Chapter 1

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

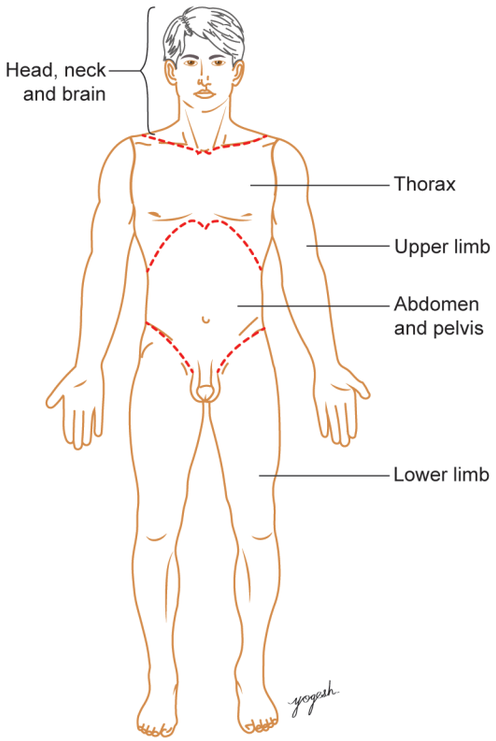


Fig. 1.1: Regions of the body

        - 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.

Chapter 2

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

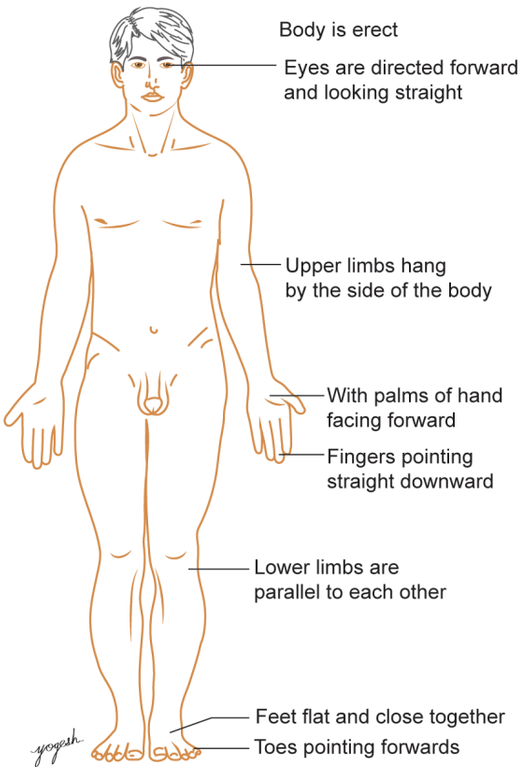


Fig. 2.1: Anatomical position

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).

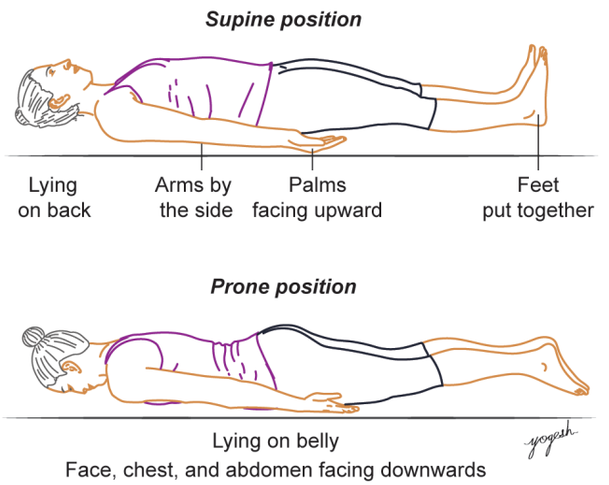


Fig. 2.2: Supine and prone position of body

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.

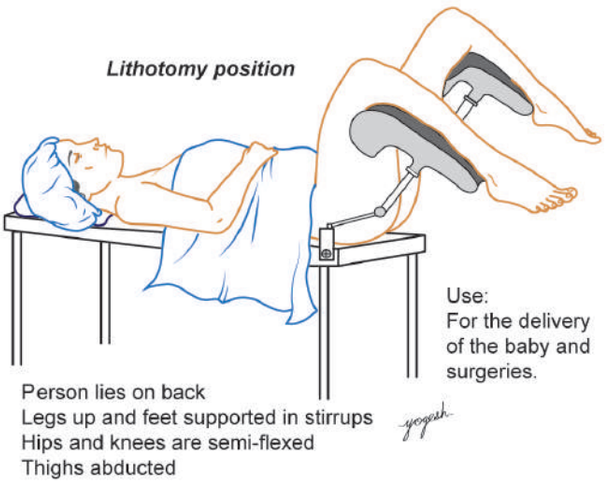


Fig. 2.3: Lithotomy position

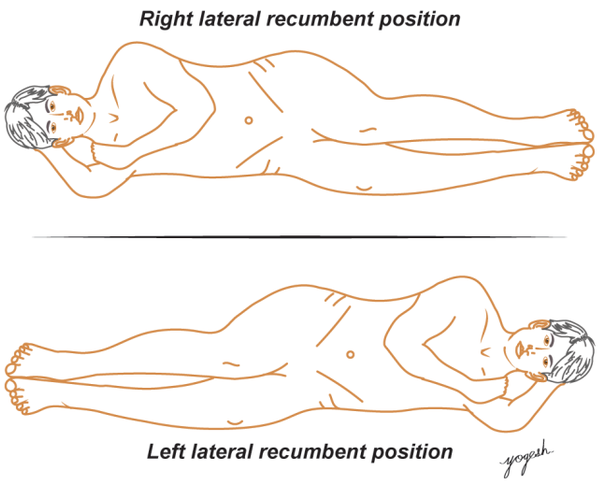


Fig. 2.4: Right and left lateral recumbent position

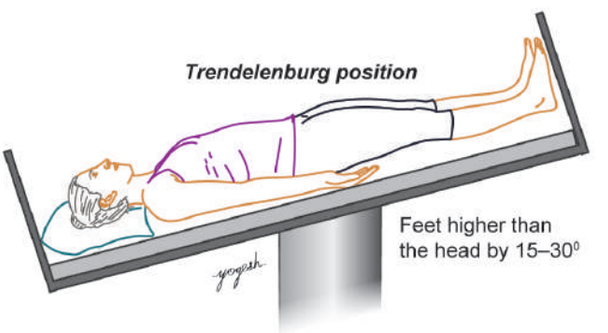


Fig. 2.5: Trendelenburg position

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).

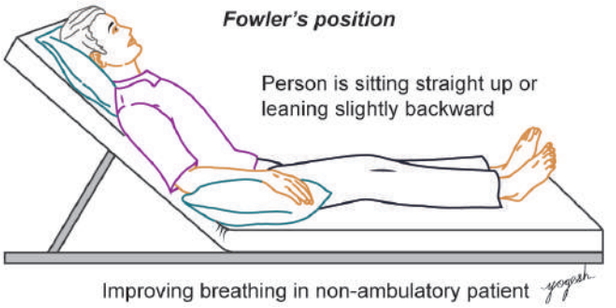


Fig. 2.6: Fowler's position

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).

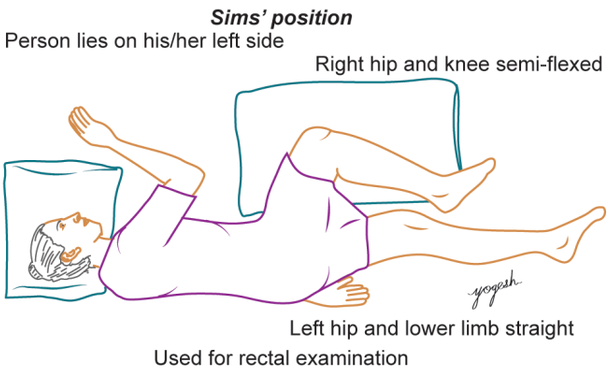


Fig. 2.7: Sims' position

ANATOMICAL PLANES OF THE BODY

- Anatomical planes are useful for description of structural arrangements of human body and relationship of structures (Fig. 2.8).
  1. *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.
  2. *Sagittal plane*: Any plane parallel to the median plane is sagittal plane.[Viva]
  3. *Coronal or frontal plane*: It passes longitudinally at right angle to the sagittal plane. It divides the body into anterior and posterior portions.[Viva]

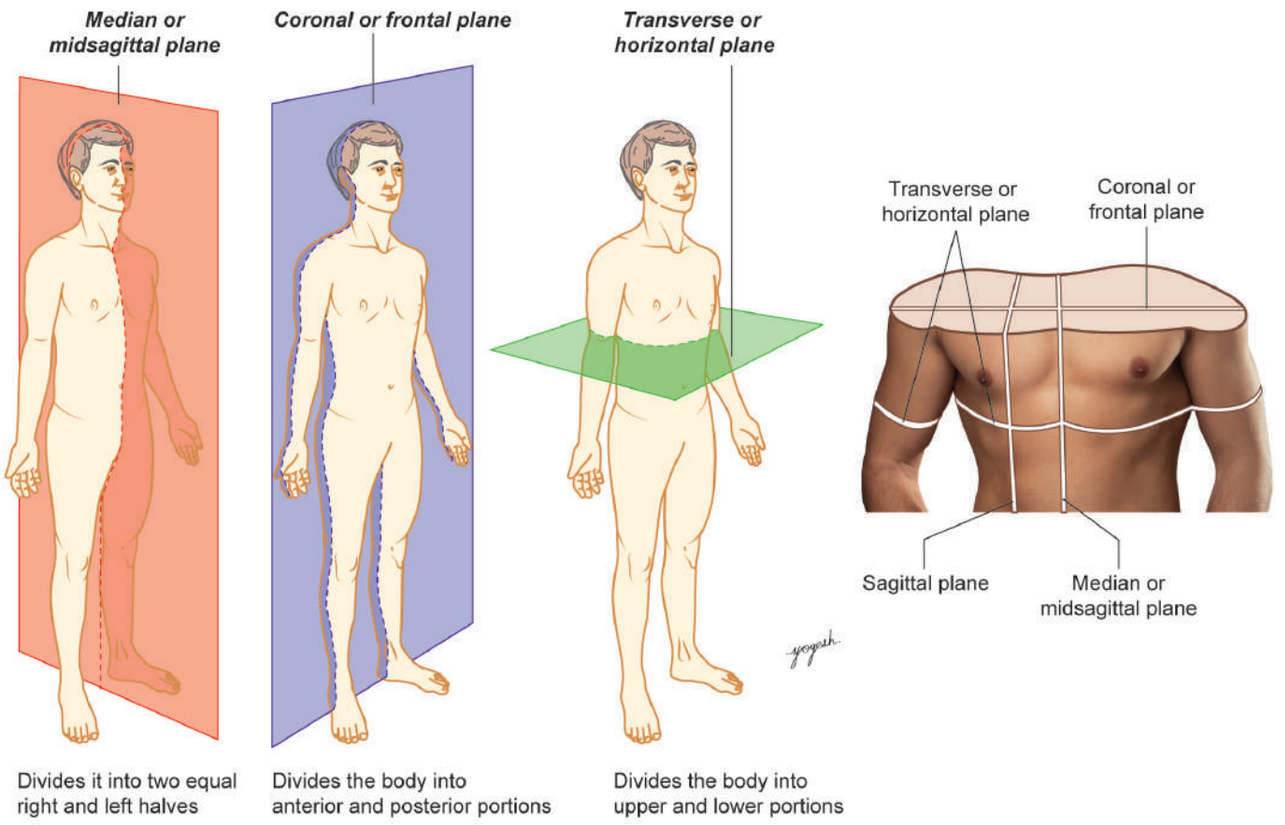


Fig. 2.8: Fundamental planes of body

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.

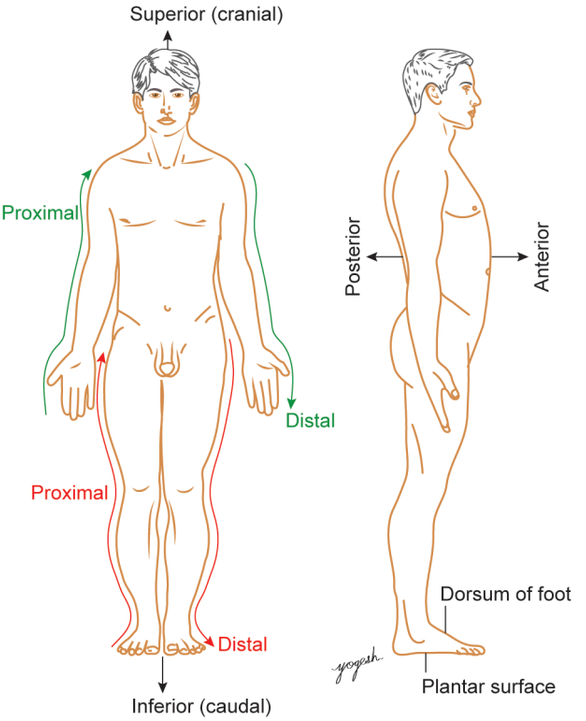


Fig. 2.9A: Descriptive anatomical terms

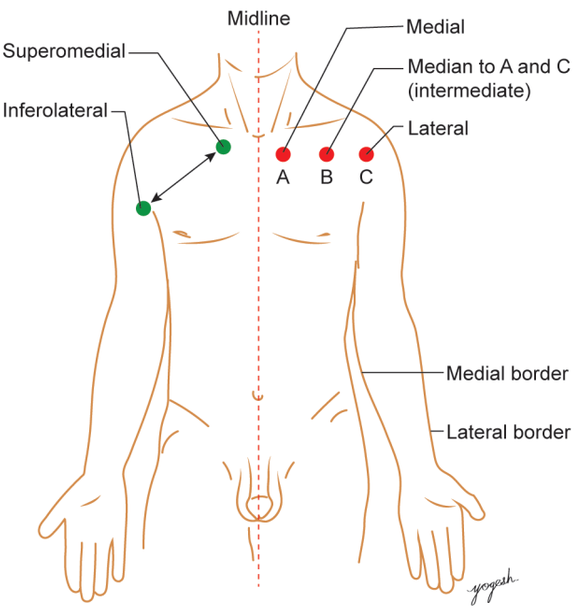


Fig. 2.9B: Descriptive anatomical terms

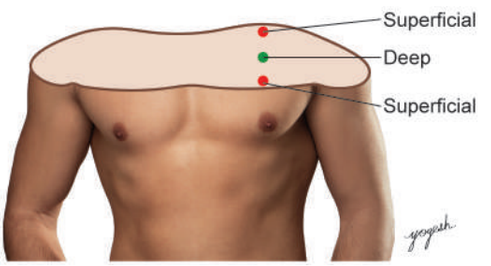


Fig. 2.9C: Descriptive anatomical terms

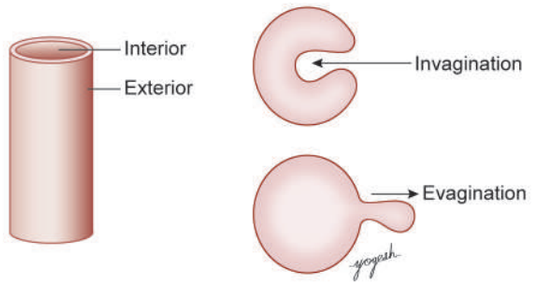


Fig. 2.9D: Descriptive anatomical terms

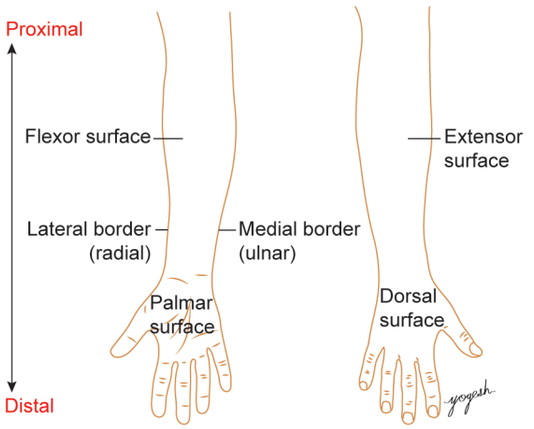


Fig. 2.10: Terms for upper limb

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.

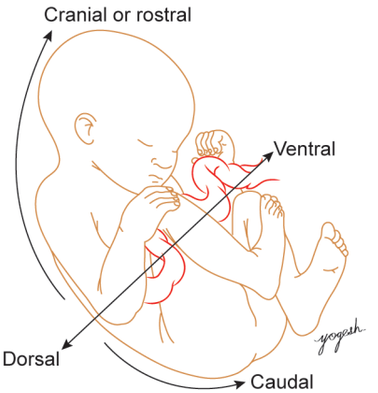


Fig. 2.11: Terms of embryonic descriptions

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.

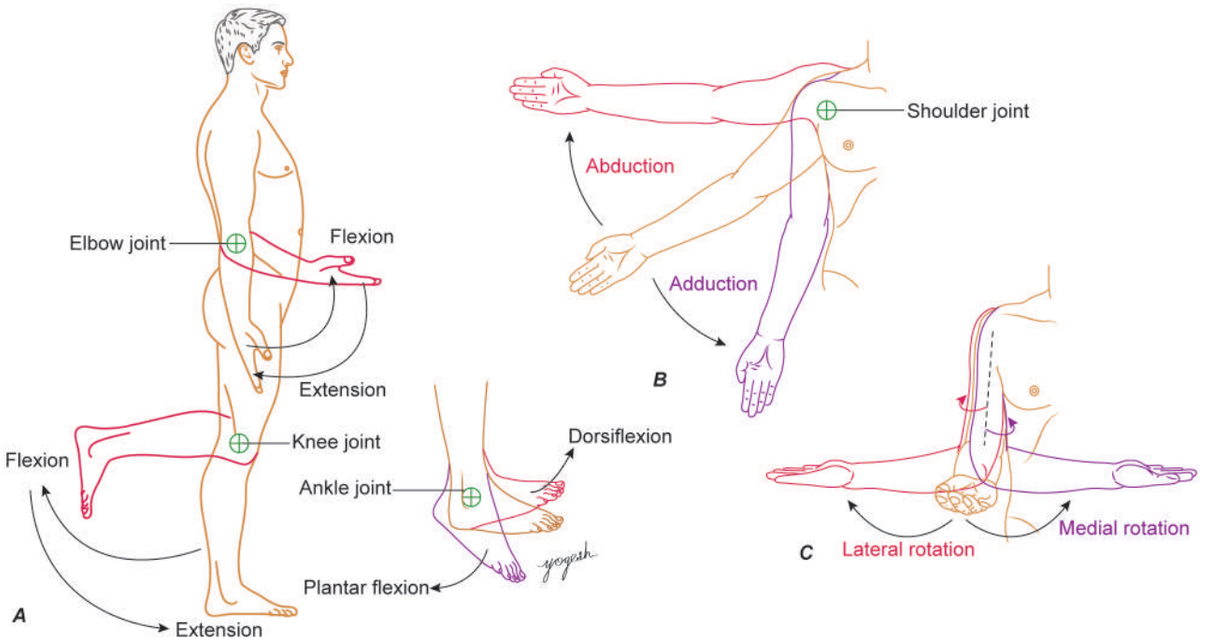


Fig. 2.12: Flexion, extension, adduction, abduction, medial and lateral rotation movements

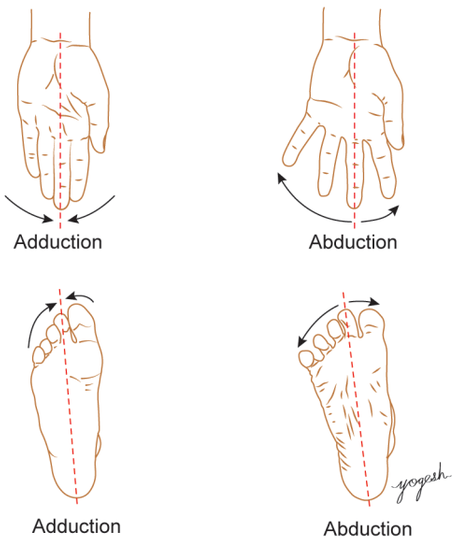


Fig. 2.13: Adduction and abduction of fingers and toes (red dotted line indicates axis of movements)

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

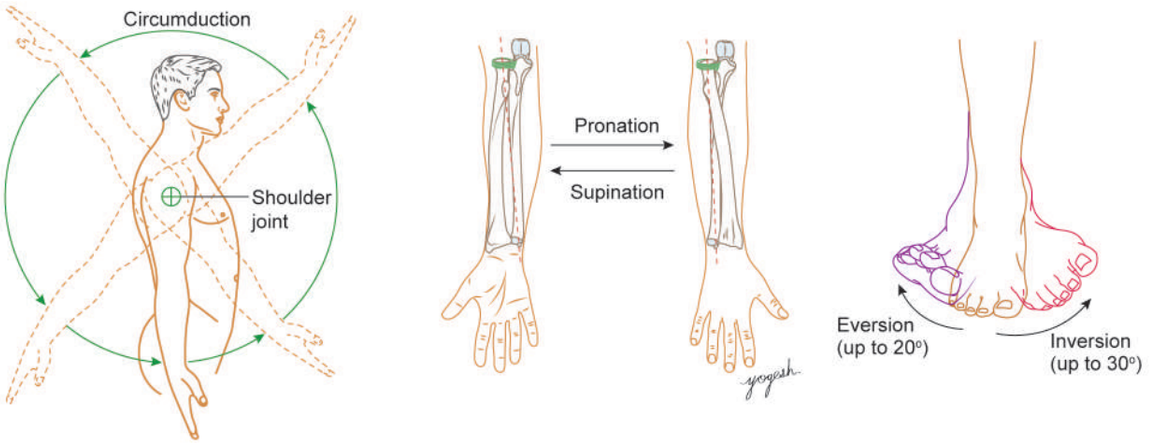


Fig. 2.14: Circumduction, supination, pronation of forearm, inversion, and eversion of foot

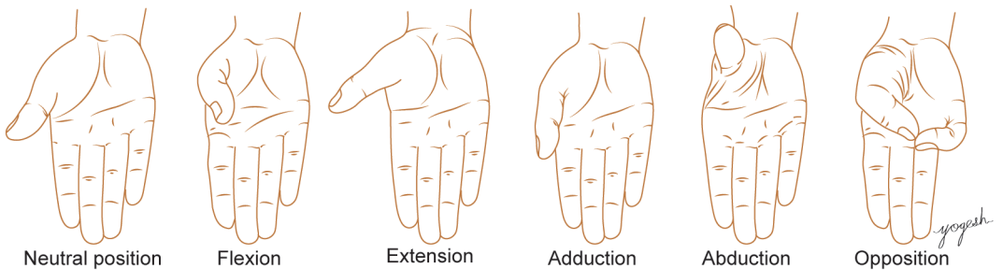


Fig. 2.15: Movements of first carpometacarpal joint (right)

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. appendicectomy (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.

Chapter

3

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.

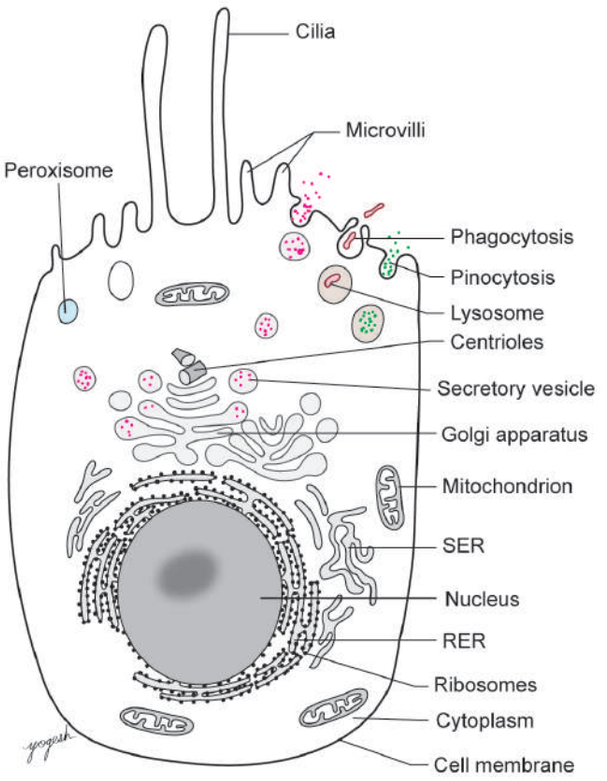


Fig. 3.1: The cell and cell organelles (practice figure)

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

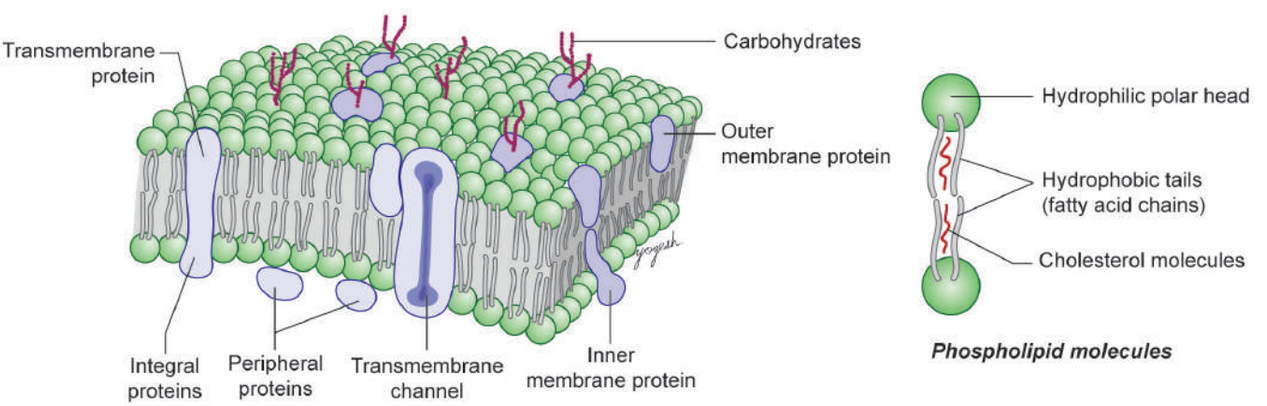


Fig. 3.2: Structure of cell membrane

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 posttransitional 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 → proteins)
  - *Checkpoint*: rER destroys defective proteins.

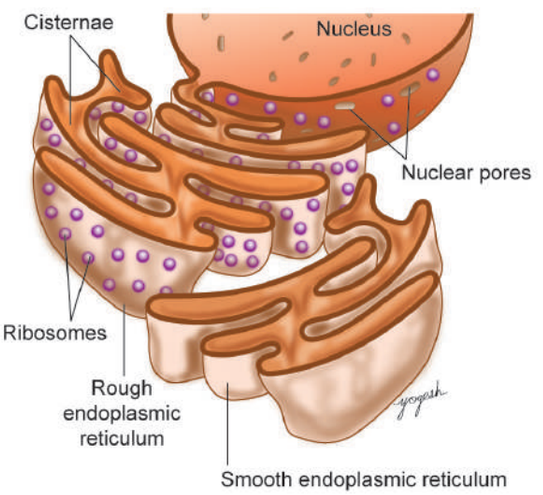


Fig. 3.3: Endoplasmic reticulum

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.

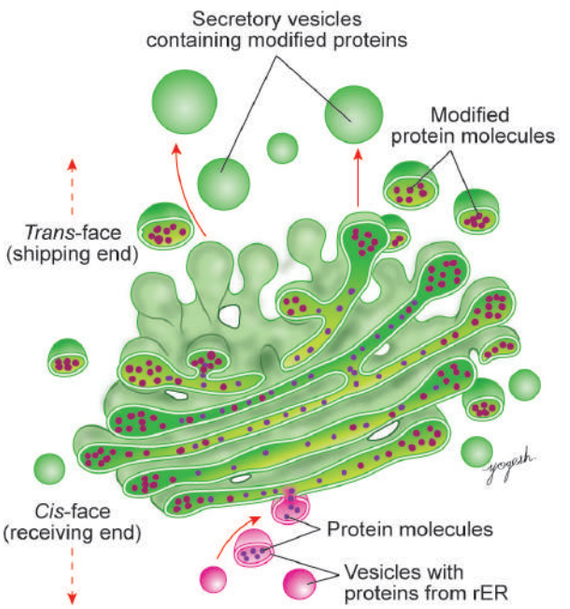


Fig. 3.4: Golgi apparatus

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 phosporylation 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).

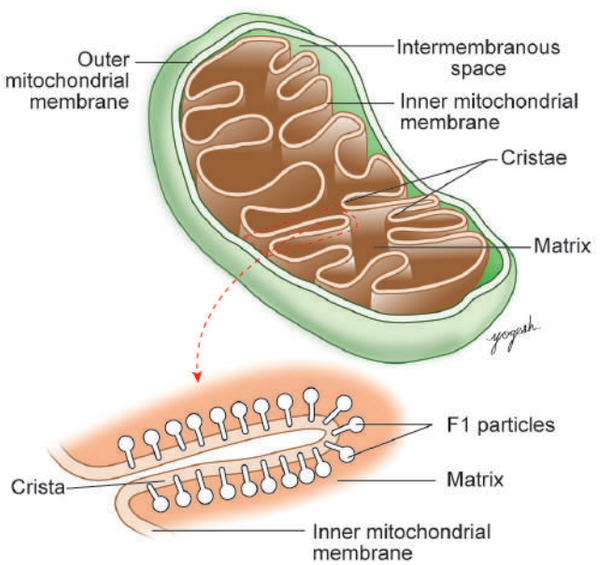


Fig. 3.5: Mitochondrion

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.

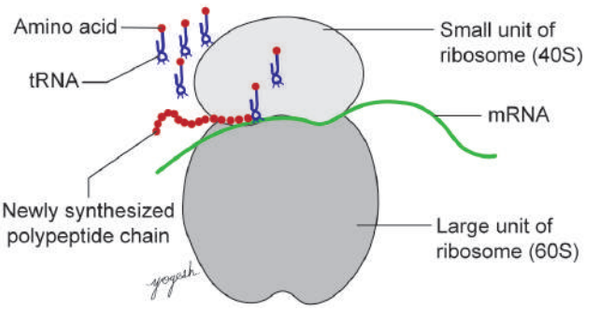


Fig. 3.6: Ribosome

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.

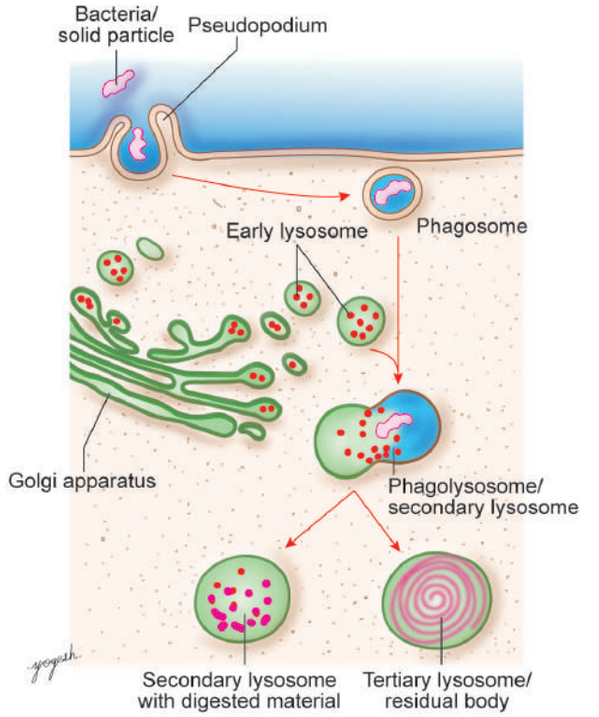


Fig. 3.7: Role of lysosome

- 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.

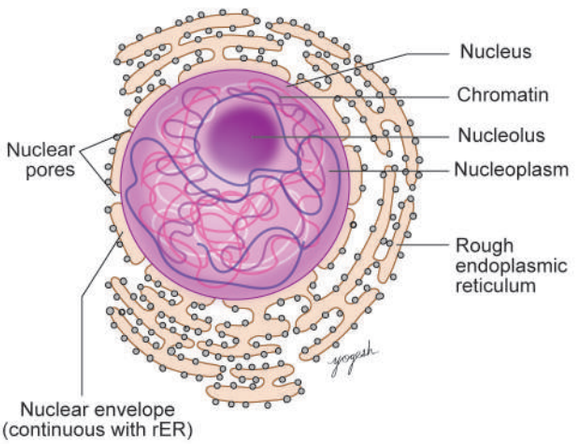


Fig. 3.8: Structure of nucleus

- *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 DNAI1 genes. It is also associated with situs invertus.
- 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.

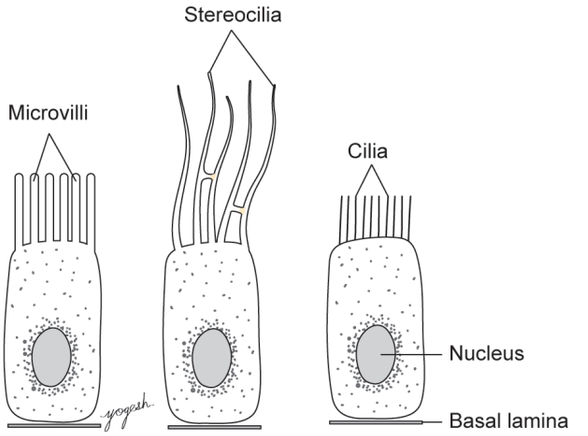


Fig. 3.9: Microvilli, stereocilia, and cilia (practice figure)

- *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 ciliated 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.

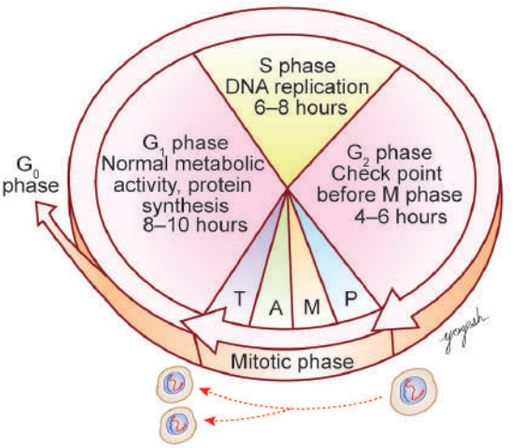


Fig. 3.10: Phases of cell division. *Abbreviations*: P: Prophase; M: Metaphase; A: Anaphase; T: Telophase

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.

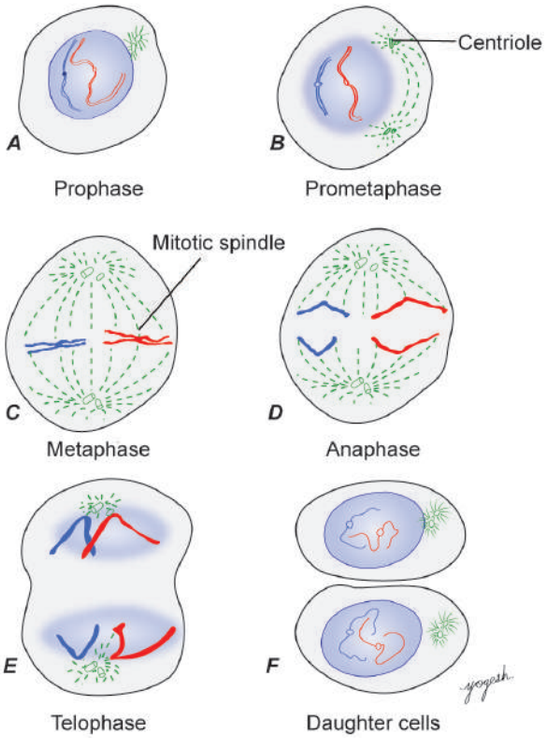


Fig. 3.11: Phases of mitosis

- *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 *equational* division	It is a reductional division
Prophase	No crossover of genetic material No synapsis	Crossover of genetic material takes place Synapsis occurs in zygotene phase
Metaphase	No chiasmata formation Chromosomes arrange at the equator	Chiasmata 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

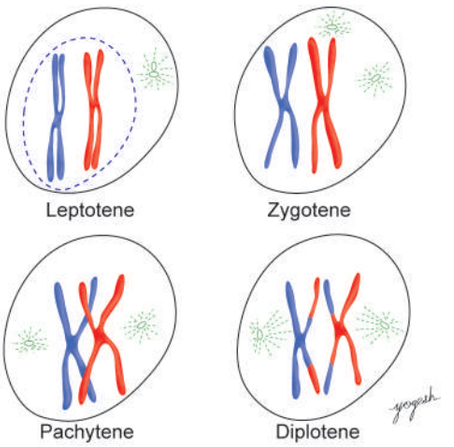
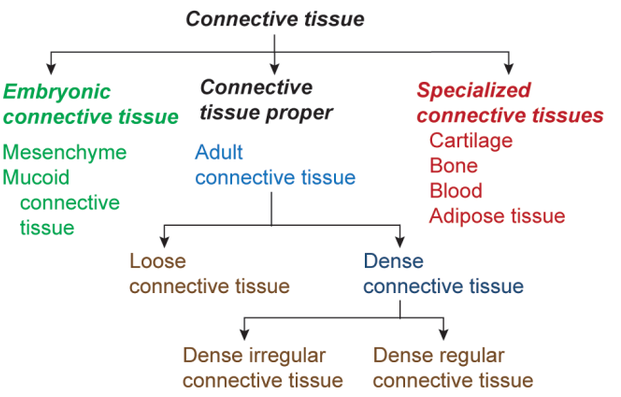


Fig. 3.12: Stages of prophase of first meiotic division

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.

Chapter

4

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

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

Types of Skeleton

- The components of skeleton are grouped into two types:
  1. Axial skeleton
  2. 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):
  1. *Skull*: It is made up of cranial and facial bones. It protects brain, eyes, ear, nose, and oral cavity structures.
  2. *Auditory (ear) ossicles*: These are three small bones in the middle ear: Incus, malleus, and stapes (the smallest bone).
  3. *Hyoid bone*: It is located in the neck, just above the larynx and below the mandible (lower jawbone)
  4. *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).
  5. *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):
  1. *Pectoral girdle*: It consists of scapula and clavicle or collar bone.
  2. *Bones of upper limbs*: They include 1 humerus, 1 radius, 1 ulna, 8 carpal bones, 5 metacarpals, and 14 phalanges.
  3. *Pelvic girdle*: It consists of two hip bones (right and left).
  4. *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.

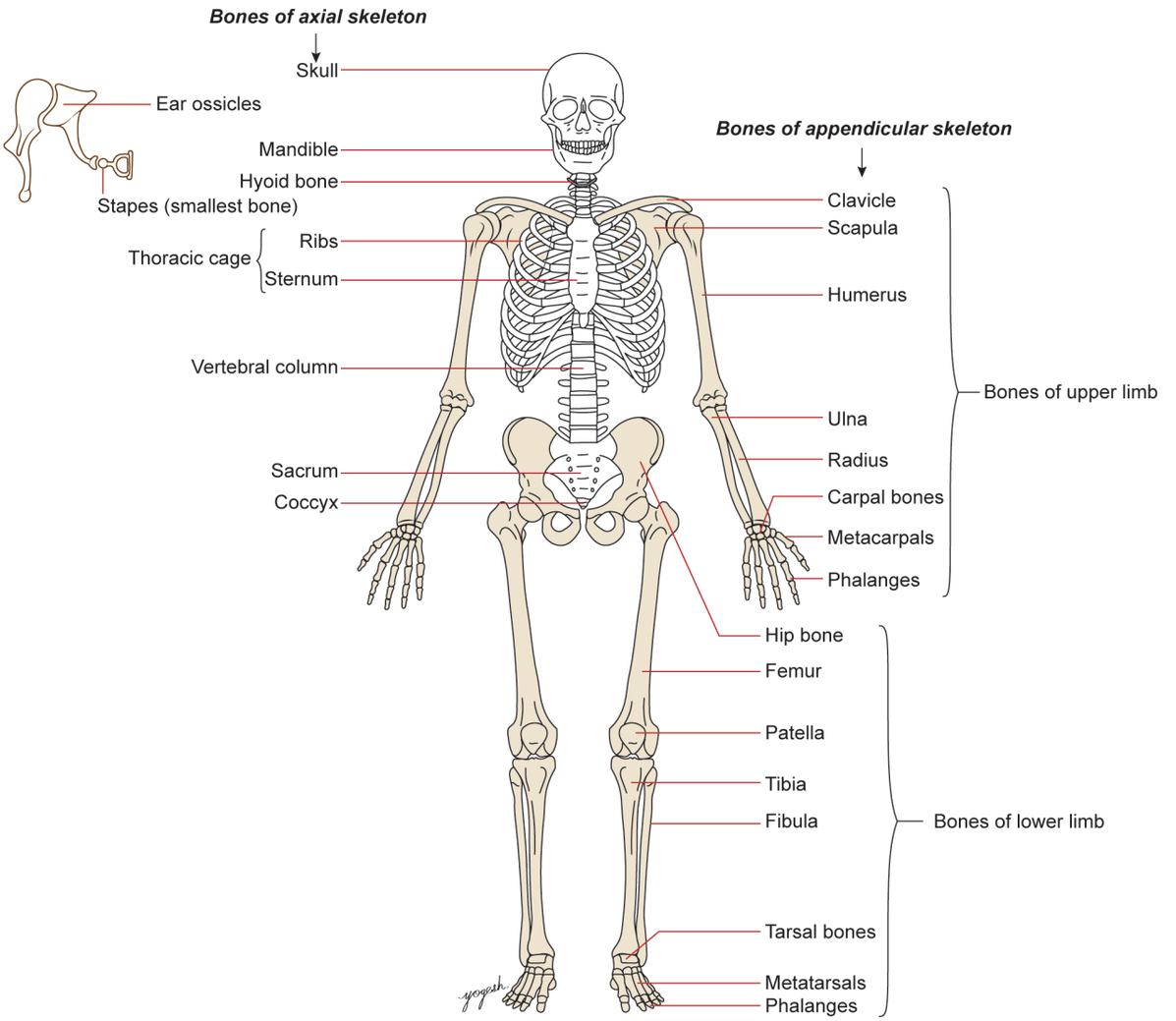


Fig. 4.1: Bone of axial and appendicular skeleton

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.

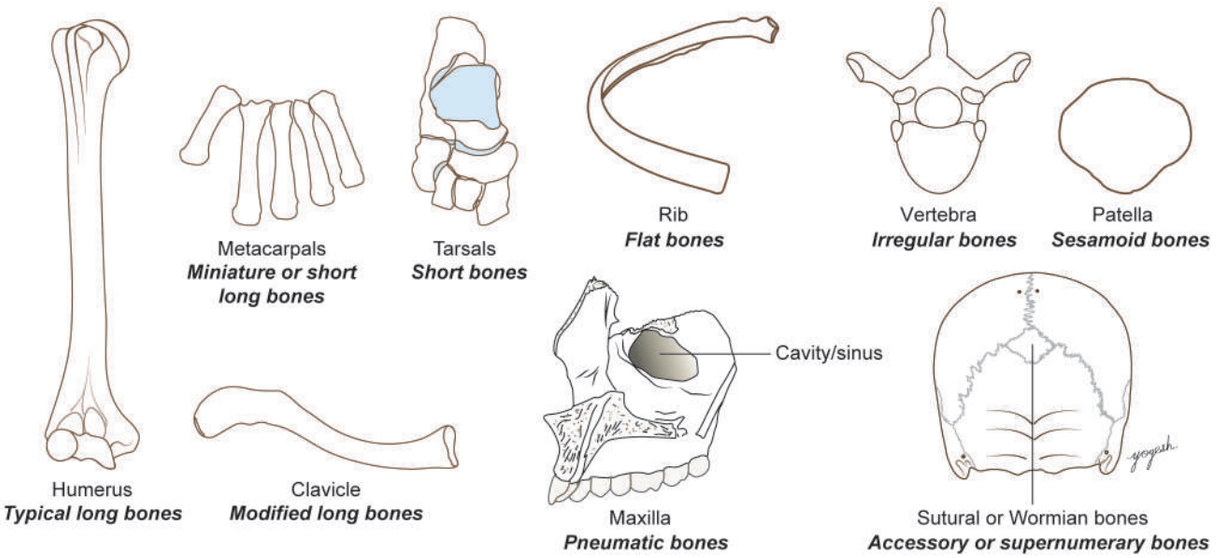
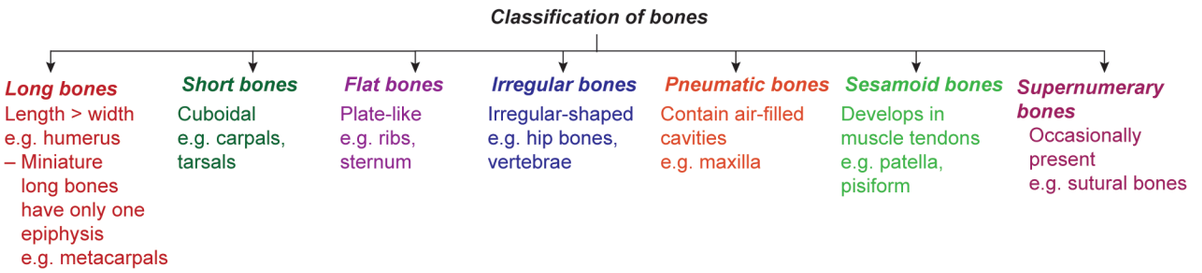


Fig. 4.2: Types of bones based on their shapes

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*

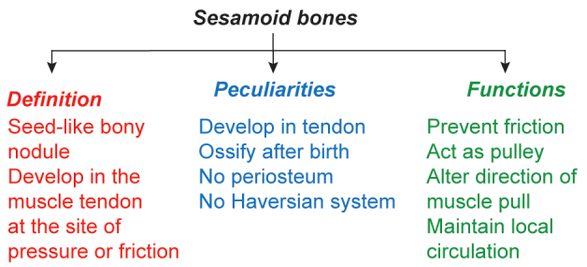
- These contain air-filled spaces or cavities.
- These are located around the nasal cavity.
- *For example*: Maxilla, frontal bone, sphenoid, and ethmoid bones. The air-filled cavities in these bones are called paranasal air sinuses.

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



Examples: Patella, pisiform, fabella, rider's bone

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 trigonium.
- 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):
    1. *Compact bones* do not have visible cavities.
    2. *Cancellous bones* (spongy or trabecular bones) have visible cavities.
  - **B.** ***Microscopic classification*** (examination under microscope):
    1. *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.
    2. *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):
  - A. *Pressure lamellae* which are arranged parallel to the line of weight transmission.
  - B. *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.

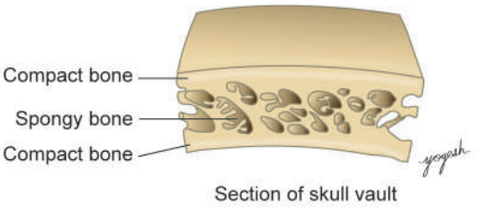


Fig. 4.3: Compact and spongy bones

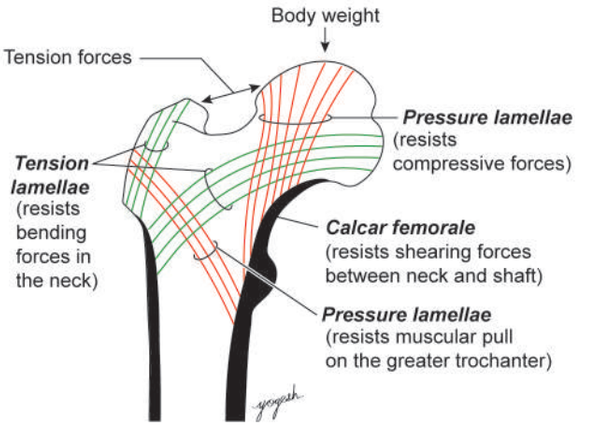


Fig. 4.4: Pressure and tension lamellae and calcar femorale (coronal section of the upper end of femur)

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):
  1. Epiphysis
  2. Epiphyseal or growth plate
  3. Metaphysis
  4. 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:
  1. *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.

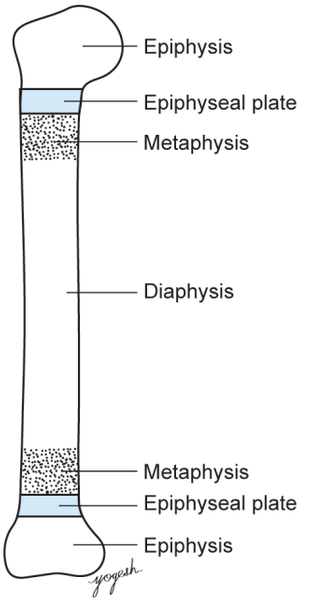


Fig. 4.5: Parts of young or growing long bone

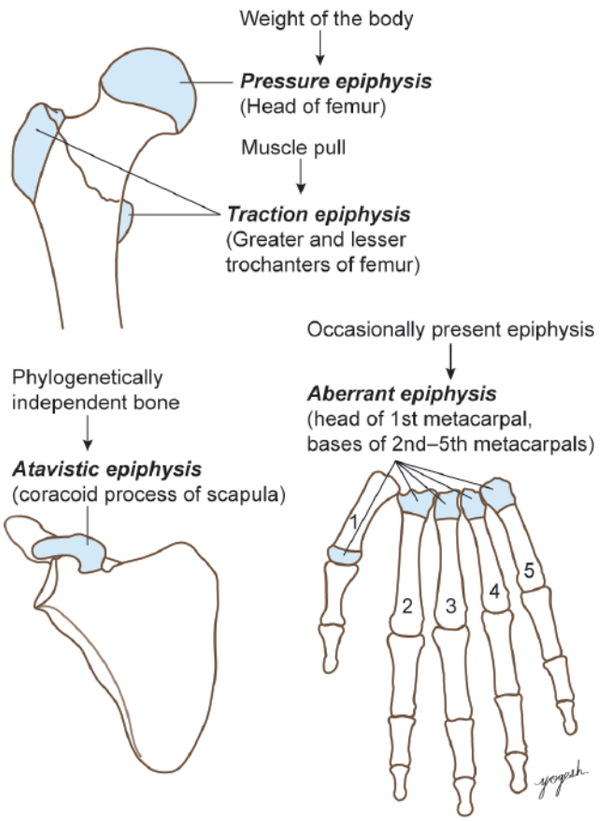
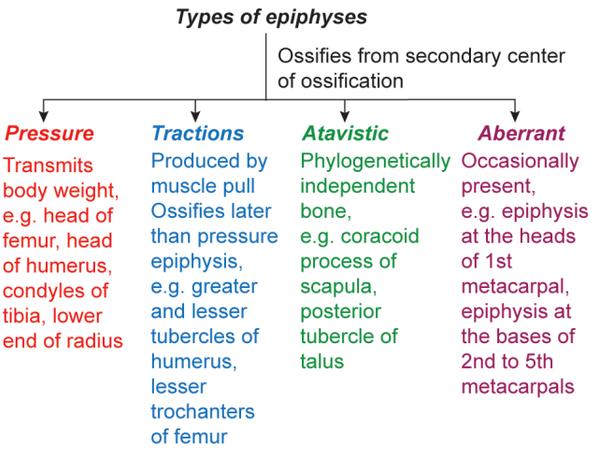


Fig. 4.6: Types of epiphyses. A: Pressure and traction epiphyses, B: Atavistic epiphysis, D: Aberrant epiphysis

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 metaphysis 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.