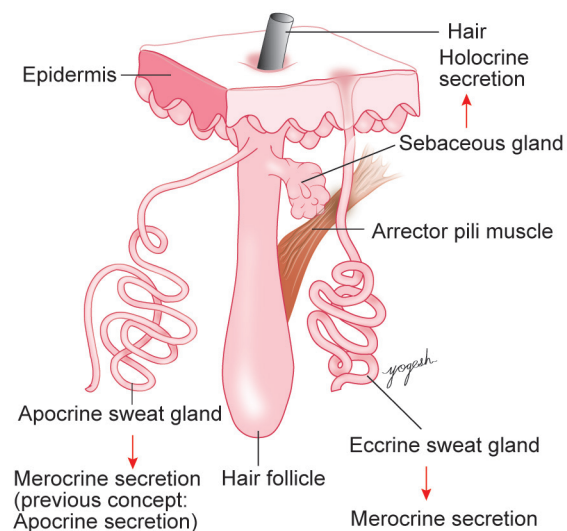


Fig. 10.16: Glands related to skin include apocrine and eccrine sweat glands, and sebaceous glands

genitalia. Apocrine glands include glands of Moll in eyelids and ceruminous glands of the external acoustic meatus.

Eccrine Sweat Glands

- Eccrine sweat glands are simple coiled tubular glands. These are distributed all over the body except lips and external genitalia. These glands are most numerous in palms and soles, forehead, scalp, and axillae. They play a major role in regulation of body temperature.
- The duct of the gland runs through dermis and opens on surface of epidermis through a funnel-shaped orifice.
- Secretory part of eccrine sweat gland consists of highly coiled terminal part of tube and is lined by a *single layer of cuboidal epithelium*.
- **Functions:** The eccrine sweat glands help in the regulation of body temperature by the production of evaporable sweat. They can produce around 8 to 10 liters of sweat per day.

TABLE 10.2: Differences between eccrine and apocrine sweat glands*Q. List the differences between eccrine and apocrine sweat glands.*

Feature	Eccrine sweat glands	Apocrine sweat glands
Secretion	Watery	Viscid
Contents	Mainly water, salts	Mainly lipid and proteins
Site of discharge	On the surface of skin through sweat pores	In the pilosebaceous canal around the hair shaft
Distribution	Throughout the body	Axilla, mons pubis and perianal region
Activity	Throughout the life	Active at puberty
Nervous control	Cholinergic postganglionic sympathetic neurons	Adrenergic postganglionic sympathetic neurons
Endocrine control	Nil	Present, affected by androgens and estrogen
Function	Thermoregulation	Production of pheromones

Apocrine/Atypical Sweat Glands

- Apocrine sweat glands are located in axilla, circumanal region, and mons pubis. Ducts of apocrine sweat glands open into hair follicle, just above levels of sebaceous ducts. These glands are not fully functional till puberty.
- These are *simple, coiled tubular glands* (occasionally branched). Secretory part of apocrine gland is located deep in dermis or may be in hypodermis.
- **Previous concept:** During secretion, a part of cell is pinched off (apocrine secretion).
- **New concept:** Transmission electron microscopy showed that cells of apocrine sweat gland follow only *merocrine secretion* (exocytosis).
- **Modified apocrine sweat glands:** Ceruminous glands of external acoustic meatus and ciliary glands of eyelids. These glands produce protein-rich secretion including *pheromones*.

Clinical Correlation

- Apocrine glands become functional with puberty. Apocrine glands secrete pheromones.
- Eccrine sweat glands are stimulated by heat and stress. Apocrine sweat glands are stimulated by emotional and sensory stimuli.
- Ceruminous glands of external acoustic meatus produce secretions that on accumulation form ear wax.
- 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 breast consists of 15–20 lobes of glandular tissue which are drained by lactiferous ducts onto the nipple.
- Gynecomastia is abnormal development of breast in males.

WOUND HEALING

- The wound healing occurs in the following stages:
 1. **Hemostasis:** It is immediate response to stop the bleeding. It involves vasoconstriction, platelet aggregation, and blood clot formation.
 2. **Inflammatory phase:** It begins within a few hours and lasts for 2–5 days. Inflammatory cell infiltration of damaged tissue, removal of blood clot dead cells and bacteria by phagocytosis activity of macrophage occurs in this phase.
 3. **Proliferation phase** lasts from 2 to 20 days. It involves proliferation of epithelial cells and fibroblasts deposition of collagen fibers and angiogenesis. The granular tissue occupies the site of wound. It consists of new capillaries, phagocytosis cells, and fibroblasts.
 4. Contraction of wound continues with deposition of collagen fibers.
 5. Epithelial cells grow and cover the wound surface and push the debris as scab. The scab separates within 3–10 days, and maturation continues from 21 days to 2 years. In this phase, the collagen fibers rearrange to acquire functional restoration. The wound or scar tissue continues to contract and become stable.

SKIN BURNS

- The total surface area of skin in adults is 1.5–2 sq meters.

Degree of Burn

- The skin burns are classified according to their severity as follows:
 1. **First-degree burn:** It destroys only epidermis. It results in redness, and swollen skin. It is painful, but it heals in 3–6 days without scarring.
 2. **Second-degree burn:** It involves epidermis and a part of dermis. It causes blister formation. It is painful. It heals in a few weeks with or without scars.
 3. **Third-degree burns:** It involves epidermis, dermis, and underlying tissues (muscles and bones). The burned area is insensitive to touch, it heals with scarring. It may require skin grafting.

Rule of Nine

- It is an easy method to estimate the percentage of body surface area affected by burns.
- According to rule of nine, the body is divided as follows (Fig. 10.17):
 1. Head and neck: 9%
 2. Each upper limb: 9%
 3. Front of the trunk: 18%
 4. Back of the trunk: 18%
 5. Each lower limb: 8%
 6. Perineum: 1%.

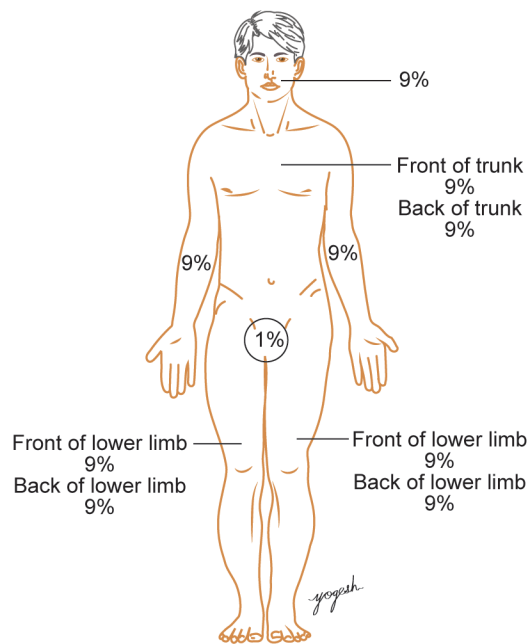


Fig. 10.17: Rule of nine to determine the surface of skin affected by burn

AGING CHANGES IN SKIN

- The aging changes in the skin include the following:
 1. Wrinkles and fine lines: As the skin ages, it loses collagen and elastic fibers that maintain firmness and elasticity. Reduced collagen and elastic fibers lead to formation of wrinkles fine lines and crease especially in the areas of respective movements (around eyes and mouth).
 2. Loss of elasticity resulting in sagging and laxity of skin.
 3. Thinning of skin and loss of subcutaneous fat. It makes the skin more prone to damage and bruising.
 4. Uneven skin tone due to uneven distribution of melanin and hyperpigmentation.
 5. Reduced hydration due to reduced activity of sweat and sebaceous glands.
 6. Reduced capacity of wound healing.
- Cosmetics reduce aging skin to a certain extent. Their overuse may be harmful.

Clinical Integration

- Some of the common clinical conditions of the skin are shown in Figs 10.18 and 10.19.

FASCIA

- Fascia is a connective tissue that surrounds the muscles, vessels, nerves, organs, and spaces of the body. It is made up of connective tissue fibers, mainly collagen fibers. It helps in maintaining the body's structural integrity and provides support and protection.

- There are two types of fasciae:
 1. Superficial fascia
 2. Deep fascia.

Superficial Fascia

Q. Write a short note on superficial fascia.

- Superficial fascia is a layer of loose connective tissue beneath the skin. *Viva*
- It connects the skin (dermis) with the underlying deep fascia, hence also called subcutaneous tissue or hypodermis. It is primarily made up of loose connective / areolar tissue with varying amounts of fat.

Features of Superficial Fascia

- Distribution of fat:** Fat is distributed in variable amount in the superficial fascia throughout the body.
- Thick or distinct superficial fascia is present in the lower part of the anterior abdominal wall, perineum, and limbs.
- Thin superficial fascia is present on the dorsum of hands and feet, sides of neck, face, and around the anus.
- Dense superficial fascia is present in the scalp palm and soles.
- In the lower part of anterior abdominal wall, perineum and upper most part of thigh, the superficial fascia shows two layers.

Fat is abundant at the following sites:

- Gluteal region or buttocks
- Lumbar region
- Front of the thigh
- Anterior abdominal wall
- Mammary gland
- Post-deltoid region, cervicothoracic region
- Fat is more abundant in females and children.

- Fat fills the spaces of axilla, orbit, and ischiorectal fossa and spaces around the organs such as kidney.

Site of absence of fat in superficial fascia ^{MCQ}

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

Some Interesting Facts

- Panniculus adiposus is the subcutaneous layer of fat.
- Paniculus carnosus* is a sheet of subcutaneous muscles in the lower animals. It consists of muscle fibers in the superficial fascia inserted into the skin.
- In humans, paniculus carnosus is represented by the following muscles.
 1. Muscles of facial expressions
 2. Platysma (in neck)
 3. Subareolar muscle of the breast
 4. Palmaris brevis (in palm)
 5. Dartus muscle of scrotum
 6. Corrugator cutis ani (around anal opening).



Acne vulgaris



Pemphigus vulgaris



Herpes zoster



Psoriasis



Keloid



Epidermolysis bullosa acquisita



Melanocytic nevus



Vitiligo



Sebaceous cyst



Clubbing of nails



Onychomycosis



Alopecia areata

Fig. 10.18: Skin, nails, and hair diseases for early clinical exposure (Image courtesy: Dr Akshay Meena, Dr. Suruthi Purushothaman)



Basal cell carcinoma



Squamous cell carcinoma



Melanoma

Fig. 10.19: Skin cancers for early clinical exposure (Dr Akshay Meena, Dr Suruthi Purushothaman)

Contents of Superficial Fascia^{Viva}

1. Adipose tissue
2. Mammary glands (Fig. 10.20)
3. Cutaneous nerve and vessels
4. Lymph nodes
5. Sweat glands
6. Subcutaneous muscles in face, neck, and scrotum
7. Hair follicles

Function

The superficial fascia performs the following functions:

1. Insulation due to presence of fat and protection against cold.
2. Padding and shock absorption.
3. Facilitates movement of skin over the underlying structures by reducing friction.
4. Supports the skin and gives external shape to the body.

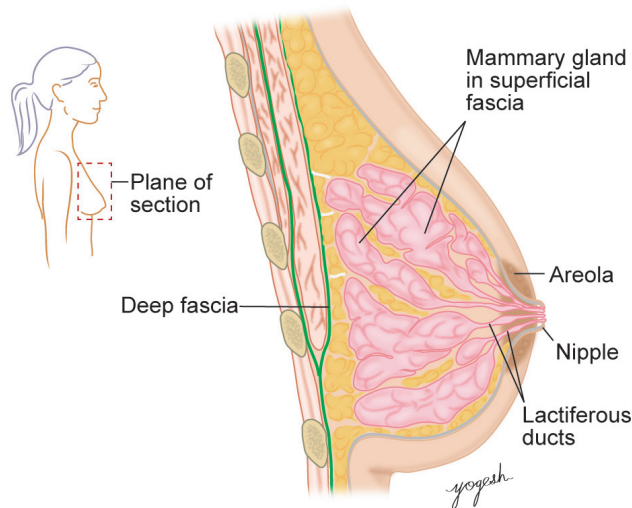


Fig. 10.20: Breast in superficial fascia

5. Reservoir of energy (fat).
6. Gives passage to nerves, vessels, and lymphatics.
7. Wound healing and immune response.

Clinical Integration

- **Subcutaneous injections:** These are administered into the fatty tissue later of superficial fascia, the common sites of subcutaneous tissue are:

1. Anterior abdominal wall
2. Anterior aspects of thigh
3. Posterior aspect of arm
4. Anterior aspects of forearm

Commonly this route is used for administration of vaccines (rabies vaccine), hormones (insulin), and so on. Due to poor blood supply, the subcutaneous route is useful. For the drugs which need slow, prolonged absorption and sustained release into the bloodstream. Subcutaneous injections are less painful due to use of small-sized needles.

Deep Fascia

Q. Write a short note on deep fascia.

- The deep fascia is a tough, inelastic fibrous membrane that encloses the tissue deep to the superficial fascia. *Viva*

Features

- **Distribution:** The deep fascia is well-defined (thick) in the limbs.
- Deep fascia keeps the soft tissue in place. It gives structural support and shape to the body.
- **Note:** The deep fascia does not cross the subcutaneous bones (both are derived from mesoderm). It fuses with the subcutaneous bone to facilitate muscle movement.

Modifications of Deep Fascia

Q. List the modification of deep fascia with their examples.

- The deep fascia shows the following modifications:

1. **Aponeurosis:** Aponeurosis is a broad, flat thick sheet of deep fascia that corresponds to the flattened tendon. *Viva*

Examples: Palmar aponeurosis (in palm), plantar aponeurosis (insole). Palmar aponeurosis represents the degenerated tendon of palmaris longus muscle, whereas plantar aponeurosis represents degenerated tendon of plantaris muscle (Fig. 10.21). *MCQ*

2. **Retinaculum:** It is a band of deep fascia that retain the tendons of long muscle in places and prevents the bowstringing of the tendons during muscle contraction.

Examples: Flexor and extensor retinacula around the wrist and ankle joints (Fig. 10.22).

3. **Fibrous sheaths:** These are condensation of deep fascia around the neurovascular bundles.

Examples:

- a. **Carotid sheath** (in neck) around the common carotid artery, internal jugular veins, and vagus nerve.
- b. **Axillary sheath** (in axilla) around the axillary vessels.
- c. **Femoral sheath** (in thigh) around the femoral vessels (Fig. 10.23).

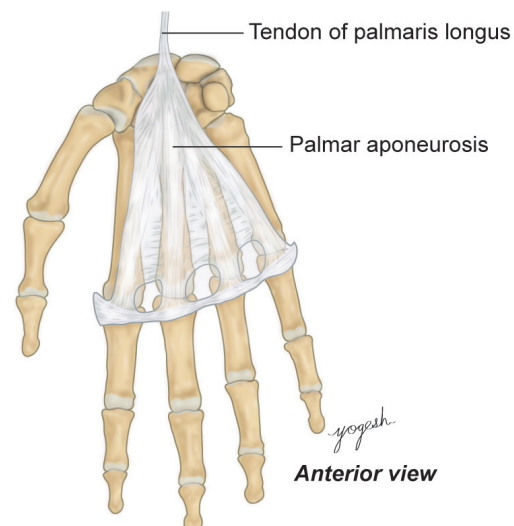


Fig. 10.21: Palmar aponeurosis (right, anterior view)

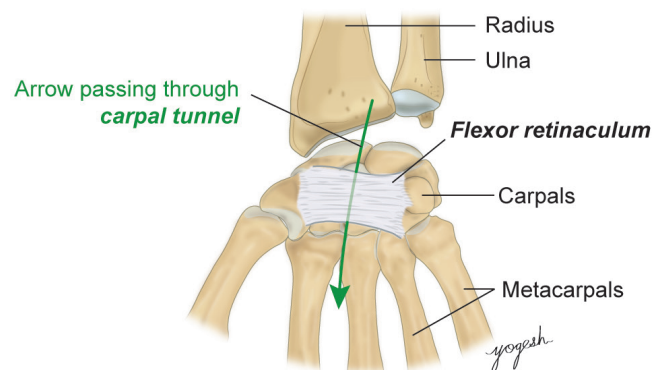


Fig. 10.22: Flexor retinaculum (right, anterior view)

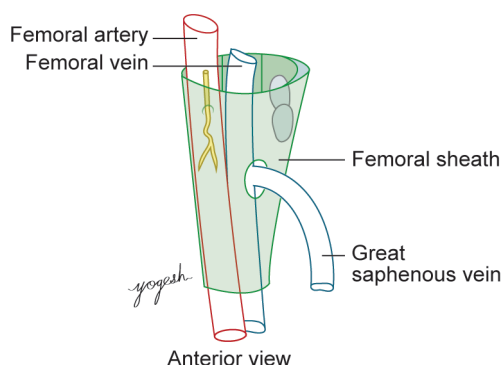


Fig. 10.23: Fibrous sheath: Femoral sheath

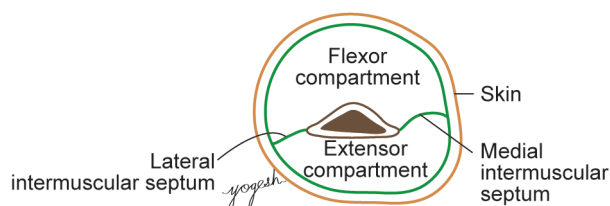


Fig. 10.24: Intermuscular septum (Transverse section through the distal one-third of arm)

4. *Fibrous capsules* are modification of deep fascia that encloses glands.

Example:

- a. Parotid fascia around parotid glands
 - b. Capsule of thyroid glands
5. *Intermuscular septa* are deeper extensions from deep fascia that separates the muscles into separate compartment of limits (Fig. 10.24).
 6. *Interosseous membranes* are modified deep fascia that connect the ulna and radius in forearm and tibia and fibula in leg.
 7. *Fibrous flexor sheaths* are thickening of deep fascia on the flexor surface of fingers and toes around the long flexor tendons. They hold the tendons in position and prevent bow-stringing of these tendons during muscle contraction.
 8. *Ligaments, fibrous capsules of joints, synovial membranes and bursae* are the modification of deep fascia.

Important Deep Fascia of Body

- Some of the important/well-defined deep fasciae of the body are as follows:
 1. Cervical fascia in the neck: It has various layers such as investing layer, pretracheal fascia, prevertebral fascia
 2. Pectoral fascia in the anterior part of chest
 3. Fascia lata in the thigh
 4. Thoracolumbar fascia in the lower back
 5. Pelvic fascia in the lower part of pelvic
 6. Renal fascia around the kidney
 7. Sibson's fascia (suprapleural membrane) at the root of the neck
 8. Endothoracic fascia in the thoracic cavity.

Sites of Absence of Deep Fascia

Q. List the sites where deep fascia is absent.

- The deep fascia is absent at the following sites:
 1. Face
 2. Breast
 3. Anterior abdominal wall
 4. Dorsum of penis and clitoris
 5. Scrotum
 6. Ischiorectal fossa.
- *Note:* The deep fascia is minimal in palms, soles, and eyelids.
- The absence of the deep fascia in these regions allows distension, flexibility, and mobility.

Functions of Deep Fascia

1. Structural support, and gives shape to the body
2. Gives area for muscular attachments
3. Compartmentalization of the body
4. Protection of structures.
5. Transmission of weight and forces
6. Facilitates movement and changes in the direction of muscle pull.

Clinical Integration

1. *Compartment syndrome:* The unyielding (inelastic) nature of accumulation of pus increased pressure with the facial compartments, and compression of content of this compartment (muscle, artery, nerve), such conditions is called compartment syndrome. It may result in severe pain, necrosis, paralysis, and so on.

Examples:

- a. Compression of median nerve in carpal tunnel syndrome
 - b. Compression of tibial nerve in tarsal tunnel syndrome
2. *Spread of infection:* Deep fascia limits the spread of infection. However, the infection may spread along the facial sleeves around the vessels and muscles due to compartment continuity of deep fascia. Planes of deep fascia are the route of infection spread, for example.
 - a. Tuberculosis abscess from the cervical vertebrae may enter the axilla along the prevertebral fascia.
 - b. Tuberculosis abscess from the thoracic/lumbar vertebrae may reach inguinal region through psoas sheath (fascial sheath around psoas major muscles).
 3. *Surgical plane:* Surgeons perform surgeries along the facial planes to avoid injury to the adjacent structure.

Some Interesting Facts

- Superficial fascia of eyelid, penis, and scrotum do not have fat.
- Temporal fascia and fascia lata are the toughest fascia of the body.
- Deep fascia is absent on the face and external genitalia.



Principles of Radiology

RADIOGRAPHY

Introduction

- Radiology is the branch of science that deals with diagnostic imaging and therapeutic intervention guided by imaging procedures.
- X-rays were invented by Wilhelm Conrad Roentgen in 1895. They are electromagnetic waves. [MCQ](#)

Diagnostic imaging

- It is a method to create visible image of morphology and function of the human body.
- It involves the following steps:
Energy has to be conducted to the body.
For example, ultrasound waves



Interaction of the energy and components of the body.

For example, reflection of ultrasound waves



Detection of modified energy.

For example, receiver to detect reflected ultrasound waves



Visualization of detected pattern.

For example, visualization of detected ultrasound waves in the form of specific pattern on the computer screen



Interpretation of visualized image (reporting).

Types of Imaging

- There are four types of imaging:
 - *Absorption*: For example, X-ray, computed tomography (CT) scan
 - *Reflection*: For example, ultrasound
 - *Induction*: For example, magnetic resonance imaging (MRI)
 - *Emission*: For example, nuclear medicine imaging, positron emission tomography (PET) scan
- Radiographs (skiagrams) are most often called X-rays. Radiographs are plane and contrast radiographs.

Components of Radiographic Lab

Components of radiographic lab are as follows (Fig. 11.1):

1. *X-ray tube*: It consists of anode and cathode fitted with a glass tube in a vacuum. X-rays are produced when electrons hit the anode. It generates X-rays that pass through a narrow window (Fig. 11.2).
2. *Object*: The individual or the body part is kept in required position.
3. *X-ray sheet or detector*: Object lies between X-ray tube and X-ray sheet or detector. X-ray films consist of an emulsion-gelatin containing radiation-sensitive silver, halide crystals, such as silver bromide or silver chloride, and a flexible, transparent, blue-tinted base. The emulsion is coated on both sides of the film (Fig. 11.3). After exposure to X-ray, the film is developed and fixed using various chemicals, then dried before observation. Digital X-ray machines use digital detector to generate digital image which is stored in digital medium in computers. (This process is somewhat similar to digital photography.)
4. *Monitor and control panel*: It is used to control dose, and duration of X-ray to visualize the digital X-ray image.

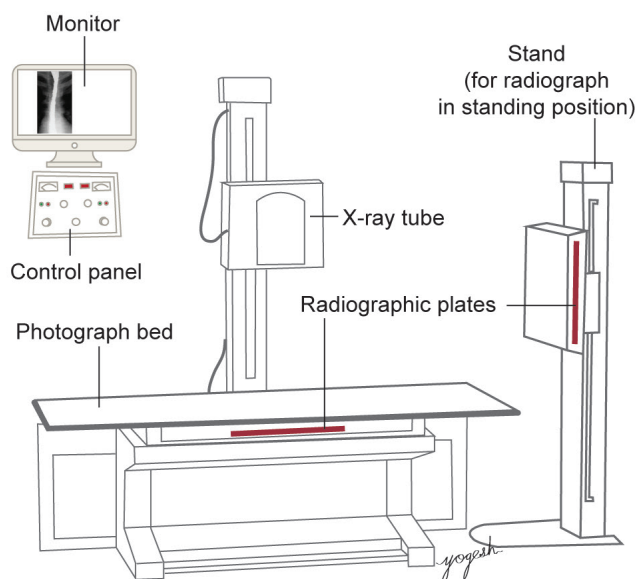


Fig. 11.1: Parts of X-ray machine

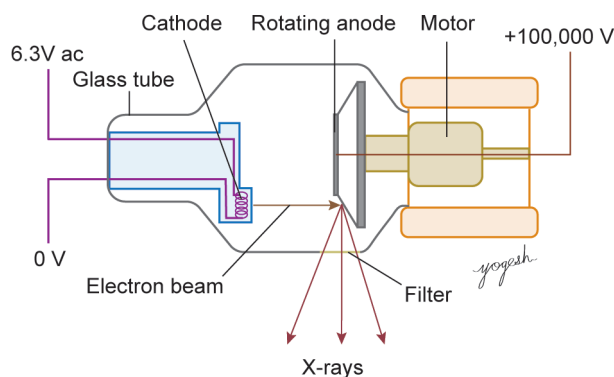


Fig. 11.2: X-ray tube

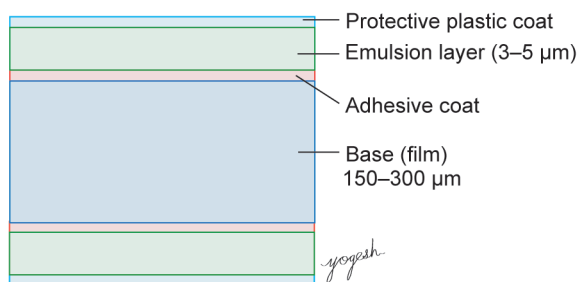


Fig. 11.3: Cross-section of X-ray sheet

Radiographic Densities

- Radiograph reading is based on four basic radiographic densities as follows (Fig. 11.4): *Practical guide*
Air → fat → water or fluid → bone
- The following are the main radiographic densities:
 - Air:** Air allows the passage of X-rays and hence, generates dark (almost black) shadow on radiograph. Hence, airy objects are called radiolucent objects. In human body, lungs, trachea, coils of intestine, fundus of stomach, nasal cavity, paranasal air sinuses, pharynx, and larynx show air.
 - Fat:** Fat has least density and shows dark-gray shadow on radiograph. Abdominal fat does not obscure the deeper structures.
 - Fluid and water:** Fluid and water show high density and hence produce radiopaque (bright) shadow.

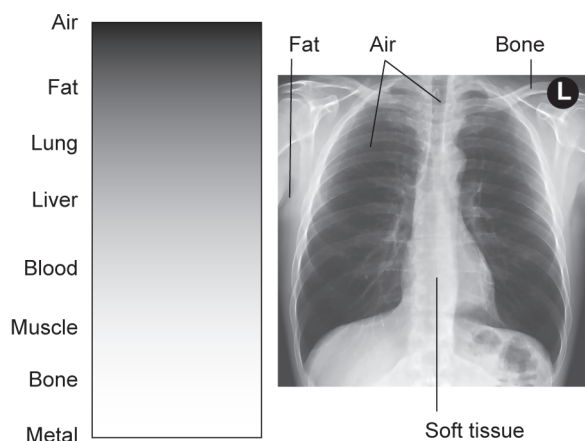


Fig. 11.4: Densities on radiography

- Bone:** This is the densest of the four basic densities and appears white or radiopaque on radiograph. Radiographic densities of human body can be further classified as (Fig. 11.4):
Air (radiolucent) → Fat → Lung → Liver → Blood → Muscle → Bone → Metal (radiopaque).

Utility of Plane Radiographs

- Bones:** Plane radiographs help to identify the presence of normal or abnormal bones.
- Fractures:** Plane radiographs help to identify the fractured bone. It is seen as break in the surface continuity of the bone.
- Dislocation:** Plane radiographs help to identify the bony articulation and dislocated bones.
- Age determination:** Up to the age of 25, plane radiographs of upper limb are useful for age determination.
- Detection of diseases** – such as rickets (vitamin D deficiency), scurvy (vitamin C deficiency), osteomyelitis (infection), and cancerous growths (osteoma, osteosarcoma, and so on).

Views of Radiograph

The plane radiographs include (Fig. 11.5):

- Posteroanterior view (PA)
- Anteroposterior view (AP)
- Lateral view.

How to Read Plain Radiographs?

While reading plain radiograph, the following sequence should be used.

- Identify the type of radiograph (plane) (Fig. 11.6)
- Identify the region (shoulder, elbow, wrist, hand, chest, abdomen, and so on).
- Identify the view (anteroposterior or lateral)
- Identify the side (right, left)

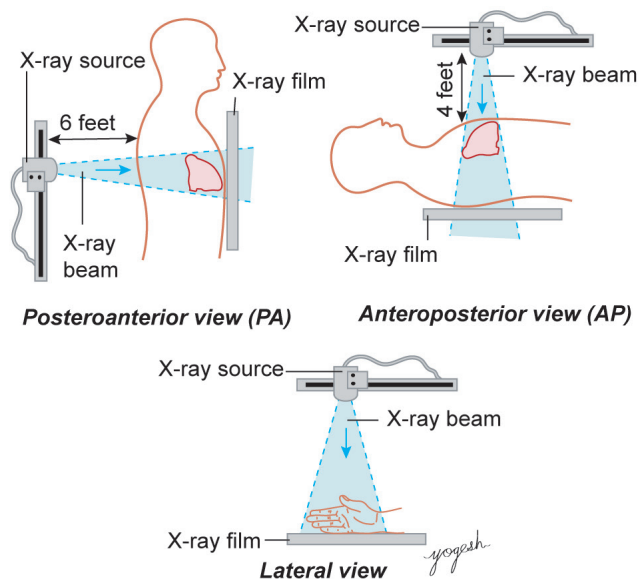


Fig. 11.5: Views of radiograph

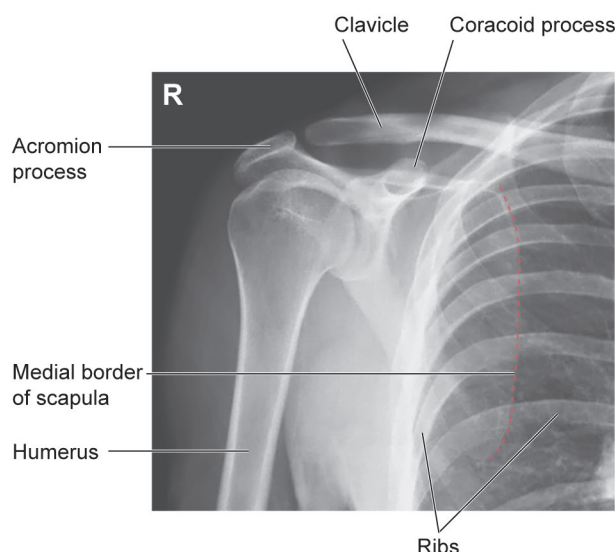


Fig. 11.6: Radiograph of normal shoulder region

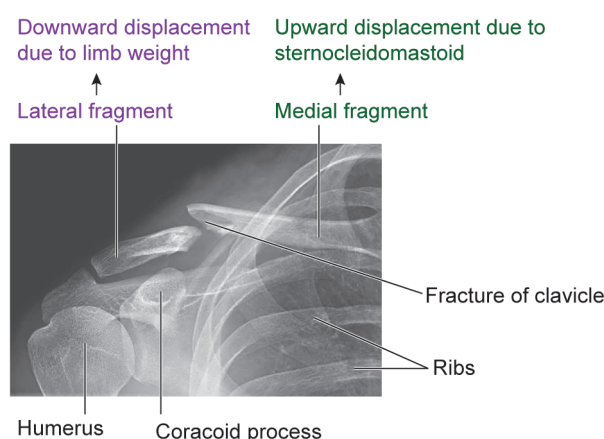


Fig. 11.7: Fracture of clavicle (radiological findings)

5. Identify the bones and their parts (name the bones and their parts)
6. Identify the following points, if required
 - a. Fracture (Fig. 11.7)
 - b. Dislocation
 - c. Ossification of bone and epiphyseal lines
 - d. Determine the age
 - e. Soft tissue shadows.

Contrast Radiography

- Contrast radiography is a technique that involves the use of a contrast agent, typically a substance visible on X-rays, to enhance the visibility of specific organs, blood vessels, or tissues. It helps highlight structures that would be difficult to visualize otherwise.
- Types of contrast radiography:
 1. Barium studies: Ingestible or injectable barium sulfate is used to visualize the gastrointestinal tract in barium swallow, barium enema, and small bowel series.
 2. Iodine-based contrast: Intravenous iodine-based contrast agents are used in procedures like CT

scans, angiography, and intravenous urography to enhance blood vessels, organs, and tissues.

3. Gadolinium-based contrast: Gadolinium-based contrast agents are used in MRI scans to improve the visibility of soft tissues, blood vessels, and certain organs.
4. Air contrast studies: Air, sometimes combined with a water-soluble contrast medium, is used in procedures like double-contrast barium enema or hysterosalpingography to highlight specific areas in the gastrointestinal or reproductive systems.

Barium Studies

- To visualize mucosal patterns and luminal outlines of the intestine, a radiopaque dye (barium) is used under fluoroscopy or radiographed on a film (Figs 11.8 to 11.10).
- Contrast medium: Barium is a radiopaque substance. It is non-toxic and is not absorbed from gut. It is odorless, crystalline, insoluble in water as barium sulphate (BaSO_4).

Barium Meal and Follow-Through

- Procedure: Ask the patient to drink 300–400 ml of 5% barium sulphate suspension in water. A series of radiographs are taken in supine position at the interval of 20–30 minutes. The barium reaches the ileocaecal region in 3–4 hours. Most of the solution is usually evacuated in 16–11 hours.
- Barium meal and follow through is performed to examine stomach, duodenum, jejunum, ileum, and large intestine (Fig. 11.9).

Barium Enema

- Barium enema is contrast radiographic analysis of the large intestine (Fig. 11.10).
- Procedure: Give mild laxatives two nights before the examination. On the day of examination, a well-lubricated enema tube is inserted into rectum through the anus. About 2 liters of barium sulphate suspension is slowly introduced. A large balloon at the tip of enema tube is inflated to keep the barium sulphate inside the intestine. Radiographs are taken for the large intestine.

Pyelography

- Pyelography (urography) is a form of radiological examination of renal pelvis and ureter. It may be intravenous pyelography (IVP) or retrograde pyelography (Fig. 11.11).
- *Intravenous or Descending Pyelography:* A contrast agent is injected slowly intravenously. After injection, abdominal X-ray (KUB) are taken at 5, 15, and 30 minutes.
- *Retrograde or Ascending Pyelography:* In this method a contrast agent is injected into the ureter using a cystoscope and a ureteric catheter.

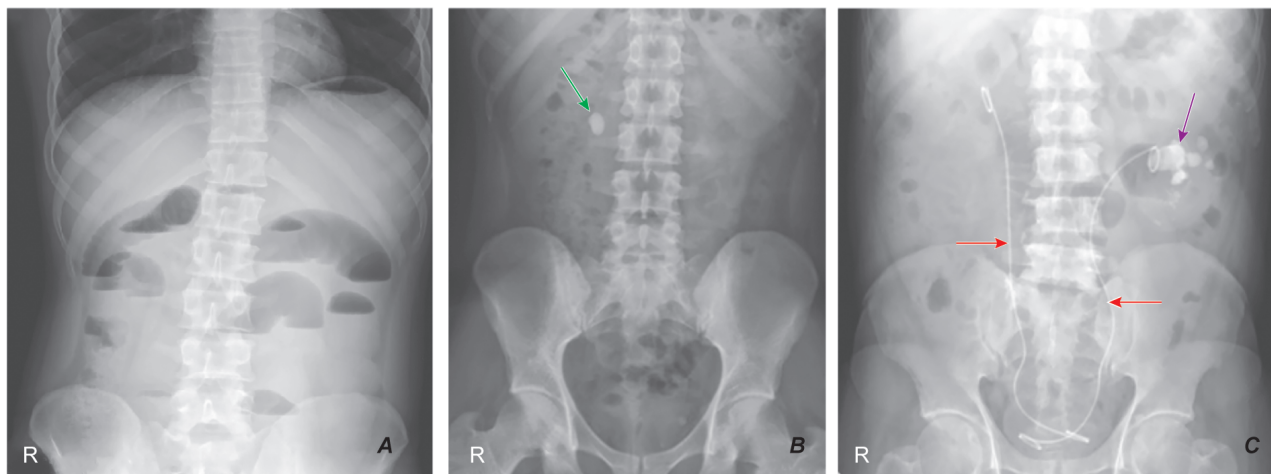


Fig. 11.8: Abdominal radiographs showing clinical conditions. A: Intestinal obstruction. B: Stone in right renal pelvis (marked by green arrow). C: Multiple calculi (marked by purple arrow) in left kidney with bilateral DJ stent *in situ* (red arrows) Note: DJ stent maintains the continuous flow of urine from kidneys to the bladder through ureters.

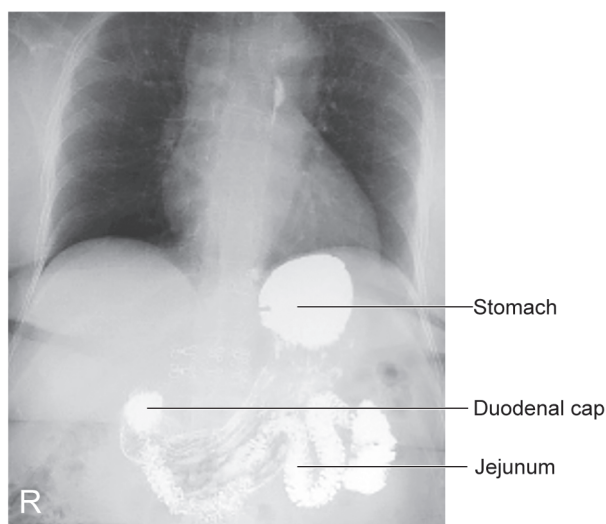


Fig. 11.9: Barium meal follow through

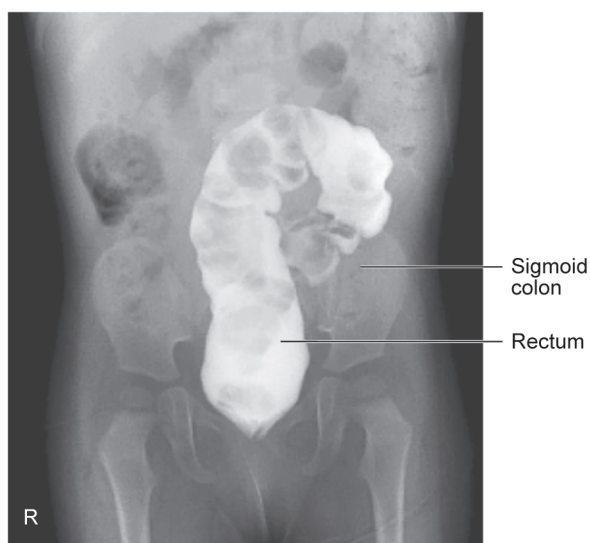


Fig. 11.10: Barium enema (SC: Sigmoid colon)

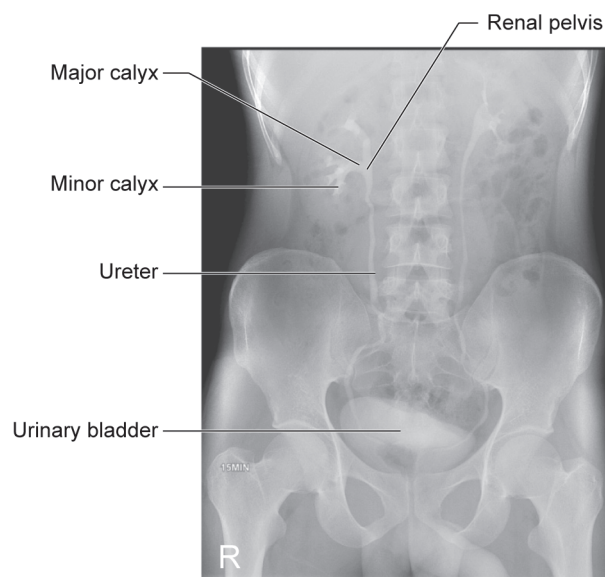


Fig. 11.11: Intravenous pyelogram

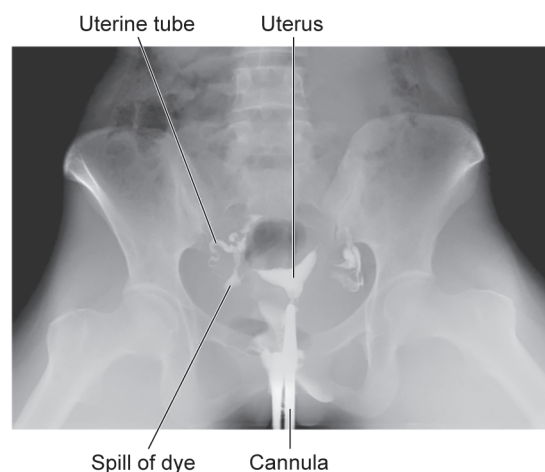


Fig. 11.12: Radiograph showing hysterosalpingography

Hysterosalpingography

- It is a radiological procedure to investigate uterus, uterine tubes, and patency of uterine tubes (Fig. 11.12).

- Procedure:** It is preferably done within the first 5–10 days of the menstrual cycle. A 5–10 ml of iodized oil (lipiodol) dye is injected into the uterine cavity through a cannula. A radiograph is taken.

- Spillage of the dye in the uterine cavity indicates patency of the uterine tube.

MAMMOGRAPHY

- *Principle:* Mammography is a specialized X-ray imaging technique designed for detecting breast cancer at an early stage. It uses low-dose X-rays to capture detailed images of the breast tissue.
- *Uses:*
 1. Breast cancer screening to detect breast cancer in its early stages
 2. Diagnostic imaging for detecting the location, spread, and other details of breast cancer
 3. Monitoring treatment
 4. Guiding precisely needle biopsies.

ULTRASONOGRAPHY

- Ultrasonography or ultrasound examination (USG) is a preferred method of investigation for abdominal examination. It is a non-invasive technique.
- It is the most useful technique to detect gallbladder diseases and fetuses.^{MCQ}

Principle of Ultrasonography

- In ultrasound examination, transducer generates ultrasound waves and records echoes generated by medium (here, tissue).
- Transducer has piezoelectric material that can generate ultrasound of typical wavelength (2–18 MHz) on electric stimulus.
- The material on the surface of transducer enables the sound to be transmitted efficiently into the body.
- To enhance the transmission, water-based gel is placed between the skin and the transducer probe.
- Returning sound waves (echoes) vibrate the transducer, which in turn generates electric pulses. These electric pulses are carried to the scanner that generates the image depending on the time required for the sound wave to come back from the object (for example, uterus), strength of the echo, and focal length of phased array.
- Depending on the strength of the echoes, scanner generates different shades of grey to produce an image.
- 2D image (slice of body) can be generated by sweeping or rotating transducer mechanically.
- 3D images can be generated by acquiring a series of adjacent 2D images.
- Doppler ultrasonography is useful to study blood flow. In Doppler ultrasonography, different detected speeds are represented in color for easy interpretation.
- Doppler shifts cells fall in audible sounds. It is represented by audibly distinctive pulsing sound (pulsed Doppler) to measure the velocity.
- In Doppler ultrasonography, use of specific color has not been set with any standard. Some use red for

artery, whereas some use red to indicate flow towards transducer.

- World Health Organization (1988) declared that diagnostic ultrasound is safe (harmless) and capable of providing clinically relevant information about most body parts, and even ultrasound is safe for fetus.

Grey Scale of Ultrasound

- On ultrasonography, substance may be (Fig. 11.13):
 1. Hyperechoic: It gives white color on screen. For example, fat-containing tissue.
 2. Hypoechoic: It gives grey scale. For example, soft tissue.
 3. Anechoic: It gives black color. For example, clear fluid (amniotic fluid), blood vessels.
 4. Acoustic shadow: Gas does not echo sound waves; hence, it produces black color.
- Bones appear black (anechoic) with bright hyperechoic rim as ultrasound does not penetrate the bone.
- Cartilage appears white (hyperechoic) as ultrasound penetrates cartilage.
- Usually, Doppler shows red for flow towards probe and blue for flow away from probe. (BART: Blue away, red toward).
- Muscles are hypoechoic, whereas other connective tissues are hyperechoic.

Ultrasound Frequency

1. High frequency probes (10–15 MHz) are suitable for superficial structures (2–4 cm depth).
 2. Mid-frequency probes (5–10 MHz) are suitable for deeper structures (5–6 cm).
 3. Low frequency probes (2–5 MHz) are suitable for more deeper structures (~10 cm depth).
- With decreasing frequency of probe, quality of image also decreases.

COMPUTED TOMOGRAPHY (CT) SCAN

- It is noninvasive radiographic imaging. It provides more detailed information than plain radiographs. CT scan was invented by Godfrey Hounsfield in 1970.
- It gives sectional views of brain. These images can be assembled to produce three-dimensional images.

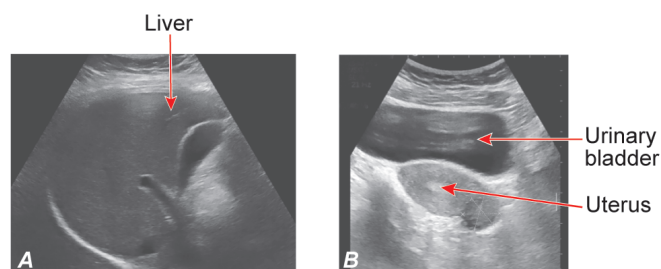


Fig. 11.13: Utility of ultrasonography in abdominal investigations. A: Liver. B: Uterus (axial view) (Image courtesy: Dr Satya Jha, All India Institute of Medical Sciences, Jodhpur, Rajasthan.)

- **Scale in CT scan:** The structures are seen ranging from back, gray to white in color as follows (Fig. 11.14): Black color → air → fat → water → CSF → white matter → gray matter → blood → bone → metal → white color. Thus, the bones look white, ventricles and CSF look black, and soft tissue has variable shades of gray color.
- **Cranial CT scan** gives information about size and shape of ventricles of brain, size of brain tissue, injuries, hematoma, calcified tissues, tumors, infarction, abscess, and encephalitis (Fig. 11.14).
- **Spinal CT scan** gives information of intervertebral disc, spinal cord injury, subarachnoid space (with injection of contrast media).
- **CT angiography (CTA)** can be performed by injecting a contrast media into peripheral blood vessel. It is useful in detection of arteriovenous malformation, aneurysm, atherosclerosis. Contrast media may be injected into carotid artery or vertebral artery to visualize the arterial pattern.

Computerized Axial Tomography (CAT or CT) Scan

- **Principle:** A computerized axial tomography (CAT or CT) scan combines X-ray images from different angles to create detailed cross-sectional images of the body's internal structures.
- **Technique:** The X-ray beams are directed through the body from various angles.
- **Uses:**
 - To diagnose injuries, infections, tumors, and internal bleeding.
 - To detect and monitor cancerous growths, aiding in treatment planning and assessing the tumor's response to therapy.
 - To assess traumatic injuries, providing detailed images of bones, organs, and tissues.
 - To guide needle biopsies, surgeries, and other medical procedures, ensuring precision and accuracy.
 - CT angiography visualizes blood vessels, identifying blockages, aneurysms, or other vascular abnormalities.

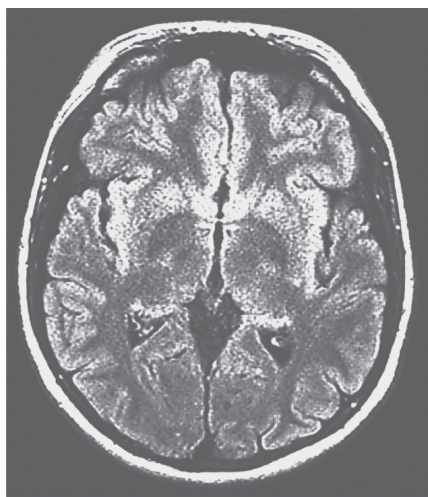


Fig. 11.14: A computerized tomography (CT) scan

MAGNETIC RESONANCE IMAGING (MRI)

- In MRI, the body is exposed to high-energy magnetic field, and using radiowaves, the sectional images are captured.
- MRI gives higher details of soft tissues and less hazardous than CT scan (Fig. 11.15).
- It provides good contrast between gray and white matters.
- MRI takes 30 to 40 minutes for imaging, whereas CT scan takes only 5 minutes.
- MRI cannot be done in patients with artificial joints, eye implants, intrauterine devices, and pacemakers.
- MRI is useful in detection of tumors of brain and spinal cord, developmental anomalies, vascular aneurysm, stroke, trauma, disease of pituitary gland, multiple sclerosis, and so on.

Some Interesting Facts

- MRI is the best technique to detect disc prolapse, tumors in brain and spinal cord.
- MRI is based on excitation of photons. If relaxation (gap) is given in excitation, then photons return to equilibrium.
- *T1 (longitudinal relaxation time)* and *T2 (transverse relaxation time)* are used in MRI as follows:
 - *T1-weighted MRI scan* differentiates fat from water (fat – brighter, water – darker)
 - *T2-weighted MRI scan* also differentiates fat from water, but here fat looks darker, and the water looks brighter (Fig. 11.16). It is useful for imaging of edema.
- **Magnetic resonance angiography (MRA)** is useful to scan arteries of neck and brain by injecting a paramagnetic contrast medium (gadolinium).
- **FLAIR MRI scan:** It is *fluid attenuated inversion recovery MRI*. It is useful to differentiate CSF (which looks darker) from anomalous tissue and inflammation (which looks brighter).
- Main limitation of MRI is motion artifact. It is inferior to CT scan in detecting acute hemorrhage, bony injury, and more time consuming.
- It is contraindicated in patients with pacemakers, cochlear implants, metallic implants (aneurysm clips, some heart valves), pregnancy, and unstable patient.

POSITRON EMISSION TOMOGRAPHY (PET) SCAN

- Positron emission tomography (PET) scan is a imaging technique that detects and measures the activity of cells in the body. It provides detailed images of metabolic processes.^{MCQ}
- PET scans are used in oncology to detect cancer, evaluate its spread, and assess treatment effectiveness. It is also utilized in neurology to diagnose brain disorders, such as Alzheimer's disease, and in cardiology to assess heart conditions.
- **Procedure:** Patients are injected with a small amount of radioactive material called a radiotracer, often a form

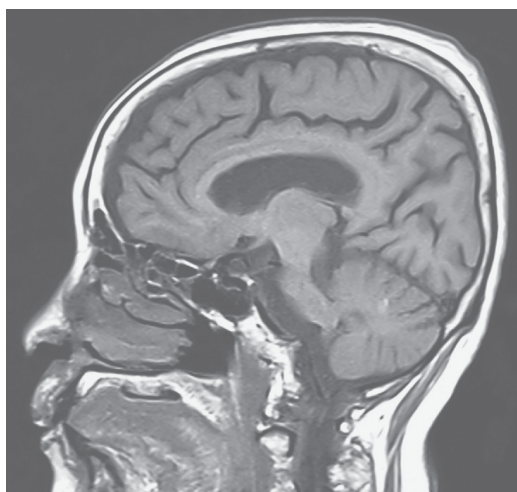


Fig. 11.15: A magnetic resonance image – brain

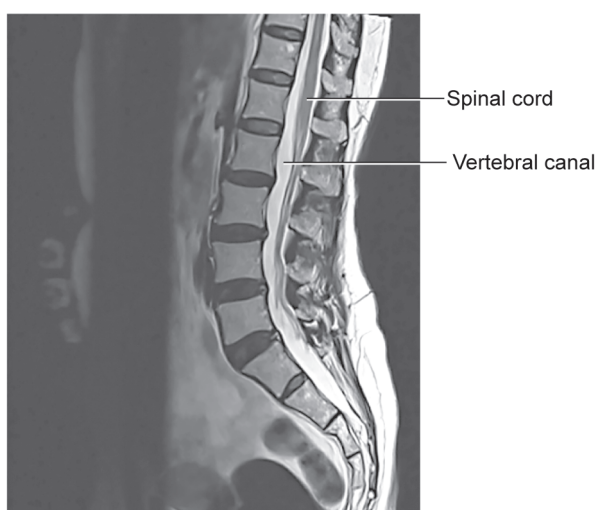


Fig. 11.16: A magnetic resonance image (lumbar spine, sagittal view, T2-weighted image)

of glucose. The scanner detects the emitted positrons (positively charged particles) as the radiotracer accumulates in active cells.

- The most commonly used radiotracer is *fluorodeoxyglucose* (FDG), a radioactive form of glucose. Cancer cells, being more metabolically active, absorb more FDG, making them visible on the PET scan images.
- PET scans offer early detection, accurate staging, and monitoring of various diseases. They help doctors make precise treatment decisions, leading to improved patient outcomes.

Magnetic Resonance Imaging (MRI)

- Interventional radiology (IR) uses minimally invasive radiological procedures to diagnose, treat, and manage diseases and conditions in various organ systems of the body.
- *Interventional radiologists* utilize imaging guidance, such as X-rays, ultrasound, CT scans, or MRI, to perform procedures through small incisions or body

orifices. These procedures are often an alternative to traditional surgery, offering less risk, less pain, and shorter recovery times.

Uses of Interventional Radiology

- The interventional radiology is useful for the following purposes:
 1. **Vascular interventions:** These procedures involve the blood vessels and include angioplasty (to open narrowed or blocked blood vessels), stent placement (to keep blood vessels open), embolization (to block abnormal blood vessels), and thrombolysis (to dissolve blood clots).
 2. **Non-vascular interventions:** These procedures involve organs and tissues and include biopsies (to obtain tissue samples for diagnosis), drainage (to remove fluid or pus from cysts or abscesses), and ablation (to destroy tumors or abnormal tissues using techniques like radiofrequency or cryoablation).
 3. **Pain management:** To perform nerve blocks to manage pain, especially in conditions like chronic back pain or cancer-related pain.

SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT)

- **Principle:** Single Photon Emission Computed Tomography (SPECT) is a nuclear imaging technique that detects gamma rays emitted by a radioactive tracer injected into the patient's body. These gamma rays indicate the distribution and concentration of the tracer, providing functional information about the organs and tissues being studied.
- **Technique:** During SPECT, a gamma camera rotates around the patient, capturing images from multiple angles. Computer algorithms reconstruct these images into detailed three-dimensional representations, allowing visualization of organ function and abnormalities.
- **Uses:**
 - To assess myocardial perfusion, help diagnose coronary artery disease, and evaluate heart function.
 - In brain imaging, SPECT measures cerebral blood flow, aiding in diagnosing conditions such as strokes, epilepsy, and neurodegenerative disorders.
 - Assists in locating and characterizing tumors, monitoring response to therapy, and planning radiation treatments.
 - Detects bone disorders, including cancer metastases, fractures, and infections.
 - To identify sites of infection or inflammation, aiding in the diagnosis and monitoring of infectious diseases like osteomyelitis.

Introduction to Cadaver Dissection



CADAVER – AS A TEACHER

- Cadaveric dissection is an effective way of learning anatomy. It gives an opportunity to dissect, feel, view, and understand the structures within the human body.
- For cadavers, it is said, “The dead teach the living”.
- The word ‘cadaver’ is derived from the Latin ‘cadere’ meaning ‘to fall’.
- The term ‘dissect’ is also derived from Latin ‘dissecare’ and means ‘to cut apart’ or ‘to separate into pieces’.
- The medical colleges receive the cadavers through an active Voluntary Body Donation Program and by accepting unclaimed bodies.

Respect the Dead

- The National Medical Commission (NMC) is strongly in favor of including ethical and attitude-related topics from the very beginning of undergraduate medical curriculum. First-year medical students are required to take the cadaveric oath at all medical colleges in India, in which they swear to respect the integrity and dignity of the cadavers that they would be working with.

Cadaver as a Teacher

- Cadaver helps in learning the human anatomy in the following ways:
 1. *Spatial appreciation*: The cadaveric dissection allows students to grasp the 3D picture of organization of human body.
 2. *Tactile appreciation*: Cadavers allow students to experience the feel and texture of human tissues.
 3. *Pathological correlation*: Dissection helps to understand the effects of any disease on the body and compare normal versus pathological structures.
 4. *Biological variability*: Cadaveric dissections clear this concept of biological variability of gender, age, and ancestry.

Cadaver Care and Dissection Hall Instructions

- Wear white/laboratory coat while dissection. Wear gloves (nitrile or latex) and other safety measures as per the instructions.

- The cadavers should always be treated with respect. The cadaver must be kept moist always. It should be covered with wet cotton gauze pieces.
- Any cadaveric material should not be removed from dissection laboratory under any circumstances. All tissues removed from cadaver are to be disposed of in *yellow container*. Do not remove cadaver identification tag or mark, if any.
- No photography or videography should be allowed without permission in the Dissection Hall. Mobile phones should preferably be kept silent and preferably outside the dissection laboratory.
- Keep their nails trimmed when they are handling cadavers and biological material. Do not eat or drink anything in the dissection hall.
- Maintain discipline in the dissection and do not leave designated places without permission.
- Report any mishap or injury to the teacher and ask for the first aid. Handle the scalpel blades with care. They should be disposed of with utmost care in white/sharp containers. Dissection tools should not be left loose on the table or the cadavers.

INSTRUCTIONS FOR THE DISSECTION

Health and Safety Rules

- Always put on your laboratory coat before entering the dissection hall.
- Never eat or drink in the dissection hall.
- Cut your nails and tie your hair properly.
- Wash hands with soap after each dissection.
- All the above instructions will help to keep you healthy and away from infections.

Cadaver and Specimen Handling Instructions

- *Ethics*: Respect the cadaver as it is the most useful material for learning medical sciences.
- Preservation of cadaver
 - Cadavers are preserved using formalin and glycerol, along with other chemicals.
 - Formalin causes discoloration (darkening) of the skin. Formalin hardens the body parts. Hence

passive movements of body parts become difficult and require more pressure to cut the body parts than in a living state. *Practical guide*

Preservation of Dissected Parts

As the dissected parts become dry due to exposure to the atmosphere, it is advised.

- To keep it covered with dissected skin on completion of the dissection.
- To moisturize the dissected part with water or glycerin.
- To cover the dissected part with wet cloth or cotton.

Always preserve the dissected structures so others can use them for further study.

First aid and Emergency

- Any accident during dissection should be immediately reported to the concerned in charge or teacher.
- If feeling giddiness, glucose solution can be taken on advice of the in-charge or teacher.
- Videography and photography should be done only with permission from the concerned teacher.

INSTRUMENTS REQUIRED FOR THE DISSECTION

- A set of instruments is required for routine dissection that includes
 - Scalpel
 - Forceps
 - Scissors
 - Hand lens and so on.

Scalpel

- It has two components (Fig. 12.1):
 1. Scalpel handle (Number 4)
 2. Scalpel blade (Number 24 or 23)
- Fit the blade carefully to the handle. Some scalpels have in-built blades.

Use

- It is used to cut the skin.
- It is used to cut the connective tissue, fascia, muscles, vessels, nerves, and other structures when required.

Care

- Use clean and new blades every time, as formalin (used for cadaver preservation) causes rusting of scalpel blades.
- The method to hold the scalpel is shown in Fig. 12.2.

Forceps

- For dissection, use forceps of 6 inches in length (Fig. 12.3). With short-length forceps such as 4 inches, handling hard cadaveric tissue will be difficult.

Use

- To hold, lift, or retract the structures.
- Also useful for blunt dissection.

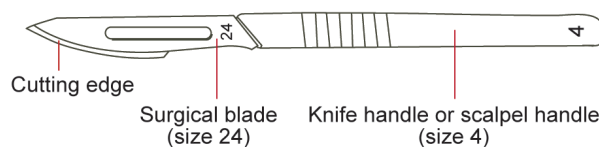
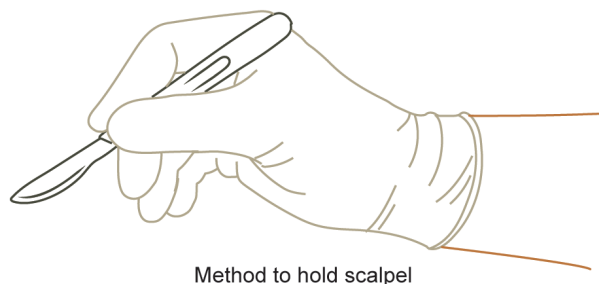
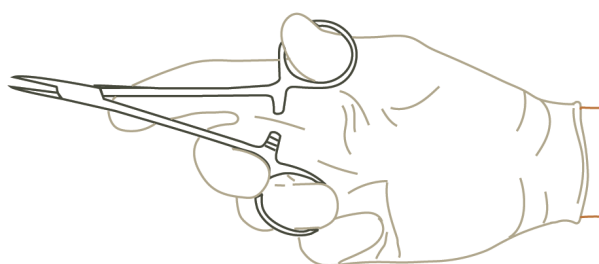


Fig. 12.1: Surgical knife (scalpel)



Method to hold scalpel



Method to hold needle holder, artery forceps, and scissors

Fig. 12.2: Instrument handling

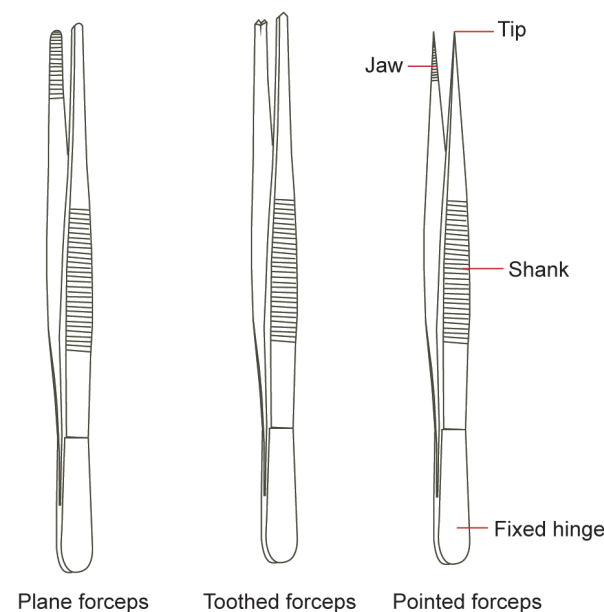


Fig. 12.3: Plane, tooth, and pointed forceps

Plane forceps

Use: To hold delicate structures such as vessels, nerves, and muscles.

Toothed forceps

Use: To hold the skin and hard structures.

Pointed forceps

Use: To show the dissected structures during discussion and for fine dissection or to hold thin nerves.

Scissors

- *Use:* To cut the tissue such as fascia, ligaments, tendons, and so on.
- There are two types of scissors commonly used for dissection (Fig. 12.4):
 1. *Straight scissors:* Use: For blunt dissection.
 2. *Curved scissors:* Use: For delicate dissection and cutting less accessible structure and also for trimming the tissue and cutting the fascia.

Artery Forceps or Hemostatic Forceps

- It has a catch or ratchet that helps in catching, clamping, and crushing the tissue (Fig. 12.4).
- *Use:* For strong grasping, holding, and catching the structures. For example, to hold and reflect the skin.
- Do not use it for holding delicate structures as it crushes the structure.

Other Instruments

- For specific purposes, other instruments are required. These are as follows (Fig. 12.5):
 1. *Saw:* To cut the bone. To take the section of body part.
 2. *Bone cutter or bone nibbler:* To cut the bone into small pieces.
 3. *Chisel and hammer:* To cut the strong bones.
 4. *Hammer:* To hit the chisel for cutting the bones.
 5. *Brain knife:* To take the section of brain.

STRUCTURES ENCOUNTERED IN DISSECTION

Q. How to differentiate arteries, veins, and nerves in a cadaver?^{Viva}

The layers of the human body encountered in the dissection are as follows:

1. Skin
2. Superficial fascia
3. Deep fascia
4. Muscles
5. Bones
6. Body cavity: Pleural, peritoneal, pericardial, cranial cavity
7. Organs/viscera

The following structures are encountered during the dissection:

Skin

- It is harder and darker in cadavers than in the living state due to the action of formalin.

Superficial Fascia

- It contains various amounts of fat (yellowish), superficial veins, and loose connective tissue (whitish). Blunt dissection is required to remove superficial fascia.

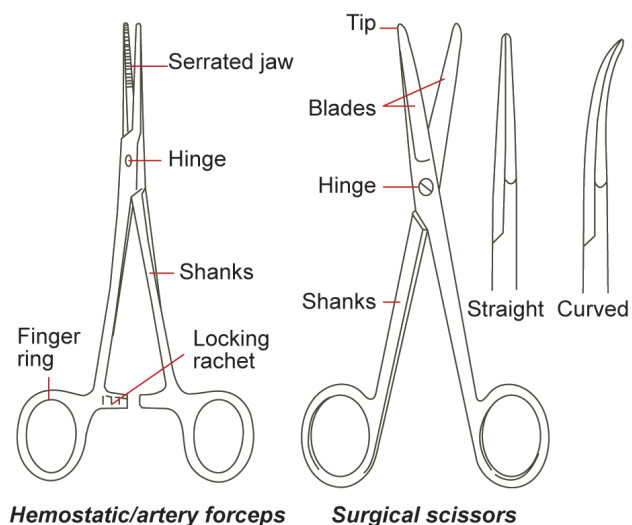


Fig. 12.4: Hemostatic forceps and surgical scissors

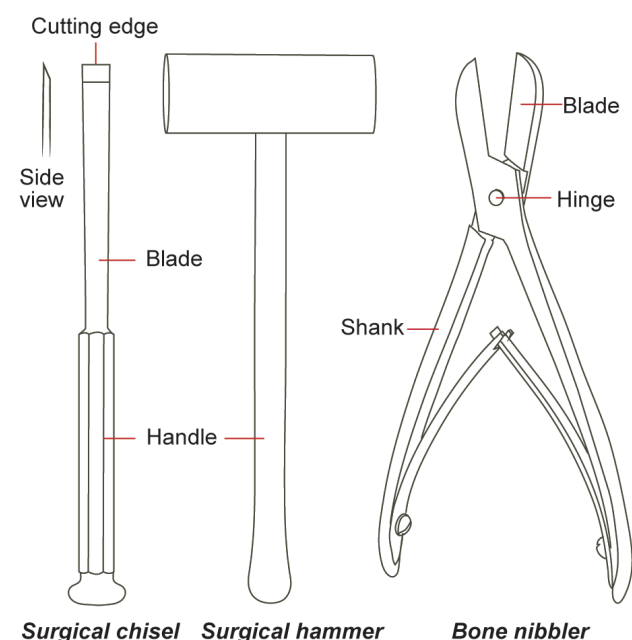


Fig. 12.5: Surgical chisel, surgical hammer, and bone nibbler

Deep Fascia

- It is the tough sheet of connective tissue (whitish) that encloses deeper structures.

Muscles

- They have muscle fibers (brown in color) and tendons (white in color). Some muscles do not have long slender tendons.

Arteries

- They are thick-walled than veins.^{Viva} They have circular lumen (can be felt by rolling between fingers).^{Viva} In cadavers, arteries are empty (do not have clotted blood). Due to their thick wall and empty lumen, they look white in color.^{Viva}

Veins

- They are thin-walled than arteries. ^{Viva} They have irregular lumen. ^{Viva} They mostly contain blood in their lumen. Deep veins usually follow major arteries.

Nerves

- They are pale-looking cord-like structures. They can be differentiated from arteries by rolling in fingers. (Arteries have a lumen, nerves do not.) ^{Viva}

Lymph Nodes

- These are small, bean-shaped, firm structures that filter the lymph. They vary in size from pinhead to large bean. They may get colored by foreign particles, such as carbon particles. They are abundant in axilla and groin.

Other Structures

- Other structures include bones, ligaments, bursae, joints, and organs (lung, heart, liver, and so on).