Section

1

General Anatomy

1. Introduction to Anatomy and Anatomical Terms
2. General Anatomy

Chapter

1

Introduction to Anatomy and Anatomical Terms

Competency achievement: The student should be able to:
AN: 1.1

Objectives

- To define human anatomy and to document the history of anatomy
- To list the subdivision of the anatomy
- To define the anatomical position and to list the anatomical planes
- To list the anatomical terms used to relating the body parts, related to muscles, vessels, movements and bones
- To list the basic clinical terminologies which are essential in understanding the case scenarios
- To explain the molecular organization of the human body
- To list the human body system and body cavities
- To know the methods of human body (cadaver) preservation for teaching gross anatomy

Human anatomy is the science concerned with the structure of the human body. The term 'anatomy' is derived from the Greek word meaning "to cut up" ("*ana*," meaning "up," and "*tome*," meaning "a cutting"). The dissection of cadavers (dead bodies) has served as the basis for understanding the structure and function of the human body. Most of the terms that form the language of anatomy are of Greek or Latin derivations. In the past, human anatomy was an academic, descriptive science primarily concerned with identifying and naming body structures. Although dissection and description form the basis of anatomy, **the importance of human anatomy is in its functional approach and clinical applications**. Human anatomy is a practical, applied science that provides the foundation for understanding physical performance and body health. Knowledge of the structure of the human body from what can be seen with the necked eye (gross anatomy) down to the molecular level is fundamental to understand the body function and how both structure and function are modified by disease. Anatomy teaching in medical schools has been traditionally based around the use of human cadaveric specimens, either taking the whole-body specimens for complete dissection or as prosected specimens. Of late more emphasis are given to identify the human body structure using radiology technique and looking at the cellular level in microscopic anatomy. We shall explore the human body using all these methods wherever they are applicable.

HISTORY OF ANATOMY

The study of anatomy goes back over 2,000 years, to the Ancient Greeks. The systematic study of anatomy was started by Greek scientists Alcmaeon and Empedocles. Alcmaeon was said to be the first person to dissect the human body and first to propose that the brain is the center of intelligence. During third century B.C.E, the Greek anatomists, **Erasistratus and Herophilus** started first scientific studies designed to discover the workings of human anatomy. It was said that they were performing the dissection on bodies of convicted criminals. During second century **Galen**, a physician from Rome contributed immense information about human body. His most important discovery was that arteries carry blood although he did not discover circulation. He identified 7 of the

12 cranial nerves and proposed that urine is formed in the kidney, not in the bladder.

During 8th to 14th century the quest for new knowledge became stagnant because of the belief that *God knows best, and so He should—since He created everything.* During 15th century many breakthroughs helped in understanding the human body and function. **Leonardo da Vinci**, Italian Renaissance artist (1452–1519) began a series of anatomical drawings depicting the ideal human form. He also made a picture closely resembling an unborn baby in the womb with the correct attachment of the umbilical cord.

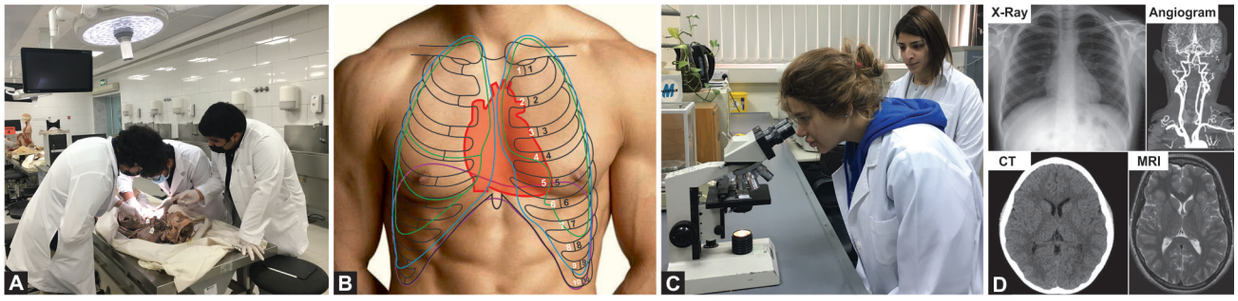
Andreas Vesalius was an anatomist and physician, born in 1514 is considered as **father of modern anatomy**. He wrote the "De humani corporis fabrica" (on the structure of the human body) which challenged traditional knowledge of human anatomy which are based on Galen's findings. This book was the first accurate description of the interior of the human body. **William Harvey** (1578–1657), an English physician described the circulation of the blood. During mid-17th century, the study of human anatomy enormously improved with the invention of the compound microscope by **Robert Hooke**. The viewing of cell structures and physiological processes were no longer limited to the naked eye. During 18th century dissection became a recognized punishment for the worst criminals. The dissections performed on hanged bodies were kept for public exhibition. **Sir Henry Gray** was a British anatomist and surgeon most notable for publishing the book Gray's Anatomy. At present, his book is considered as the most authoritative in medical science. During 19th century the study of anatomy of humans and animals further improved with the advancement of histology and developmental biology. In recent past the advances in radiological techniques have permitted researchers to make remarkable connections between anatomy and physiology. This also have allowed them to integrate and relate the study of anatomy with other medical disciplines.

SUBDIVISION OF HUMAN ANATOMY

1. **Gross anatomy:** It is the study of structures of a cadaver that can be observed with naked eye (Fig.1.1A). The study of gross anatomy may involve dissection or noninvasive methods. The aim is to collect data about the larger structures of organs and organ systems. In dissection, the scientist cuts open the human cadaver and examines its organs. Medical and dental students perform dissection as part of their practical work in gross human anatomy during their studies. Of late emphasis are made on living anatomy using techniques like endoscopy, where an endoscope is inserted through mouth or nasal cavity or anal canal to visualize the gastrointestinal tract.
2. **Surface anatomy:** It deals with surface features of the body that can be observed or palpated (felt firmly). It is often neglected part of anatomy as we focus more on studying the internal anatomy. A knowledge of surface anatomy is essential to one's competence in many procedures such as cardiopulmonary resuscitation, surgery, physical therapy, taking X rays and electrocardiograms, giving injections, drawing blood, listening to heart and respiratory sounds, measuring the pulse and blood pressure, and finding pressure points to stop arterial bleeding, among other procedures (Fig.1.1B).
3. **Microscopic anatomy**: It deals with the study of structures with the help of a microscope. The cytology (study of cells) and histology (study of tissues) are specialties of anatomy that have provided additional understanding of the structure and function of the human body. Certain cells/tissues can be stained by certain dyes (vital stains) which colour selectively the elements in the cell. By looking at tissue under the microscope, one can learn about the architecture of the cells (Fig.1.1C). For example, if a person has cancer, examining the tissue under the microscope will reveal how the cancer cells are acting and how they affect normal human tissue. Histology involves studying tissues and cells using histological techniques such as sectioning and staining, and then looking at them under a light or electron microscope. This will be discussed in a separate section.
4. **Radiological anatomy:** It involves the study of anatomical structures as they are visualized by X-rays, ultrasound scans or other specialized procedures (CT/MRI scans) performed on living body. In contrast X-ray, radiopaque substances can be ingested or injected for visualizing internal organs. Angiography involves making a radiograph after injecting a dye into the blood stream. Since radiographs compress the body image with an overlap of organs and tissues, diagnosis is often difficult. The computerized axial tomography technique (CT or CAT scans) has greatly enhanced the versatility of X-rays, using a computer to display a cross-sectional image similar to that which could only be obtained in an actual section through the body. Magnetic resonance imaging (MRI) and positron emission tomography (PET) are the other techniques used to observe the organ structures of the body. Most clinicians view internal anatomy with the aid of radiographic images and procedures. Proper interpretation of these images requires a detailed knowledge of anatomy (Fig.1.1D).

5. **Surgical anatomy:** To the surgeon knowledge of gross anatomy is of paramount and permanent importance. Precise incision on various parts of the body, relations of viscera and their vascularity and endoscopic procedure requires sound knowledge of anatomy (Fig.1.1E). Surgical anatomy studies anatomical landmarks important for surgical procedures. It is the application of anatomy in surgical diagnosis, and treatment.

6. **Developmental anatomy (embryology):** It deals with the study of prenatal stages of human development. The series of dynamic events unfolding from the time of fertilization to the birth of new individual. It is helpful in understanding the adult anatomy and congenital anomalies (birth defects). Understanding of human development resulted in development of new techniques for prenatal diagnosis and treatments (Fig.1.1F).



Gross anatomy: cadaveric dissection | Surface anatomy | Microscopic anatomy/ histology | Radiological anatomy

Surgical anatomy | Developmental anatomy

Fig. 1.1 A to F: Branches of human anatomy

ANATOMICAL TERMS

Though we are familiar with the common terms of many parts and regions of our body, it is essential that we use internationally accepted anatomical names/ terms.

Body Positions

The following are the positions/postures of the human body during clinical examination/cadaver dissection/ anatomical description.

Anatomical position: All descriptions of the human body are based on the assumption that the person is (Fig.1.2):

- Standing erect
- Eyes look straight to the front
- Upper limbs are by the sides of the body and palms facing forward
- Lower limbs are together and digits (toes) pointing forward

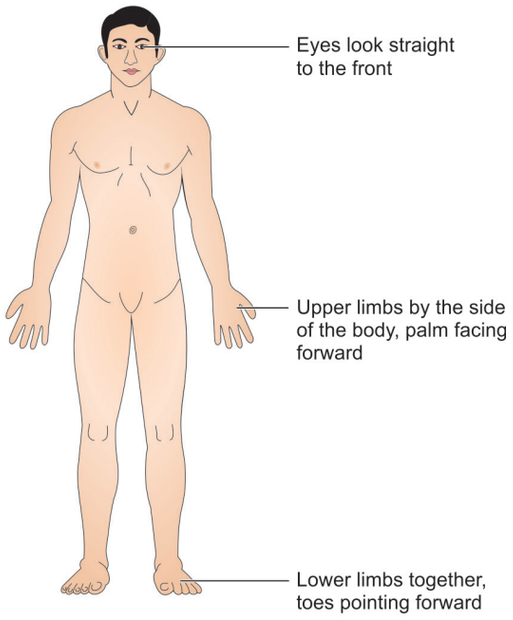


Fig. 1.2: Anatomical position

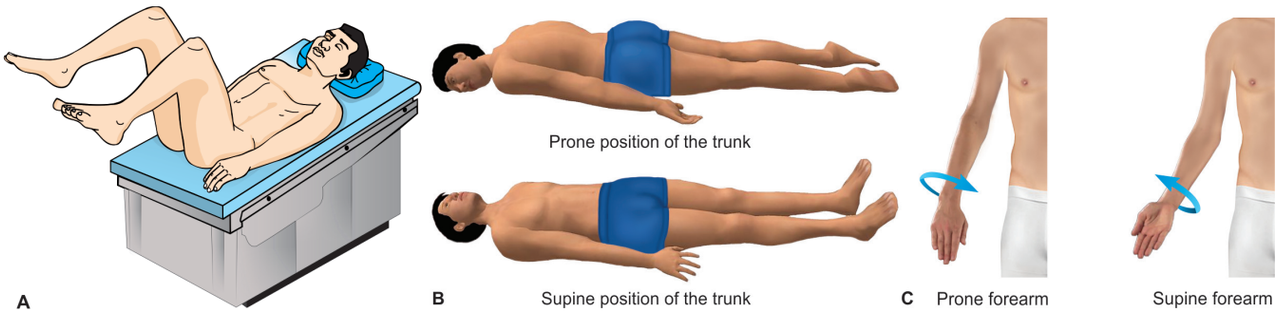


Fig. 1.3: Other types of body positions: **A:** Lithotomy position; **B:** Supine and prone position of the trunk; **C:** Supine and prone position of the forearm

Supine position: The person is lying down on back with the face directed upwards (Fig.1.3).

Prone position: The person is lying down facing the ground (Fig.1.3).

Lithotomy position: The person is lying down on his back with fully flexed (knees pointing to the roof) and abducted (widely spread) thighs.

Anatomical Planes

These are imaginary planes (lines) that cut through the body when it is in anatomical position. They help in identifying and studying the relative position of a structure/organ in relation to one another. They further help us in making precise surgical incisions (Fig. 1.4).

- **Median Plane:** It is an imaginary vertical/sagittal plane passing longitudinally through the middle of the body from front to back, dividing it into two equal halves. It is also called mid-sagittal plane.
- **Sagittal Planes:** These are imaginary vertical planes passing through the body parallel to the median plane. These planes are also referred as lateral planes or parasagittal planes.
- **Coronal Planes:** These are imaginary planes passing through the body at right angle to the median plane, dividing it into anterior (front) and posterior (back) portions. It is also referred as frontal plane.
- **Horizontal Planes:** These are imaginary planes passing through the body at right angles to both the median and coronal planes. This plane is parallel to the ground. This plane divides the body into superior (upper) and inferior (lower) parts. This plane is also referred as transverse or axial plane.
- **Oblique Planes:** Any plane other than those mentioned above, they slant or deviate from the other planes.

Terms of Relationship

Superior (cranial): Nearer to the head.
Inferior (caudal): Nearer to the feet. This relationship uses horizontal plane (Fig. 1.5).

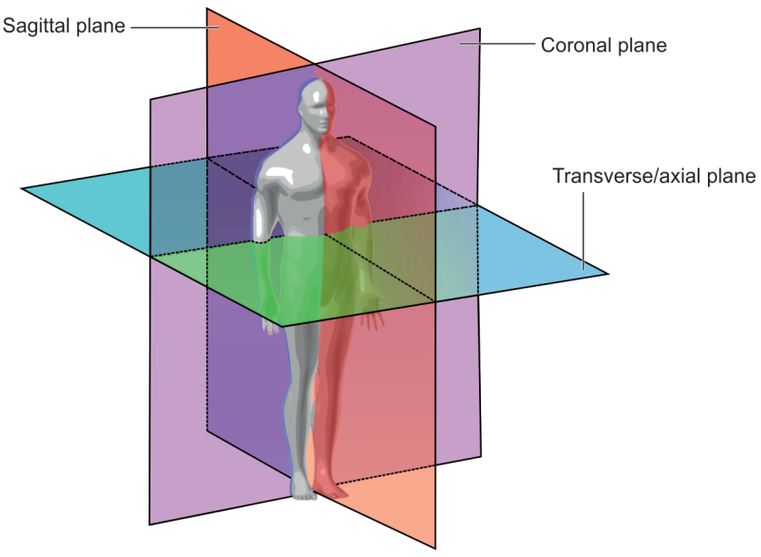


Fig. 1.4: Anatomical planes

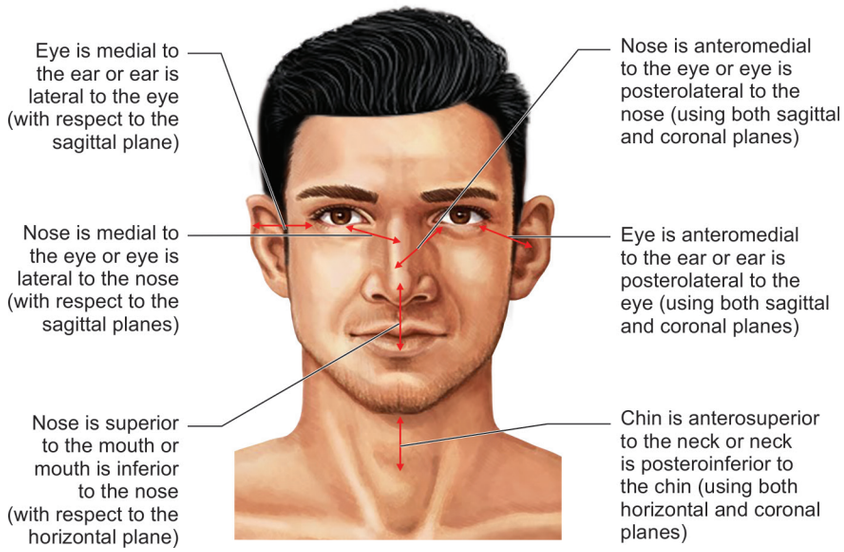


Fig. 1.5: Anatomical terms of relations

For example, the head is superior (above) to the neck. The abdomen is inferior (below) to the thorax/chest.

Anterior (ventral): Nearer to the front.

Posterior (dorsal): Nearer to the back. This relationship uses coronal plane.

For example, the nose is anterior to the eyes. The ear is posterior to eyes (when compared through coronal plane).

Medial: Nearer to the median plane.

Lateral: farther (away) from the median plane. This relationship uses sagittal or parasagittal planes.

For example, the nose is medial to the eye. The eye is lateral to the nose (when compared through median or sagittal planes).

Further using these terminologies more precise relationship between the structures can be described using combination of sagittal, coronal and horizontal planes .

For example, nose is anteromedial to the eye. The ear is posterolateral to the eye.

Intermediate—means between—your heart is intermediate to your lungs.

There are also terms that describe specific body parts. Palmar describes the palm side of the hand. Dorsal describes the back side of the hand. Plantar describes the bottom of the foot.

Terms of Comparison

Compare the relative positions of two structures with each other.

Proximal: Nearer to the trunk/point of origin.

Distal: Away from the trunk/point of origin.

For example, the elbow is proximal to the hand, while the hand is distal to the forearm (Fig.1.6A).

Superficial: Nearer to/on the surface.

Deep: Farther from the surface (Fig.1.6B).

For example, skin is superficial to fascia, while the muscles are deeper to the fascia.

External: Towards/on the exterior.

Internal: Towards/in the interior (Fig.1.6C).

For example, the heart is externally covered by pericardium and internally covered by endocardium.

Central: Nearer to/towards the center.

Peripheral: Away from the center.

For example, the inferior vena cava passes through central part of the diaphragm. The peripheral part of the diaphragm is mainly attached to the rib cage.

Parietal: External wall of a body cavity.

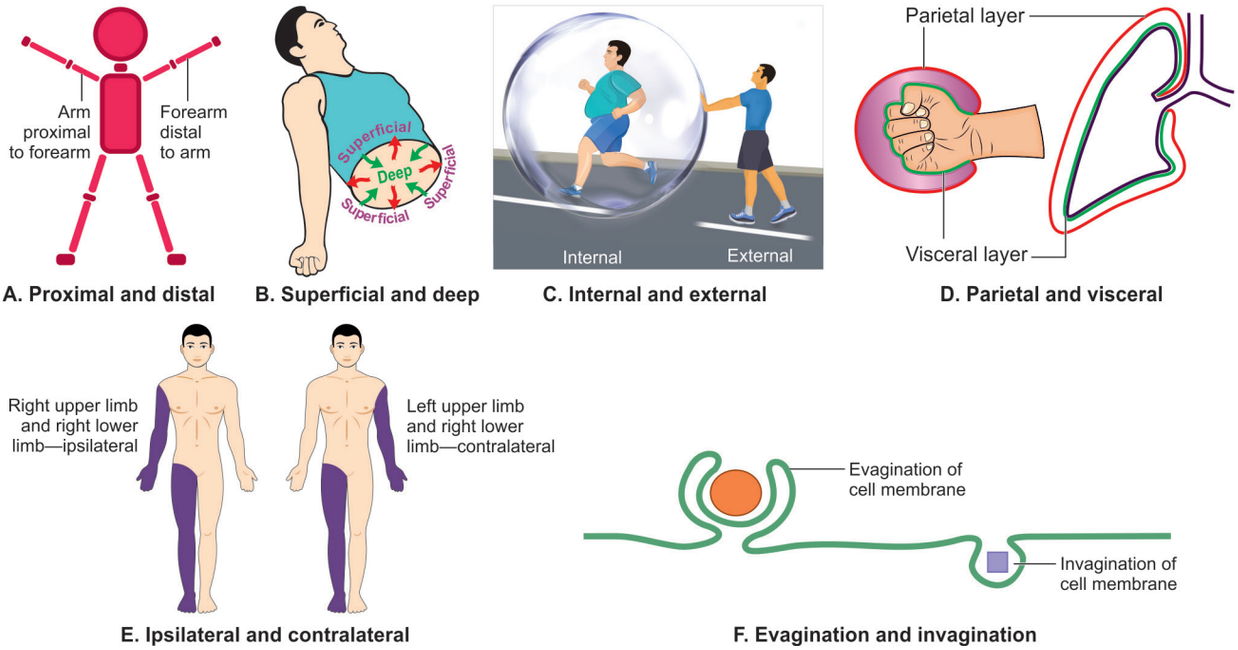
Visceral: Pertaining to covering of an organ (Fig.1.6D).

For example, the pleura has an outer/external parietal layer and an inner visceral layer with pleural cavity between them.

Ipsilateral: On the same side of the body.

Contralateral: On the opposite side of the body (Fig.1.6E).

For example, the ipsilateral limbs are affected means right (or left) upper limb and right (or left) lower limb are affected. Contralateral refers to when right (left) upper limb and left (right) lower limb are affected.



A. Proximal and distal | B. Superficial and deep | C. Internal and external | D. Parietal and visceral

E. Ipsilateral and contralateral | F. Evagination and invagination

Fig. 1.6: Anatomical terms of comparison

Evagination: Outward bulging of the wall of a cavity.

Invagination: Inward bulging of the wall of a cavity. This is often referred to the activity of cytoplasmic membrane (Fig.1.6F).

Terms Describing Movements at Joints

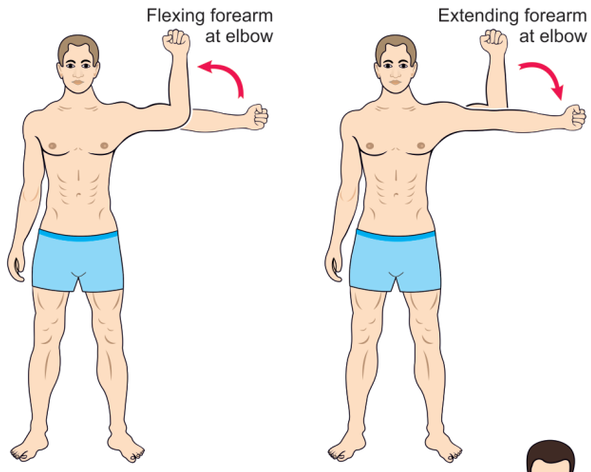
- **Flexion:** Bending/making a decreasing angle between the bones or parts of the body. In this movement there is an approximation of flexor surfaces (Fig. 1.7A and B).
- **Extension:** Straightening of a bent part or making an increasing the angle between bones of the body. In this movement there is an approximation of extensor surfaces (Fig. 1.7A and B).
- **Abduction:** Moving away from the median plane (Fig. 1.7C and D).
- **Adduction:** Moving toward the median plane (Fig. 1.7C and D).
- **Rotation:** Moving around the long axis.
- **Medial rotation:** Inward rotation (Fig. 1.7E).
- **Lateral rotation:** Outward rotation (Fig. 1.7E).
- **Circumduction:** Circular movement combining flexion, abduction, extension and adduction.
- **Eversion:** Raising the lateral border of the foot.
- **Inversion:** Raising the medial border of the sole of the foot.
- **Pronation:** Rotation of the forearm so that the palm is turned backwards (Fig. 1.7F).
- **Supination:** Rotation of the forearm so that the palm is turned forwards (remember in anatomical position).
- **Dorsiflexion:** Forefoot is raised and the angle between the front of the leg and dorsum of the foot is reduced (Fig. 1.7G).
- **Plantar flexion:** The forefoot is depressed and the angle between the front of the leg and dorsum of the foot is increased (Fig. 1.7G).
- **Protrusion:** Moving anteriorly (forward) (Fig. 1.7H).
- **Retraction:** Moving posteriorly (backward) (Fig. 1.7H).

Terms Related to Muscle

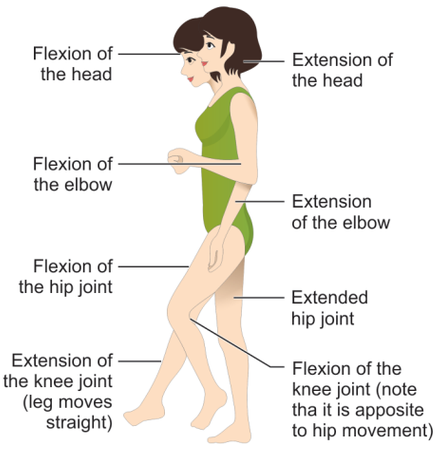
- **Origin:** It is the end of the muscle, which is fixed and shows relatively less movement during contraction.
- **Insertion:** It is the end of the muscle, which shows relatively more movement during contraction. The origin of the muscle is considered as proximal attachment and insertion as distal attachment (Fig. 1.8).
- **Belly:** The fleshy and contractile part of a muscle.
- **Tendon:** The fibrous, non-contractile part of the muscle.
- **Aponeurosis:** The flattened, sheet of dense conective tissue, which attaches the muscles to the bone/skin.
- **Raphe:** A fibrous band made up of interdigitating aponeurotic fibers of the muscles.

Terms Related to Blood Vessels

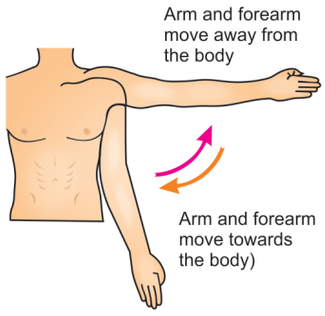
- **Arteries:** They carry oxygenated blood away from the heart. They are thick-walled structure with small lumen (Fig. 1.9A and B).



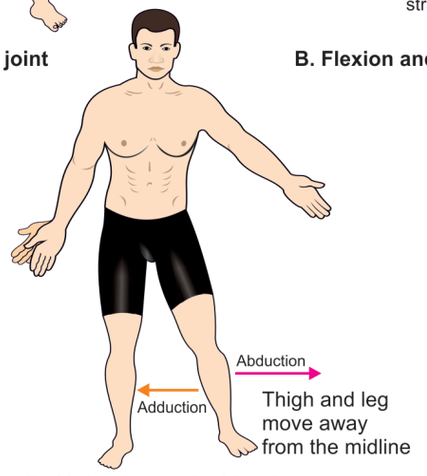
A. Flexion and extension at the elbow joint



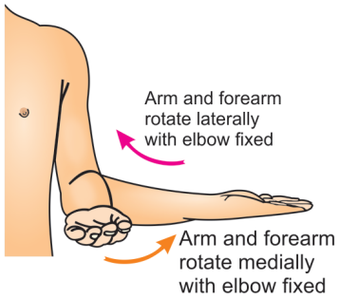
B. Flexion and extension at various joints of the body



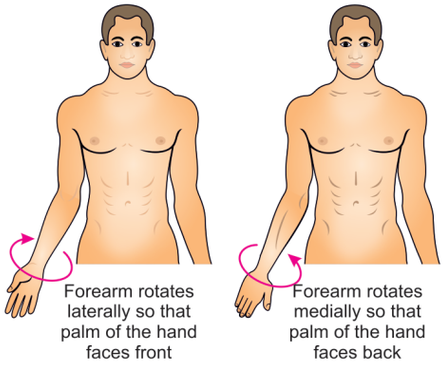
C. Adduction and abduction at the shoulder joint



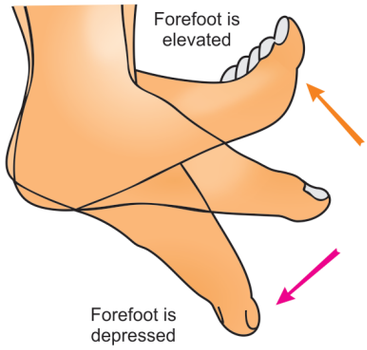
D. Abduction and adduction at the hip joint



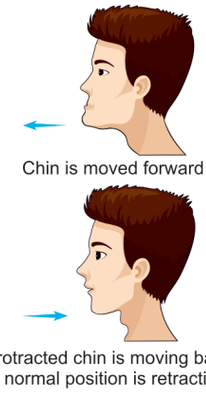
E. Medial (internal) and lateral (external) rotation of the shoulder joint



F. Supination and pronation movements of the forearm occurring at the radioulnar joints



G. Dorsiflexion and plantar flexion of the foot joints



H. Protraction and retraction of the lower jaw at the temporomandibular joint

Fig. 1.7: Anatomical terms describing the movements at the joints of the body

- **Veins:** They carry deoxygenated blood towards the heart. They are thin-walled structure with comparatively large lumen (Fig. 1.9A and B). Valves are the structures inside the veins/heart which maintain unidirectional blood flow.
- **Arterioles:** These are the smallest branches of the arteries within the tissue (with diameter 100 mm or less).
- **Venules:** These are the minute vessels in the tissue, which join to form vein.

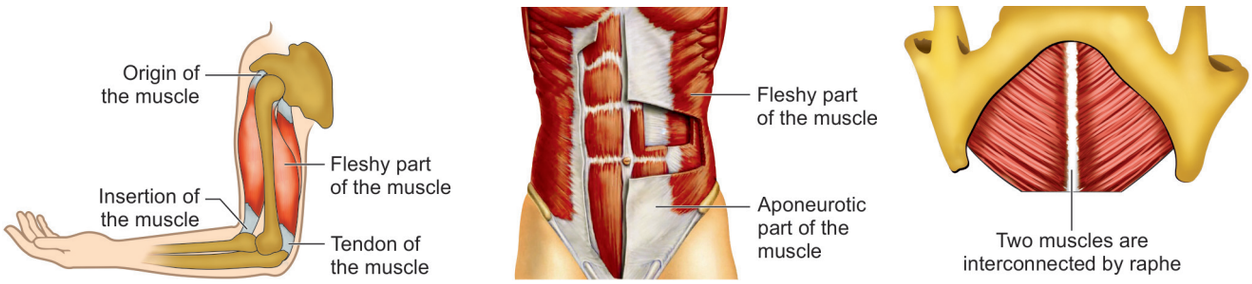


Fig. 1.8: Anatomical terms related to the skeletal muscle

- **Capillaries:** These are microscopic vessels connecting arterioles to venules.

The umbilical artery and pulmonary artery are exceptions, which carry the deoxygenated blood. The pulmonary vein and umbilical vein carry oxygenated blood.

The terms related to the joints, lymphatic and nervous systems are discussed in the next chapter (General Anatomy).

Terms Related to Lymphatic System

Lymph: It is also called lymphatic fluid which is a collection of the extracellular fluid derived from blood plasma. The fluid drains from cells and tissues (that is not reabsorbed into the capillaries). The fluid also contains white blood cells (lymphocytes).

Lymphatic vessels: These are the network of capillaries (microvessels) and a large network of tubes located throughout your body that transport lymph away from tissues.

Lymph nodes: They are bean-shaped glands that monitor and filter the lymph and produce lymphocytes.

Terms Related to Bones

Terms related to articulations

Condyle: A rounded knob that articulates with another bone, example occipital condyles of skull or condyles of the femur.

Facet: A smooth, flat, slightly concave or convex articular surface, eample articular facets of the vertebrae.

Head: The prominent expanded end of a bone, sometimes rounded, example head of femur (thigh one) and humeru (bone of the arm).

Extensions and projections

Crest: A narrow ridge, example iliac crest of pelvis.

Epicondyle: A projection superior to a condyle, example medial epicondyle of the femur.

Line: A slightly raised, elongated ridge, example nuchal lines of the skull.

Process: Any bony prominence, example mastoid process of the skull.

Protuberance: A bony outgrowth or protruding part, example mental protuberance of the chin.

Spine: A sharp, slender, or narrow process, example spine of the scapula.

Trochanter: Two massive processes unique to the femur.

Tubercle: A small, rounded process, example greater tubercle of the humerus.

Tuberosity: A rough elevated surface, example tibial tuberosity.

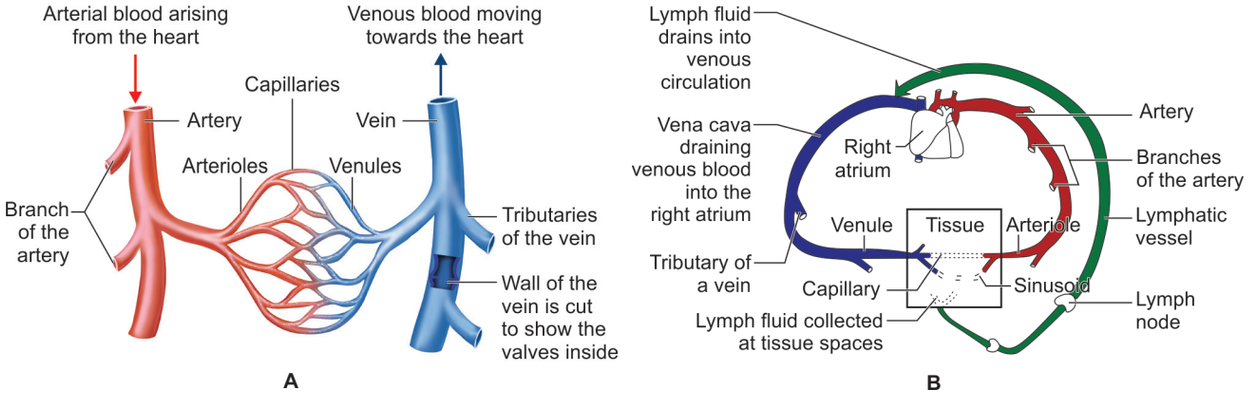


Fig. 1.9: A: Anatomical terms related to the blood vessels; **B:** Anatomical terms related to the blood vessels and lymphatic system

Depressions

Alveolus: A pit or socket, example tooth socket.

Fossa: A shallow, broad, or elongated basin, example andibular fossa.

Fovea: A small pit, for example fovea capitis of the femur.

Sulcus: A groove for a tendon, nerve, or blood vessel, example intertubercular sulcus of the humerus.

Passages and cavities

Canal: A tubular passage or tunnel in a bone, example condylar canal of the skull, or optic canal.

Fissure: A slit through a bone, example orbital fissures behind the eye.

Foramen: A hole through a bone, usually round, example foramen magnum of the skull or small nutrient foramen for th. passage of the blood vessel.

Meatus: An opening into a canal, example acoustic meatus of the ear.

Sinus: A space in a bone, example frontal sinus of the forehead.

Terms Related to Nervous System

Nerve/nerve fibre: It is a cable-like structure within the body designed to conduct nerve impulses that relay information from one part of the body to the other. They are mainly collections of axons of the neurons.

Afferent nerve: Impulses conveyed from periphery to the CNS (sensory nerve).

Efferent nerve: Impulses conveyed from CNS to the periphery (motor nerve).

BASIC CLINICAL TERMINOLOGIES

Throughout this book, you find number of case scenarios which mimics the actual cases which you face in future. Being first year medical students, you are not expected to know the diagnosis and management/treatment. There are number of questions after each case scenarios which you must attempt to answer. These questions signify importance of learning anatomy and its applicability in future. However, while reading the case scenarios you will come across many clinical terminologies which you might not be familiar with. Hence, some of the commonly used clinical terminologies are listed here and this should help you to grasp the case better. However, it is advised to every student keep their own medical dictionary.

- **Abrasion:** A type of open wound that is caused by the skin rubbing against a rough surface.
- **Abscess:** A local accumulation of pus anywhere in the body.
- **Acute:** Sudden but usually short.
- **Aneurysm:** An enlargement (dilatation) of an artery caused by weakness in its wall.
- **Auscultation:** The act of listening to sounds arising within organs (as the lungs or heart) usually using a stethoscope.
- **Avulsion:** An injury in which a body structure is torn off by either trauma or surgery.
- **Biopsy:** Removal of cells or tissues from the body for examination by a pathologist.
- **Blood pressure:** The blood pressure is the pressure of the blood within the arteries. It is produced primarily by the contraction of the heart muscle which ensures that blood is pumped to all tissues adequately.
- **Bradycardia:** It refers to a slow heart rate, when the heart beats less than 60 beats per minute.
- **Cellulitis:** It refers to inflamed or infected tissue beneath the skin.
- **Cyanosis:** A bluish color of the skin and the mucous membranes due to insufficient oxygen in the blood.
- **Ectopic:** It refers to location of a structure (cells/tissues/organs) in the wrong place or out of place.
- **Edema:** Body parts swell from injury or inflammation
- **Embolism:** The obstruction of a blood vessel by a foreign substance or a blood clot that travels through the bloodstream which plugs the vessel.
- **Erythema:** Redness of the skin or mucous membranes, caused by hyperemia (increased blood flow) in superficial capillaries. It occurs with any skin injury, infection, or inflammation.
- **Febrile:** It refers to feverish condition or having a fever. A fever is an abnormally high body temperature, typically as the result of illness.
- **Fibrosis:** Formation or development of fibrous connective tissue as a reparative response to injury or damage.
- **Gestation:** The period (time) between conception and birth.
- **Haemorrhage:** It refers to bleeding.
- **Heart rate:** The number of heart beats per unit of time, usually per minute.
- **Hematoma:** A localized swelling that is filled with blood caused by a break in the wall of a blood vessel.
- **Herniation:** Abnormal protrusion of tissue/organ through a weak area in the body wall or within the body cavity.
- **Hypertension:** It refers to a repeatedly elevated blood pressure.
- **In remission:** The disease which is not getting worse
- **Ischemia:** Inadequate blood supply to a local area due to blockage of blood vessels supplying that area.

- **IV cannula:** Intravenous (IV) cannulation is a technique in which a cannula is placed inside a vein to provide venous access. This venous access allows sampling of blood, as well as administration of fluids, medications.
- **Laceration:** A wound that is produced by the tearing of soft body tissue, which is often irregular and jagged
- **Lesion:** It refers to a wound, sore, or cut.
- **Lump:** A protuberance or localized area of swelling that can occur anywhere on the body. It may be solid, fluid, or gaseous. Lumps may be described as soft and fluctuant, firm or even 'stony hard'. Fluctuation indicates a fluid swelling.
- **Maneuver:** Any form of management or procedure that acts on a patient to evoke a result or outcome.
- **Melanoma:** A form of skin cancer that begins in the cells (melanocytes) that control the pigment in the skin.
- **Metastasis:** The spread of cancer cells from the place where they first formed to another part of the body.
- **Necrosis:** The death of living cells or tissues.
- **Neonate:** A neonate refers to a newborn and the neonatal period is the first 4 weeks of a child's life.
- **Neuralgia:** An intense burning or stabbing pain caused by irritation of or damage to a nerve.
- **Noninvasive:** It refers to a technique or a procedure which does not require entering the body with instruments.
- **Numbness:** A loss of sensation or feeling in a part of your body.
- **Pallor:** A pale color of the skin that can be caused by many facts but most often because of reduced amount of oxyhaemoglobin.
- **Palpation:** It is a method of feeling with the fingers or hands during a physical examination. The health care provider touches and feels your body to examine the size, consistency, texture, location, and tenderness of an organ or body part.
- **Paralysis:** Loss of power of muscle contraction.
- **Percussion:** It is a method of tapping body parts with fingers, hands, or small instruments as part of a physical examination. It is done to determine, the size, consistency, and borders of body organs or presence or absence of fluid in body areas.
- **Phlebotomist:** A person who draws blood for diagnostic tests.
- **Polyp:** A mass or growth of thin tissue.
- **Pulse:** The rhythmic dilation of an artery that results from beating of the heart.
- **Severed:** It refers to divide one structure into two parts or to remove one part or keep apart.
- **Sprain:** An injury to a ligament (stretch or tear) that results from overuse or trauma.
- **Tachycardia:** It refers to a heart rate over 100 beats per minute.
- **Tachypnea:** It refers to fast, shallow breathing, which can be due to a lack of oxygen or too much carbon dioxide in the body.
- **Tenderness:** It refers to pain or discomfort when an affected area is touched. It should not be confused with the pain that a patient perceives without touching. Pain is patient's perception, while tenderness is a sign that a clinician elicits.
- **Thrombosis:** The formation or presence of a blood clot in a blood vessel.
- **Tourniquet:** A device, such as a strip of cloth or a band of rubber, that is wrapped tightly around a leg or an arm to prevent the flow of blood to the leg or the arm for a period of time.
- **Tumour:** An abnormal mass of tissue that forms when cells grow and divide more than they should or do not die when they should. Tumors may be benign (not cancer) or malignant (cancer).
- **Valgus:** A deformity in which an anatomical part is turned outward (away from the midline) from the body
- **Varus:** A deformity in which an anatomical part is turned inward toward the midline of the body.
- **Venipuncture:** The puncture of a vein with a needle to withdraw blood and is also called phlebotomy.

HUMAN BODY ORGANIZATION

Study of the human body will begin with an overview of microscopic anatomy and then proceed to the gross and macroscopic anatomy of each organ system. When considering events from the microscopic to macroscopic scales we are examining several interdependent levels of organization.

To begin with chemical or molecular level of organization, the human body consists of over a dozen different elements, but four of them (hydrogen, oxygen, carbon and nitrogen) account for more than 99% of the total number of atoms (Fig. 1.10A).

At the chemical level, atoms interact to form compounds with distinctive properties. The major classes of compounds in the human body are illustrated in (Fig. 1.10B).

1. **Cellular level:** The cell is the basic structural and functional component of life. It is at the cellular level that such vital functions of life as metabolism, growth, irritability and adaptability, repair and reproduction are carried out. Cells are composed of minute articles called atoms, which are bound together to form larger particles called molecules. Certain molecules are arranged into small functional sources called organelles. Each organelle carries out a specific function within the cell. The nucleus, mitochondria and endoplasmic reticulum are organelles. The human body contains many distinct kinds of cells; each specialized to perform specific

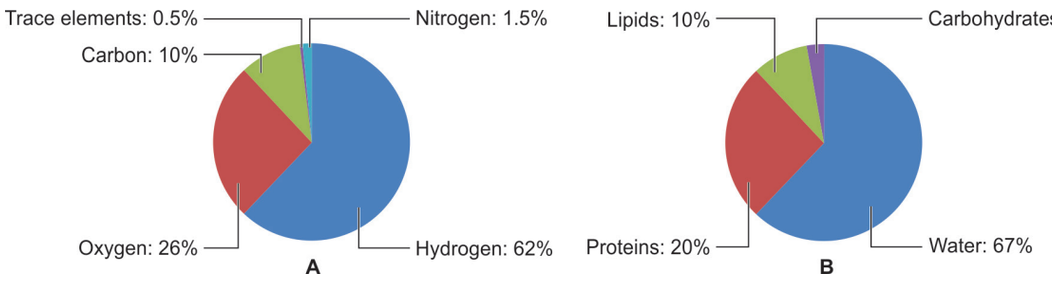


Fig. 1.10: A: Molecular organization; **B:** Major classes of compound

function, e.g. muscle cells, bone cells, fat cells, blood cells and nerve cells.

2. **Tissue level:** Tissues are groups of similar cells that perform specific functions. An example of a tissue is the muscle within the heart, which functions to contract and pump the blood through the body.
3. **Organ level:** An organ is an aggregate of two or more tissues, integrated to perform a particular function. Each organ usually has one or more primary tissues and several secondary tissues. In the stomach, for example, the inside lining epithelium is considered as primary tissue because it performs the basic functions like secretion and absorption. Secondary tissue of the stomach is the supporting connective tissue and vascular, nervous and muscular tissue which are present in its wall.
4. **System level:** The system of the body constitutes the next level of structural organization. A body system consists of various organs that have similar or related functions. Examples of systems are the circulatory system, endocrine system, etc. Certain organs may serve several systems. It should be kept in mind that these divisions are somewhat arbitrary as to which organs are included and which organs are excluded. Skeletal muscles attached to bones are part of the muscular system, but the smooth muscles around soft tissues are not. Skeletal muscles are attached to bones, and serve to move the bones, but bones are part of the skeletal system, not the muscular system. All the systems of the body are interrelated and function together, constituting the total organism.

HUMAN BODY SYSTEMS

There are 11 organ systems in the human body:

1. **Integumentary system:** It refers to skin which is body's largest organ. It protects us from the outside world, and is our first defense against bacteria, viruses and other pathogens. Our skin also helps regulate body temperature and eliminate waste through perspiration. In addition to skin, the integumentary system includes hair and nails. It is also site for many sensory receptors.
2. **Skeletal system:** It consists of **206 bones** that are connected by tendons, ligaments and cartilage. The skeleton not only helps us move, but it is also involved in the production of blood cells and the storage of calcium.
3. **Muscular system:** It consists of about **650 muscles** that aid in movement, blood flow and other bodily functions. There are three types of muscle: Skeletal muscle which is connected to bone and helps with voluntary movement, smooth muscle which is found in the walls of the organs and helps to move substances through their lumen, and cardiac muscle which is found in the heart and helps pump the blood.
4. **Lymphatic system:** The lymphatic system includes lymph nodes, lymph ducts and lymph vessels, and also plays a role in the body's defenses. Its main job is to make and move lymph, a clear fluid that contains white blood cells, which help the body fight infection. The lymphatic system also removes excess lymph fluid from bodily tissues and returns it to the blood.
5. **Respiratory system:** It allows us to take in vital oxygen and expel carbon dioxide in a process we call breathing. It consists mainly of the trachea, the diaphragm and the lungs.
6. **Digestive system:** It consists of a series of connected tubular organs that together, allow the body to break down and absorb food, and remove waste. It includes the mouth, esophagus, stomach, small intestine, large intestine, rectum, and anus. The liver and pancreas also play a role in the digestive system because they produce digestive juices.
7. **Nervous system:** It controls both voluntary action (like conscious movement) and involuntary actions (like breathing) and sends signals to different parts of the body. The central nervous system includes the brain and spinal cord. The peripheral nervous system consists of nerves that connect every other part of the body to the central nervous system.
8. **Endocrine system:** It consists of eight major glands that secrete hormones into the blood. These

hormones, in turn, travel through the bloodstream to different tissues and regulate various bodily functions such as metabolism, growth and sexual function.

9. **Cardiovascular system:** The cardiovascular system consists of heart and blood vessels. Heart pump the blood to various organs of the body through arteries. Veins bring back blood to the heart from organs. The blood contains nutrients, oxygen, carbon dioxide, and hormones.
10. **Urinary system:** It helps to eliminate waste product called urea from the body, which is produced when certain foods are broken down. The urinary system includes two kidneys, two ureters, the bladder, two sphincter muscles and the urethra. Urine produced by the kidneys travels down the ureters to the bladder and exits the body through the urethra.
11. **Reproductive system:** It allows humans to reproduce. The male reproductive system mainly includes the penis and the testes (which produce sperm). The female reproductive system consists of the vagina, the uterus and the ovaries (which produce eggs/ovum). During conception, a sperm cell fuses with an egg cell, which creates a fertilized egg that implants and grows in the uterus.

Although these systems have different names, they all work interdependently, meaning they work together and depend on each other.

Vital Organs

Humans have five vital organs that are essential for survival. These are the brain, heart, kidneys, liver and lungs.

The human brain is the body's control center, receiving and sending signals to other organs through the nervous system and through secreted hormones. It is responsible for our thoughts, feelings, memory storage and general perception of the world.

The human heart is a responsible for pumping blood throughout our body.

The job of the kidneys is to remove waste and extra fluid from the blood. The kidneys take urea out of the blood and combine it with water and other substances to make urine.

The liver has many functions, including detoxifying of harmful chemicals, breakdown of drugs, filtering of blood, and secretion of bile and production of blood-clotting proteins.

The lungs are responsible for extracting the oxygen from the air we breathe and transferring it to our blood where it can be sent to our cells. The lungs also remove carbon dioxide, which we exhale.

Body Regions

The human body is divided into several regions that can be identified on the surface of the body (Fig. 1.11). Learning the terminology used with reference to these regions now will make it easier to learn the names of underlying structures later. The major body regions are the head, neck, trunk, upper extremity and lower extremity. The trunk is frequently divided into the thorax and abdomen.

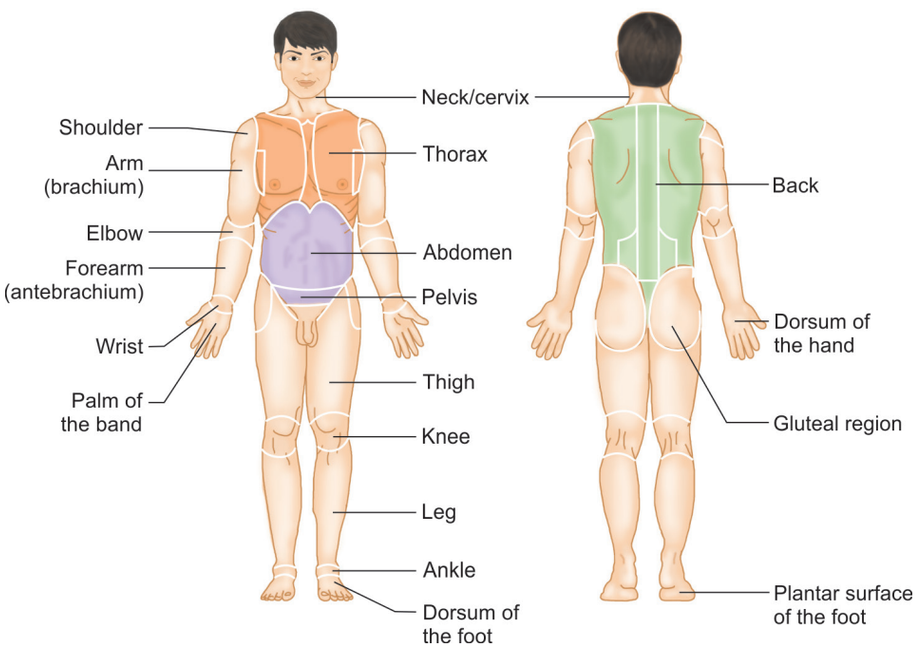


Fig. 1.11: Human body regions

Head: The head is divided into a facial region (which includes the eyes, nose and mouth) and a cranial region, which covers and supports the brain.

Neck: The neck referred to as the cervix or cervical region, supports the head and permits it to move.

Thorax: The thoracic region is commonly referred as chest. The mammary region of the thorax surrounds the nipple and in sexually mature females is enlarged as the breast. Between the mammary regions is the sternal region. The armpit is called axilla. The vertebral region, following the vertebral column extends the length of the back.

Abdomen: The abdomen is located below the thorax. The umbilicus is a landmark on the front and center of the abdomen. The abdomen has been divided into nine regions in order to describe the location of internal organs. The abdomen is anatomically divided by two horizontal lines and two vertical lines. These lines when intersect each other, make nine abdominal quadrants, which you shall study in the abdomen.

The **pelvic region** forms the lower portion of the abdomen. The **perineum** is the region containing the external sex organs and the anal opening. The center of the backside of the abdomen is called lumbar region. The sacral region is located further down at the point where the vertebral column terminates. The large hip muscles form the buttock or gluteal region.

Upper extremity (upper limb): The upper limb is anatomically divided into the shoulder, brachium (arm), antebrachium (forearm) and hand. The front of the hand is referred to as the palm and back of the hand is called dorsum. The fingers are referred as digits.

Lower extremity (lower limb): The lower limb consists of thigh, knee, leg and foot. The sole of the foot is referred to as the plantar surface. The dorsum of the foot is the top surface.

Body Cavities

Body cavities are confined spaces within the body. During development, the cavity within the trunk is called coelom, which is lined with a membrane that secretes a lubricating fluid. The coelom is divided by the muscular diaphragm into an upper thoracic cavity, or chest cavity, and a lower abdomino-pelvic cavity (Fig. 1.12). Organs within the coelom are collectively called viscera. The thoracic cavity is further divided into **two pleural cavities** by invagination of lungs on both sides and a **pericardial cavity** in the middle by the heart. Similarly, with invagination of some abdominal organs, the abdominal cavity is referred as **peritoneal cavity**. In addition to these large cavities, there are several small cavities like oral or buccal cavity, middle ear cavities and nasal cavities. The cranial cavity contains brain and its coverings.

Human Body Preservation for Teaching Gross Anatomy

Gross anatomy has been taught in most of the medical schools using a dead human body (cadaver). These cadavers are therefore used as educational tools. These cadavers are obtained as unclaimed dead bodies from the authorized government

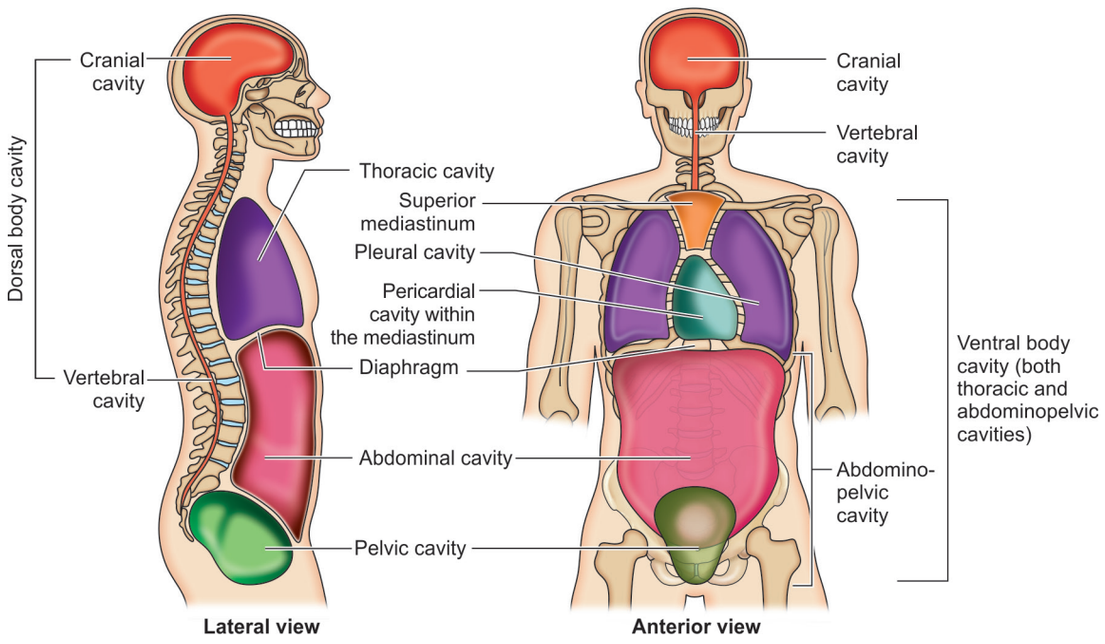


Fig. 1.12: Human body cavities

institutions. Of late lot many people are donating their body for medical schools voluntarily after death. As medical students you need to value and respect these cadavers. It is also important for you to know the principles and methods preserving these cadavers. It is important that the dead bodies are fixed and preserved properly keeping in the mind the safety of students as well as teachers.

Embalming: It is a procedure of fixing the dead human body with appropriate chemicals and preventing them from destruction and decomposition. This is achieved by treating the cadaver with special chemicals, and one of the most important chemicals used for this purpose is formaldehyde. The selected embalming fluids should ensure that any infection is not transmitted from dead body on contact and prevention of putrefaction. Formaldehyde is bactericidal, fungicidal, and insecticidal. Formaldehyde, CH_2O, is a highly reactive aldehyde gas formed by oxidation or incomplete combustion of hydrocarbons. The embalming fluid is mixture of formalin, alcohols, glutaraldehyde, methanol, ethanol, phenol, water, and dyes. The commercially available formaldehyde is 37% of formalin in water (formalin is formaldehyde dissolved in water). It is diluted with water and now a day's fixative embalming fluid is not just formalin, instead it is mixture of many chemicals. Fixative solutions labelled as 10% buffered formalin are 4% solutions of formaldehyde (a 10% solution made from a 37–40% solution of formaldehyde).

Before the embalming begins, the body is washed in a disinfectant solution. Limbs are massaged to relieve the stiffening of the joints and muscles. Any necessary shaving would also take place at this time. During the surgical portion of embalming process, the blood is removed from the body through the veins (femoral vein in the thigh and internal jugular vein in the neck) and replaced with embalming fluid through the arteries (femoral artery in the thigh and common carotid artery in the neck). After the arterial embalming, the body's cavities must be embalmed as well. A small incision is made in the lower part of the abdomen and a trocar (a sharp surgical instrument) is inserted into the body cavity. The organs in the chest cavity and the abdomen are then punctured and drained of gas and fluid contents. Once the entire blood flows out and embalming fluid start draining through the veins and the body becomes heavy, the body is fully embalmed. These embalmed cadavers can be refrigerated (cold stored) or in the formalin tank (5 to 10% concentration) for anatomical study and dissection. Students and employees who handle formalin fixed cadavers must have read and understood the safety guidelines of their institution regarding hazards of formaldehyde concentration. Given an opportunity every medical student must observe the process of embalming.

Chapter

2

General Anatomy

Competencies

AN: 1.2, 2.1 to 2.6, 3.1 to 3.3, 4.1 to 4.5, 5.1 to 5.8, 6.1 to 6.3, 7.1 to 7.8

Objectives

- To list the functions and layers of the skin
- To list the variety of skin lines and their locations in the body
- To define fascia and to discuss its layers, structure and functions briefly
- To name the three types of cartilage and to list their locations in the body
- To list the functions of the bone
- To identify the bones in a human skeleton
- To classify the bone based on the position, shape, gross structure and development giving examples to each variety
- To name the three types of muscles present in the body and to give their locations and functions
- To discuss the arrangement of skeletal muscle fibres, lubricating mechanisms associated with it
- To know the importance of nerve supply to the skeletal muscle
- To discuss the mechanism of action of the skeletal muscle
- To classify the joints giving examples to each variety
- To list the different types of synovial joints and to give examples to each variety
- To describe the structure of a typical synovial joint
- To describe the importance of nerve supply to the joint
- To describe the movements occurring at the synovial joint
- To define artery, arterioles, capillaries, sinusoids, venules and veins
- To list the types of arterial anastomoses and to give their location and significance
- To define lymph, lymph vessels and lymph node
- To list the functions of lymphatic system
- To list the cells forming the nervous tissue with their functions
- To define a nerve, sensory nerve and motor nerve
- To describe the formation of a typical spinal nerve
- To list the twelve cranial nerves

SKIN

Skin covers the entire external surface of the body including external auditory meatus (outer ear) and lateral aspect of tympanic membrane.

Structurally skin is complex and highly specialized lamina having a surface area between 1.2 and 2.2 m^2. The thickness ranges from about 1.5 to 4.0 mm. Skin is also called cutis or integument. Skin consists of an outer epidermis (cellular layer) and inner dermis (connective tissue layer). Skin is associated with sweat and sebaceous glands and also hair follicles (Fig. 2.1). These structures will be discussed in Chapter 7.

Functions

- Skin protects against micro-organisms, toxic substances, ultraviolet radiation and friction.

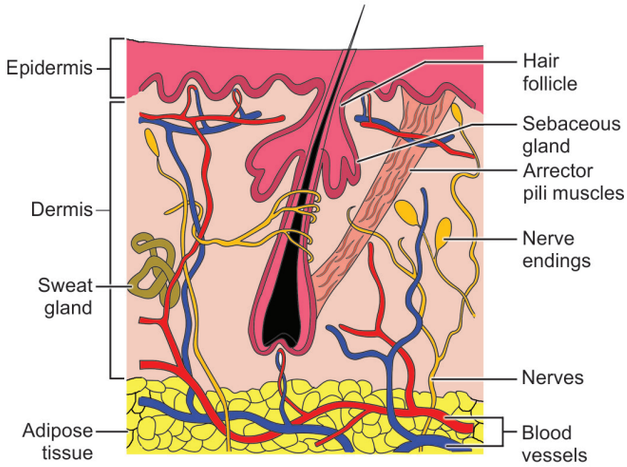


Fig. 2.1: Schematic representation of skin

- It helps to maintain the homeostasis (constant body environment) by preventing the water loss (dehydration) and regulates body temperature.
- It acts as a sensory receptor, as it has receptors. Thus, it provides information to the brain about the change in the external environment.
- It has role in excretion through sweat, and sebaceous secretions.
- It has endocrine function by secreting hormones, cytokines and growth factors and vitamin D metabolism.
- Certain lipid-soluble substances may be absorbed through the skin.

The outer surface of the skin presents various markings which are referred as skin lines. They include:

Flexure lines: Externally visible grooves of the epidermis near or opposite to the joints. These are commonly known as skin creases or skin joints. They are skin folds allow the movements of the joints. As the folding of skin normally occurs during flexion, they are known as flexure lines. Look at your skin at the back of the elbow, where you can find prominent flexure lines.

Tension lines: Skin is normally under tension because of collagen and elastic fibres present in their dermis. They are also known as **Langer's lines** or **lines of cleavage.** They are linear clefts in the skin that indicate the direction of orientation of the underlying collagen fibres. This direction of rows of collagen is known as **Langer's line**. These Langer's lines tend to run longitudinally in limbs, horizontally in the neck and trunk. A surgical incision along the rows of collagen fibres (parallel) causes minimum disruption of collagen and leaves minimum amount of scar.

Papillary ridges: These are lines on thick hairless skin of the palmar aspect of the hands and sole of the feet. They appear as epidermal or papillary ridges (colloquially known as fingerprints), where the sweat pores open. Each one of us has unique ridges except in identical twins.

Striae gravidarum: These are bands appear after rapid local expansion of underlying structure (after pregnancy). It is also referred as lineae albicantes or stretch marks.

Voight lines (Futcher lines): These are boundary lines (pigmentary demarcation) between darker and lighter areas on the upper limbs.

Mongolian spots: They are a type of birthmark caused by the pigment in the skin. They are often present at birth but may also appear in the infant's first weeks of life. They are flat, gray blue color patches which can be small or large, often present in the trunk. They are caused by some pigment that didn't make it to the top layer when baby's skin was being formed.

Naevus (mole): It is the accumulation of pigment cells in the epidermis. It is due to a local proliferation of pigment cells (melanocytes). It is more correctly called a melanocytic naevus. They do not produce any harmful effects.

Types of Skin

The fundamental structure of skin of the entire body is similar, but there are local variations like degree of keratinization, size and number of hairs, pigmentation, vascularity, innervation and others. On this basis, skin is classified into two types.

1. **Thin hairy skin** (hirsute) constitutes great majority of body's covering.
2. **Thick hairless skin** (glabrous) forming the surfaces of palms of hand, soles of feet and flexor surfaces of digits.

The skin of the upper part of the back is thick where dermis is exceedingly thick. The skin is very thin in the eyelids.
The nerve which is supplying the skin is called cutaneous nerve. This nerve can also be referred as sensory nerve because it carries sensation from the skin. At the end of the anatomy course, you should be able to name all the cutaneous nerves supplying different parts of the body and also their root value (from which segment of the spinal cord, these nerves are originated). Further these aspects will be discussed at the end of this chapter under the heading nervous tissue.

FASCIAE

Fasciae a connective tissue layer present deep to the skin. They are further divided into superficial fascia and deep fascia.

Superficial fascia: It is subcutaneous and mainly composed of adipose tissue (fat). It provides insulation and padding and lets the skin or underlying structure move independently. It allows the passage of nerves and vessels to the skin. The thickness of the superficial fascia varies in different parts of the body. The superficial fascia of the neck presents a muscle called platysma and, in the palm, called palmaris brevis.

Deep fascia: It is mainly made up of connective tissue fibers. They also surround the muscle groups, blood vessels, nerves, binding some structures together or allowing the structures to glide smoothly over each other. In the limbs the deep fascia forms compartments

between flexor and extensor group of muscles. Deep fascia forms **retinacula** around the joint to hold the tendons of the muscle. The deep fascia also provides thick protective coat for arteries in the form of carotid sheath, axillary sheath and femoral sheath. In few places the deep fascia gives attachment to the underlying muscles. Further modifications of the deep fascia in the different regions of the body are explained in later sections. Understanding of the arrangement of the fascial planes, their extent and attachments are important for surgeons. Fascia often limits the spread of infection and malignant disease.

CARTILAGE

Cartilage is a specialized dense connective tissue. It is hard but not rigid like bone. It can be bent and also brought back into its original form when bending force is withdrawn. This cartilage forms the 'skeletal' basis of some parts of the body (auricle of the ear, external nose). At the time of birth, most parts of the skeletal framework of the newborn are made up of cartilage. Later this cartilage will be converted into bones by a process called 'ossification'. However, depending on the functional need, some of them remain as cartilages even in adults. Cartilages are avascular structure. It has extracellular fibres (collagen or elastic or both) embedded in the matrix and also have cells called chondrocytes. There are three types of cartilages in the body—hyaline, elastic and fibrous.

Hyaline cartilage: It is the most common types of cartilage present in the body. They are located at:

1. **Costal cartilages of the ribs** (look at the anterior ends of the ribs where they are attached to the sternum), where they protect heart and lungs along with ribs, but resilience of the rib cage is because of these cartilages. Hence, it allows respiratory movements. In aged people these cartilages may ossify and may limit or disturb respiratory movements.
2. **Cartilage covering the articulating surfaces of the bones:** Bones are externally covered by vascular connective tissue called periosteum. However, at the places where bone articulates with another bone (joint) the periosteum is replaced by cartilage and mostly by the hyaline cartilage for the fact that cartilages are avascular and eases the movement at the joint and also protect the underlying bone (Fig. 2.2).
3. **Epiphyseal plates of growing bone:** As mentioned before, at the time of birth most of our skeleton is still a cartilage but the bone formation process has started. The complete replacement of cartilage by bone in long bone occurs during puberty. Hence, in the growing bone you always see a hyaline cartilage which is called epiphyseal plate (see the radiograph of a young individual and differentiate the bone from the cartilaginous epiphyseal plate, *refer* to Fig. 2.7A).
4. **Cartilages of the larynx**—thyroid and cricoid cartilage. Larynx is a part of the respiratory tract, and its lumen needs to be kept patent for the free passage of the air. It requires rigid wall and cartilage provides rigidity. Larynx is also the voice box, and the voice/sound is produced by the movement of tiny cartilages.
5. **The tracheal rings and irregular cartilages of bronchial tree:** The proximal air passage needs to be kept patent. In the wall of the nasal cavity there are bones and cartilages. In the wall of the trachea there are cartilaginous rings keep its lumen open. Further down in the respiratory tract the cartilage becomes smaller and at the level of bronchioles cartilages are absent.

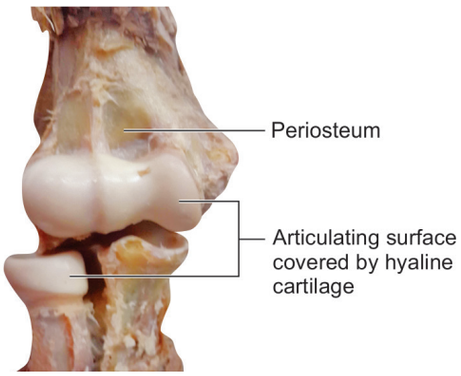


Fig. 2.2: Articular cartilage

Elastic cartilage: Elastic cartilage is more flexible than hyaline cartilage. They are located at the pinna of the external ear, epiglottis, corniculate and cuneiform cartilages of the larynx and medial part of the auditory tube.

Fibrocartilage (white fibrocartilage): It is intermediate in character between hyaline cartilage and dense connective tissue. The examples (or locations) for the white fibrocartilages are:

- Articular disc of the temporomandibular joint and sternoclavicular joint.
- Intervertebral discs present between the bodies of vertebrae.
- Glenoid labrum of the shoulder joint.
- Acetabular labrum of the hip joint.
- Menisci of the knee joint.

BONES

Bone is a highly vascular living connective tissue in which the matrix is calcified by the deposition of calcium phosphate. It is the main constituent of the adult skeleton. The adult human skeleton consists of **206 bones**.

Functions of the Bone

- Bone provides supporting framework and shape for the body.
- It protects vital organs of the body. The rib cage (thoracic cage) protects heart and lungs, skull protects brain and the vertebral column protects the spinal cord.
- They help in transmission of the body weight, for example, bones of the lower limbs act as pillars to support the trunk when we stand.
- They provide attachment to the muscles and act as levers of the joints helping in movement.
- Bone is the storehouse of calcium, phosphorus and various minerals.
- It serves as an energy reservoir by storing lipids/fats, stored in adipose cells of the yellow marrow of the bone.
- It is involved in blood cell production (erythropoiesis) from its red marrow.

Bones of the Human Body

As mentioned before the human skeleton is made up of 206 bones, which are listed below. With the help of an atlas and with Fig. 2.3 and also using the skeleton hanging in your lab., try to identify these bones yourself.

Skull: It consists of 22 bones and 6 ear ossicles (3 in each ear) together forms 28. The bone located in the neck is hyoid bone and together with it forms 29. The skull bones are connected to each other by sutures and they are immobile. The only moveable bone is the mandible (lower jaw). In the skull identify the frontal, parietal, occipital, temporal and maxilla. The remaining bones of the skull and their details shall be studied in head and neck section.

Vertebral column (spine): It consists of **33 vertebrae**. The vertebral column is subdivided into cervical part with **7 cervical vertebrae**, thoracic part with **12 thoracic vertebrae**, lumbar part with **5 lumbar vertebrae** and sacral region where 5 sacral vertebrae fused to form a **sacrum** and tailbone (coccyx) which is made up of fused 4 coccygeal vertebrae. Identify these different regions in the human skeleton placed in your dissection room and note their curvatures.

Thoracic cage: The skeletal framework of the thorax forms thoracic cage. It consists of sternum (breastbone) anteriorly. On each side it consists of 12 ribs. The first to seventh ribs anteriorly articulate with the sternum through the cartilaginous pieces called costal cartilage. The lower ribs (8th to 10th) articulate anteriorly with the higher cartilages. The anterior ends of the 11th and 12th ribs are free (does not articulate). Posteriorly each rib articulates with vertebrae through synovial joints.

Upper limb: It consists of **scapula** (shoulder blade), **clavicle** (collar bone), **humerus** (bone of the arm), **radius and ulna** (bones of the forearm, ulna being medial, and radius is lateral), **8 carpal bones**, **5 metacarpals** (bones of the hand) and **14 phalanges** (bones of the fingers, 3 for each finger except thumb where there are 2 phalanges).

Pelvis: The bony pelvis is consists of right and left **hip bone** and posteriorly the sacrum. Each hip bone is made up of three elements—ilium, ischium and pubis.

Lower limb: It consists of **femur** (thigh bone), **patella** (a sesamoid bone present in front of the knee), **tibia and fibula** (bones of the legs, tibia being medial, and fibula is on lateral side), **7 tarsal bones** (talus, calcaneus, navicular, cuboid and three cuneiforms) and **5 metatarsal** bones (bone of the foot) and 14 phalanges (2 for the great toe and 3 for the remaining four toes).

Classification of the Bone

Bones are classified according to their position, shape, structure and according to the development (Table 2.1).

According to their position

1. **Axial:** Bones forming the axis of the body, e.g. skull, ribs, vertebrae.
2. **Appendicular:** Bones of the limbs.

According to the shape

1. **Long bones:** They have three parts: Upper end, lower end and a middle shaft. The ends of these bones take part in forming the joint (articulates with other bone), e.g. bones of limbs (humerus, ulna, radius, femur, tibia, fibula).
2. **Short bones:** These bones are small and generally cuboidal in shape, e.g. carpal and tarsal bones.
3. **Flat bones:** These bones are expanded and are flat, e.g. sternum, scapula, ribs, and parietal bone.
4. **Irregular bone:** The shape is irregular without any proper outline, e.g. vertebrae, sphenoid, temporal bones, etc.

According to gross structure

1. **Compact (lamellar bone):** Structurally it is made up of bony plates (lamellae) which are arranged compactly, e.g. outer cortical part of the long bone (Fig. 2.4).
2. **Spongy bone (cancellous):** Structurally it is made up of bony plates, which are arranged irregularly leaving spaces in between them. It gives a spongy appearance, e.g. flat bones, irregular bones, and ends of the long bone (Fig. 2.4).

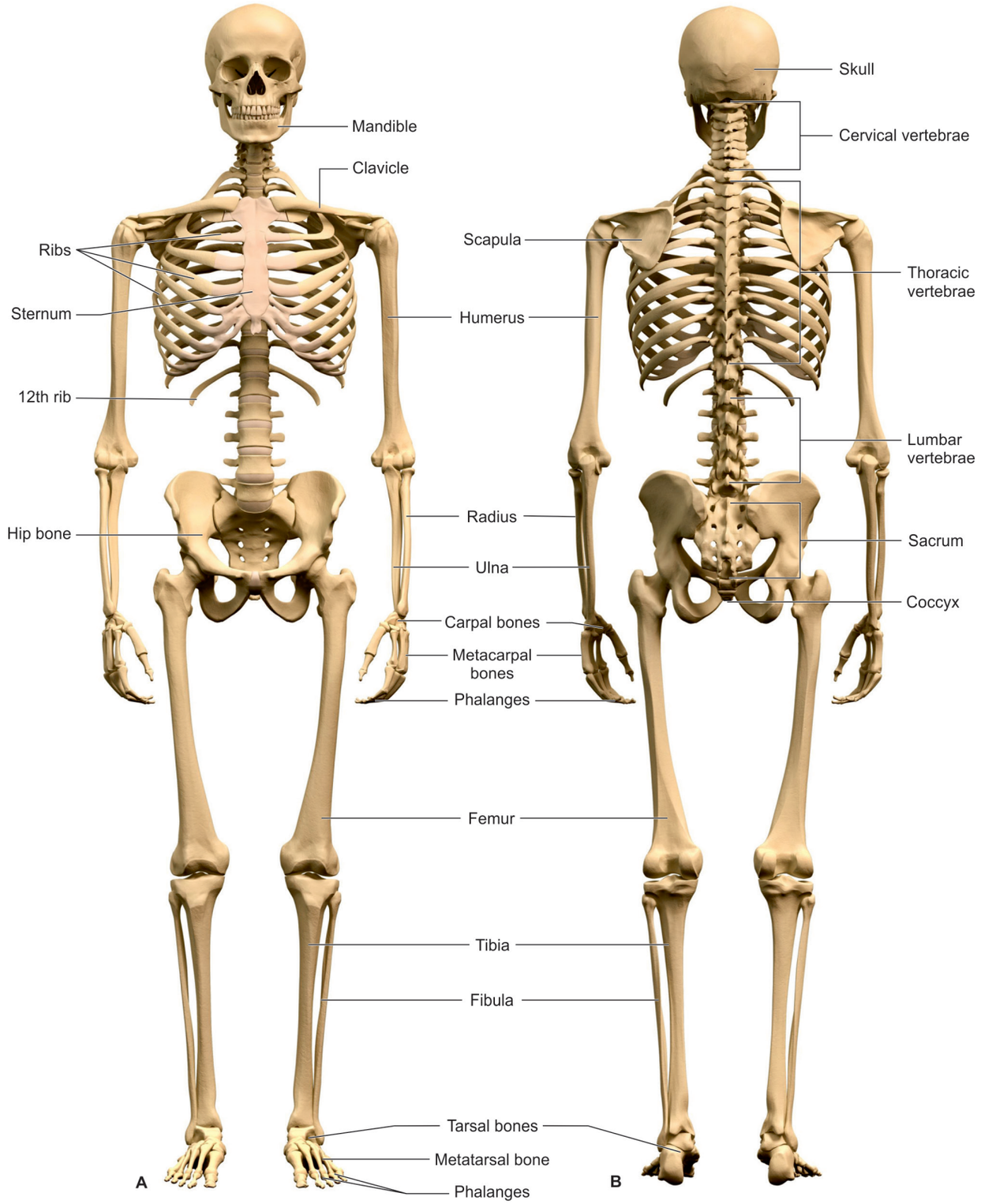
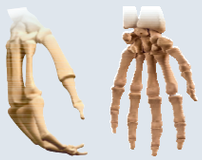


Fig. 2.3: Human skeleton. **A:** Anterior view; **B:** Posterior view

Table 2.1: Classification of bones

Bone types	Appearance	Function	Picture	Example(s)
Long bones	Their length is more and consist of upper and lower ends with middle shaft	Mechanical strength		Femur, tibia, fibula, humerus, ulna, radius
Short bones	Cube-shaped	Multi-directional motion		Carpal bones (of the hands/wrists) and the tarsal bones (of the feet/ankles)
Flat bones	Thin and flat has large surfaces for muscle attachments	Mechanical protection to soft tissues beneath		• Cranial bones • Sternum • Ribs • Scapulae
Irregular bones	Complicated shapes that cannot be classified as "long", "short" or "flat"	Provides major mechanical support for the body Vertebra protects the spinal cord		• Vertebrae • Hyoid bone • Sphenoid bone • Facial bones
Sesamoid bones	Most sesamoid bones are unnamed	Protects from additional friction and are located in the muscles of the hand and sole		Patella in front of the knee, pisiform in the hand

3. **Diploic bone:** It consists of inner and outer tables of compact bone with an interval, which is occupied by bone marrow and diploic veins, e.g. most of the cranial bones (parietal, frontal, occipital).

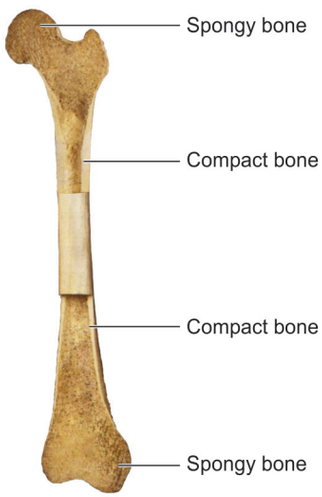


Fig. 2.4: A section through a long bone showing compact and spongy bones

According to the development

All the bones are developed from the mesenchymal tissue which is mainly developed from mesoderm. Bones of the face and skull cap (calvaria) are developed from neural crest, which is ectoderm.

1. **Membranous bones:** The mesenchymal tissue (mesoderm) is directly transformed into a bone, e.g. clavicle, bones of the face and cranial vault.
2. **Cartilaginous bones:** The mesenchymal tissue is first transformed into a cartilage. Later cartilage undergoes ossification to form bones, e.g. majority of the limb bones and bones at the base of the skull.

Special types of bones

1. **Pneumatic bones:** These are flat or irregular bones with hollow spaces in their body. These spaces contain air, e.g. ethmoid, maxilla, and mastoid part of temporal bone.

2. **Sesamoid bones** (Sesamoid = seed-like): These bones develop within the tendon of some muscles.
   - They do not possess periosteum and Haversian system.
   - They ossify after birth.
   - They minimize the friction and also change the direction of the pull of a muscle.

For example, pisiform bone (in the tendon of flexor carpi ulnaris muscle), patella (in the tendon of quadriceps femoris muscle), fabella (in the tendon of lateral head of gastrocnemius muscle).

Macroscopic Structure of a Bone

- The long bone consists of two ends (epiphysis) and a shaft (diaphysis).
- The shaft consists of a cylindrical cavity inside called '**medullary cavity**', which is filled with **bone marrow**. The outer (cortical) part of the shaft is made up of **compact bone** (Fig. 2.5).

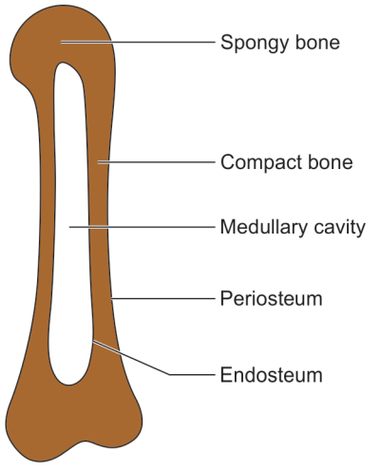


Fig. 2.5: Adult long bone

- The two ends of the long bone are filled with tiny plates of bone containing numerous spaces. This is referred as **spongy bone** to which the medullary cavity does not extend.
- The outer surface of the bone is covered by a highly vascular connective tissue membrane called **periosteum** except at the articular surfaces. This articular surface is covered by articular cartilage, usually hyaline type.
- The medullary cavity is lined by another connective tissue membrane called **endosteum,** consists of single layer of osteoprogenitor cells.

Periosteum

The external surface of the bone is covered by a connective tissue membrane called 'periosteum' except the articular surface. The periosteum consists of outer fibrous layer and inner cellular layer consisting of osteoprogenitor cells. The outer fibrous layer is made up of collagen fibres which are arranged parallel to the surface of the bone. However, where ligaments and tendons attached to the bone where collagen fibres from these structures extend obliquely or at right angles to the long axis of the bone where they continue with collagen fibres with extracellular matrix. These fibres are called **Sharpey's fibres** or perforating fibres.

Bone Marrow

It is the vascular connective tissue presents in the cavity (medullary cavity) of the bone. The bone marrow differs in composition in different bones and at different ages. It occurs in two forms, yellow marrow and red marrow.

The **red marrow** is actively engaged in the production of blood cells (Fig. 2.6). It consists of blood cells, reticular cells and fibres that serve as supporting framework for the developing blood cells. As an individual grows, the amount of red marrow does not increase proportionately with bone growth.

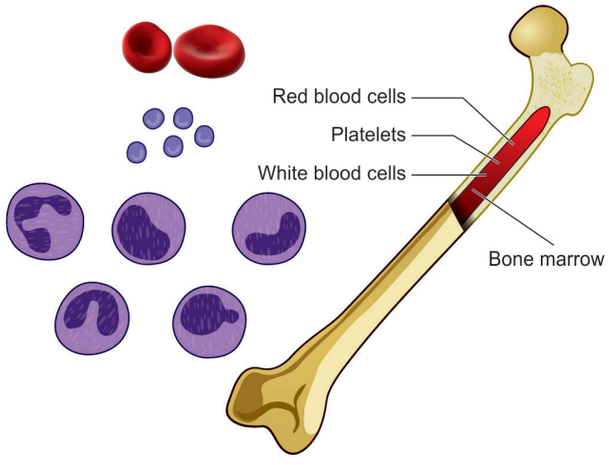


Fig. 2.6: Bone marrow

The **yellow marrow** derives its colour from the large quantity of fat cells it contains. At birth the red marrow is present throughout the skeleton. After about fifth year of postnatal life, the red marrow is gradually replaced by yellow marrow in the long bones.

In response to appropriate stimuli, such as extreme blood loss, yellow marrow can revert to red marrow. In adults, red marrow is normally restricted to the spaces of spongy bone in few locations such as the sternum and iliac crest. That is why for diagnostic purpose or for transplantation, the bone marrow samples are obtained from these bones.

Parts of the Developing Long Bones

1. **Epiphysis** is the part of the bone, which develops from the secondary center of ossification (Fig. 2.7A and B), e.g. ends of the long bones.

Types of epiphyses

Pressure epiphyses: They ossify from centers exposed to pressure at the joints, e.g. epiphysis of the head of the femur.

Traction epiphyses: They ossify from centers subjected to tension by the pull of the muscle, e.g. greater and lesser trochanters of the femur.

Atavistic epiphyses: These epiphyses are formed by centers of ossification which are believed to represent the skeletal elements which were separate in some lower vertebrates, e.g. coracoid process of scapula.

2. **Diaphysis** is the part of the bone, which develops from the primary center of ossification, e.g. shaft of the long bones.

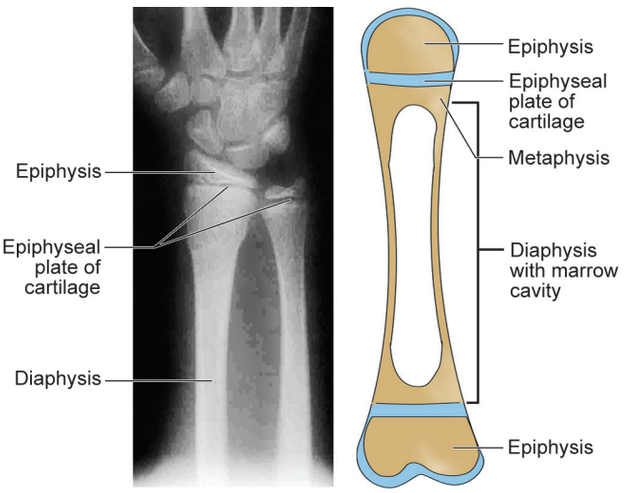


Fig. 2.7A: Typical growing long bone

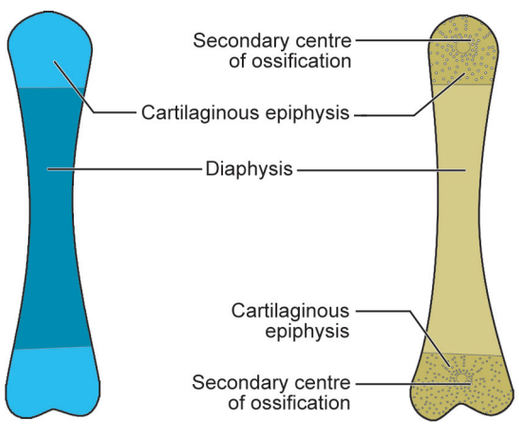


Fig. 2.7B: Formation of a typical long bone

3. **Metaphysis** is the zone of the bone where active growth is seen. It is present at the junction of the epiphysis and diaphysis of the long bones.

Ossification

The process of bone formation is called **ossification**. All the bones are developed from the mesenchymal tissue of the embryo. There are two types of ossification (Fig. 2.8).

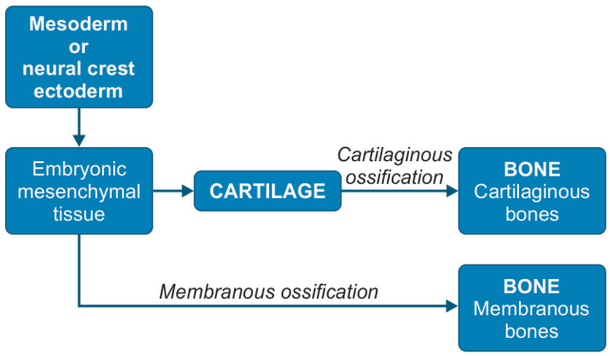


Fig. 2.8: Process of bone formation

Membranous ossification: The embryonic mesenchymal tissue will directly form the bones (dermal bones), e.g. bones of the cranial vault, mandible, and clavicle.

Cartilaginous ossification: The mesenchymal tissue is first transformed into a 'cartilage'. Later this cartilage is ossified to form a bone.

Ossification of a Long Bone

The ossification begins in one or more areas of future bone model. These areas are called centers of ossification.

Primary Centre of Ossification: The ossification starts in the central part of the cartilaginous model (i.e. at the centre of the future shaft). The portion of the long bone developed from this primary centre of ossification is called **diaphysis**. The primary centre of ossification normally appears before birth.

Secondary Centre of Ossification: These centres appear at the two ends of the long bone usually after birth.

- The portion of the long bone developed from secondary center of ossification is called **epiphysis**.
- The two ends of the diaphysis, which are actively involved in growth, are called **metaphysis**.
- In a long bone between epiphysis and diaphysis is a part of the cartilage remains unossified until epiphysis fuses with diaphysis and it is called **epiphyseal plate**. They also undergo ossification at puberty.

Laws of Ossification

- The epiphysis which ossifies first (or appears first) unites (fuses) with the diaphysis last and the epiphysis which ossifies last fuses first. Exception: Lower end of the fibula.
- The end of a long bone where epiphysis appears first and fuses last is called the 'growing end' of the bone (upper end of the humerus, lower ends of the radius and ulna, lower end of the femur and upper ends of the tibia and fibula are the growing ends).
- The direction of nutrient artery is always away from the growing end.
- In the long bones, growing ends fuse with the shaft at about 20 years and the opposite ends at about 18 years.

Blood Supply to a Long Bone

The arteries that enter the bone marrow cavity through the nutrient foramina supply blood to the shaft of long bones. **Nutrient foramina** are openings in the bone through which blood vessels pass to reach the marrow.

Nutrient artery: It enters the shaft through a nutrient foramen with one or two veins. On reaching the bone marrow cavity they divide into ascending and descending branches. They proceed towards each end, supplying the bone marrow, spongy bone, and deeper portion of the compact bone (Fig. 2.9).

Epiphyseal arteries: They are several in numbers and enter the bone near the ends.

Metaphyseal arteries: They enter the bone along the line of attachment of capsular ligament (near the articular end). The metaphyseal and epiphyseal arteries mainly from the arteries supplying the joint. **The metaphyseal arteries in children (before epiphyseal union) form hairpin bends. The bacteria or infective emboli get trapped in these bends may cause osteomyelitis.**

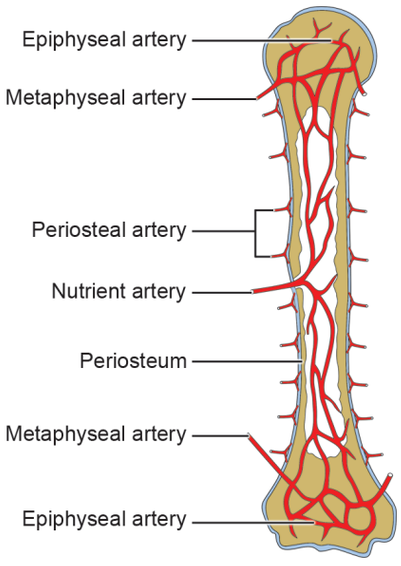


Fig. 2.9: Blood supply to a long bone

Periosteal arteries: They are numerous and enter the bone along the muscular attachment. These branches are responsible for nourishment of most of the compact bone.

Branches of all these arteries form a rich sinusoidal plexus in bone marrow. Many branches from the plexus enter Haversian canal.

These vessels provide blood to the superficial osteons of the shaft. The blood that nourishes bone tissue moves from the bone marrow cavity into and through the bone tissue and out via periosteal veins; thus, its flow is in a centrifugal direction. During endochondral ossification, these vessels also enter the epiphyses providing blood to the secondary ossification centres. Following the closure of epiphysis all these sets of vessels become extensively interconnected.

Nerve Supply to the Bone

Bones are innervated by sensory nerves and injuries can be very painful. Nerves accompany nutrient vessels into the bone tissue and bone marrow. They traverse through perivascular spaces of Haversian canals. Osteoblast has receptors for several neuropeptides found in these nerves.

MUSCLE

Muscles are contractile tissue, which brings movement of the body. The special terms used to muscle include the prefixes **sarco** and **myo**. Muscles are structurally and functionally specialized for contraction which requires two types of protein filaments called myofilaments (actin and myosin). All muscles are developed from mesoderm except smooth muscle present in the iris, which is developed from ectoderm. Muscles are often called **muscle fibres** or **myofibres**.

There are three types of muscles—skeletal, cardiac and smooth (Fig. 2.10A to C).

Smooth Muscle (Non-striated/Involuntary)

- Each muscle fibre is an elongated spindle-shaped cell with a single nucleus placed centrally.
- The length of the smooth muscle is highly variable (15–500 μm).
- They often aggregate to form bundles and fascicles.
- They are found in the walls of gastrointestinal tract, respiratory tract, urogenital tract, blood vessels and few muscles of the eye.

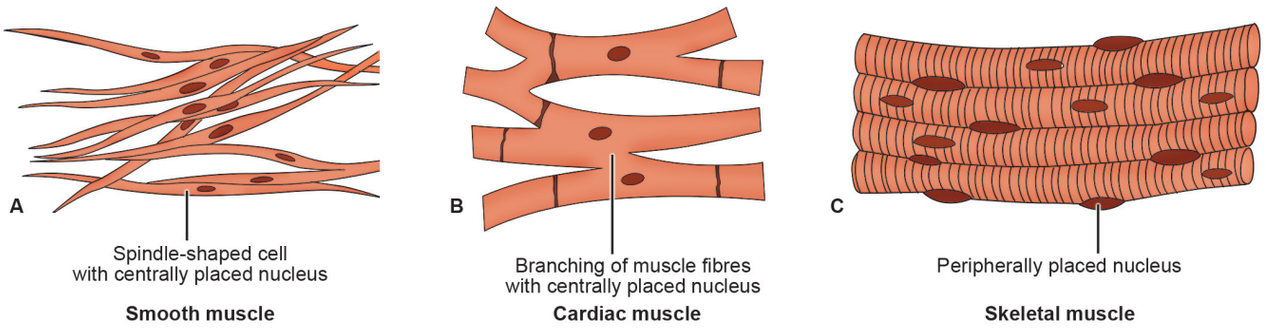


Fig. 2.10A to C: Types of muscle fibres

- They are arranged circularly inside and longitudinally outside in the walls of the gastrointestinal tract, urogenital tract, etc.
- They do not exhibit cross striations and are smooth in form, supplied by autonomic nerves, hence involuntary (not under your control).
- They are made up of actin and myosin filaments.
- These muscles respond slowly to stimuli, being capable of sustained contractions, therefore do not fatigue easily.
- There are two types of smooth muscles—multi-unit and unitary.
  - Multi-unit smooth muscles: Nerve fibres establish direct contact with several myocytes. Muscles contract under nervous stimulus, e.g. smooth muscles of iris and large arteries.
  - Unitary smooth muscles: They have their own rhythmic contractility that is independent of nerve supply. Contraction of muscle is stimulated by stretch. However, the nerve supplying them can alter the rate of contraction, e.g. smooth muscles of the stomach, intestine, uterus and ureter.

Cardiac Muscle (Striated/Involuntary)

- It forms the myocardium (musculature) of the heart, in the sense the wall of the heart is made up of cardiac muscles. They show striations but are involuntary. It is meant for automatic and rhythmic contractions.
- Each muscle fibre has a single-rounded nucleus placed centrally.
- Each muscle fibre branches and anastomoses with the neighboring fibres at intercalated discs.
- Myocytes are about 80 µm long and 15 µm broad.
- Their sarcoplasm contains a greater number of mitochondria and a smaller number of myofibrils and sarcoplasmic reticulum when compared to skeletal muscle.

Skeletal Muscle (Striated/Voluntary)

- These are most abundant, found attached to the skeletal system.
- The skeletal muscle has two parts—fleshy and fibrous. The fleshy part is contractile (having actin and myosin filaments) under the stimulus from the nerve. The fibrous part is noncontractile and is made up of collagen fibres. The fibrous part can be aponeurotic and tendinous.
- They exhibit cross striations under the microscope.
- They are supplied by somatic (cerebrospinal) nerves, hence under voluntary control.
- Each muscle fibre is a multinucleated cylindrical cell containing a group of muscle fibrils, e.g. muscles of the limb and body wall.

Arrangement of the Skeletal Muscle Fibres

The arrangement of muscle fibres varies according to the direction, force and range of movement at a particular joint. **The force of contraction is directly proportional to the number and size of muscle fibres, and the range of movement is proportional to the length of the fibre.** The fascicles of the muscle can be parallel or oblique. When fascicles are obliquely set to the line of pull, the power of contraction is more, but range of movement is less.

Based on the arrangement of fasciculi. The skeletal muscles are classified into (Fig. 2.11A to F):

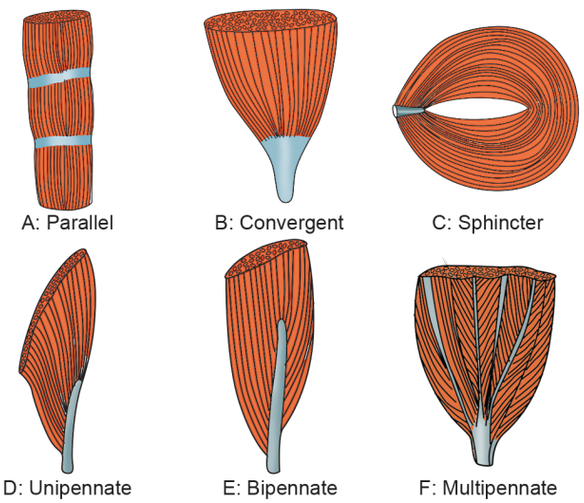


Fig. 2.11: Arrangement of fasciculi of skeletal muscle

Parallel muscles: The fascicles are arranged in the same direction as the long axis of the muscle. The majority of skeletal muscles in the body have this type of organization. Some parallel muscles have a larger central region called a **muscle belly** tapering to tendons on each end. This arrangement is called **fusiform** such as the biceps brachii muscle.

Circular: The circular muscles are also called sphincters. When they relax, the sphincters' concentrically arranged bundles of muscle fibres widens the size of the opening, and when they contract, the size of the opening is reduced to the point of closure. The orbicularis oris muscle is a circular muscle present around the mouth. When a muscle has a widespread expansion over an area and the fascicles come to a single, common attachment point, the muscle is called **convergent** (example pectoralis major). The attachment point for a convergent muscle could be a tendon (cord like), an aponeurosis (flat), or a raphe (a very slender tendon).

Pennate (*penna* = "feathers"): The muscle fibres join into a tendon that runs through the central region of the muscle for its whole length. There are three subtypes of pennate muscles.

a. **Unipennate:** The fascicles are located on one side of the tendon, e.g. palmar interossei of hand and flexor pollicis longus.
b. **Bipennate:** It has fascicles on both sides of the tendon as in the arrangement of a single feather, e.g. rectus femoris or dorsal interossei of the hand.
c. **Multipennate:** They have fascicles that insert on multiple tendons tapering towards a common tendon, like multiple feathers converging on a central point, e.g. middle fibres of deltoid. This type of arrangement allows to accommodate many muscle fibres in a smaller volume and force of contraction is powerful.

While studying a skeletal muscle, the student must focus on following four important components—origin, insertion, nerve supply and the action.

Origin: The origin of the muscle refers to its proximal attachment and remains mostly stationary when contracts.

Insertion: The insertion refers to the distal attachment and which moves towards the point of origin when the muscle contracts. Hence, knowing the insertion gives an idea about the action of the muscle.

Nerve supply: The skeletal muscle requires stimulus for contraction. The nerves bring stimulus for contraction. The muscle may be supplied by a branch from the spinal or cranial nerves.

Action(s): The action of the muscle refers to the movement brought by the muscle on the joint which it crosses. Lever systems of the body help in turning a force into a large movement. The bones act as levers while the joints act as fulcrum. The effort refers to the force generated by the contraction of the muscles in the lever system (Fig. 2.12A).

A muscle can bring different functions on a particular joint based on the direction in which it crosses the joint. For example, the anterior fibres of the deltoid cause flexion of the shoulder joint while posterior fibres of the deltoid cause extension of the shoulder joint. Some muscles may cross more than one joint and can bring different action on different joint.

Muscles can be classified as either shunt or spurt muscles (Fig. 2.12B).

Shunt muscles: The muscle has its origin near the joint on which it acts but its insertion is greater distance away from the joint. As a shunt muscle contracts it applies force along the bones and pulls the joint surfaces together in order to stabilize the joint. The brachialis and brachioradialis are examples of shunt muscles.

Spurt muscles: The muscle has its origin far away from the joint on which it acts but its insertion is close to the joint. This helps the spurt muscle to apply force across the bone instead of along to create movement about the joint. Spurt muscles tend to be prime movers and the biceps brachii is classified as a spurt muscle.

Lubricating Mechanisms for the Muscles

Synovial bursa: Bursa is a lubricating device to minimize the friction. Structurally, it is a closed sac of synovial membrane with synovial fluid. Bursa is often present around the joint, but it can be subcutaneous (just deep to the skin, for example prepatellar bursa in front of the knee). Bursa can communicate with joint the cavity. Inflammation of the bursa is called bursitis.

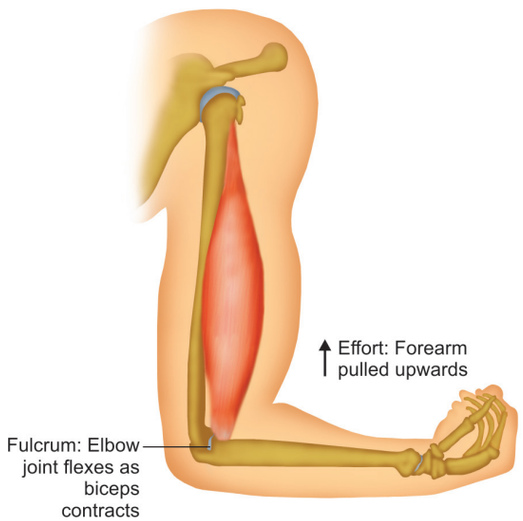


Fig. 2.12A: Fulcrum and lever action of muscle

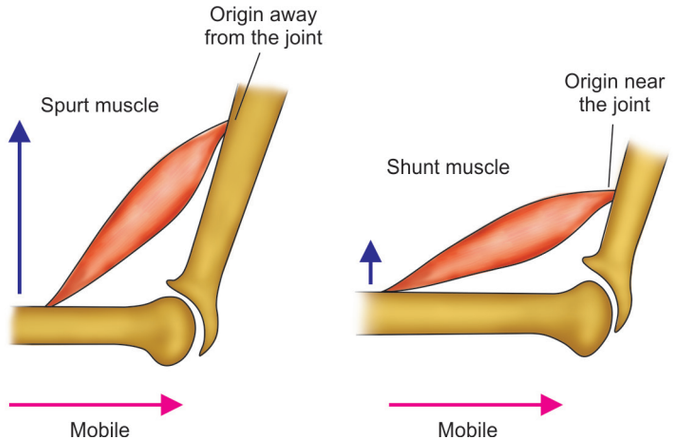


Fig. 2.12B: Shunt and spurt muscle

Synovial sheaths: The tendinous part of the muscle while passing deep to fibrous bands is surrounded by synovial sheath.

Blood supply to skeletal muscle: The blood vessels and nerves enter the muscle at a point called neurovascular hilum. The arteries branch repeatedly to form arteriole and capillaries in the muscle.

Connective Tissue Support to the Muscle

A connective tissue membrane called **endomysium** surrounds each muscle fibre. Similar membrane covering each bundle of muscle fibres (fascicles) is called **perimysium**. **Epimysium** surrounds the entire muscle (Fig. 2.13).

From macroscopic to microscopic level, the muscle is made up of:

a. **Muscle fascicles:** These refer to bundle of skeletal muscle fibres surrounded by perimysium.
b. **Muscle fibres:** The cells which are basic building blocks of the muscle having nucleus and many myofibrils.

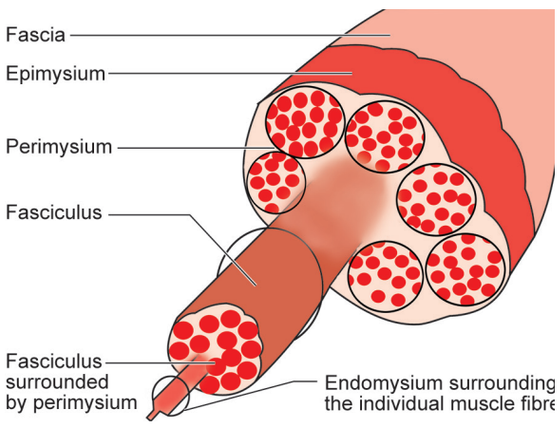


Fig. 2.13: Connective tissue framework of a skeletal muscle (transverse section)

c. **Myofibrils:** These are elongated contractile element present in the skeletal muscle.
d. **Myofilaments:** These are filaments of myofibrils made up of proteins basically actin and myosin.

Nerve Supply of Skeletal Muscle

- The nerve supplying the muscle is called **motor nerve**. However, this motor nerve has 60% motor fibres, 40% sensory fibres and also autonomic fibres.
- The motor fibres are axons of the ventral horn cells of the spinal cord. On stimulation, the muscle contracts.
- The sensory fibres arise from muscle spindles (stretch receptors present in the muscle) which give information about the status of the muscle (proprioceptive sensation).
- Autonomic fibres innervate the smooth muscles present in the wall of the blood vessels inside the skeletal muscles.

Action of Muscle

When a muscle contracts, it shortens by 30% of its original length (length of fleshy part) and brings about a movement.

Agonists (prime movers): They bring the desired movement. When a prime mover helps opposite action by active controlled lengthening against gravity, then this action is called **action of paradox**, e.g. keeping an empty glass back on the table after drinking is assisted by gravity but controlled by a gradual active lengthening of biceps brachii.

Antagonists (opponents): They are opposite to the prime movers, but they help prime movers by active controlled relaxation so that the desired movement is smooth and precise. The terms agonist and antagonist are not set properties of a muscle; they apply to a muscle depending on whether the muscle is doing the movement or indirectly helping that movement. For example, when biceps brachii acts as an agonists

and flexing elbow, the triceps acts as antagonists by relaxing. When triceps is acting as agonist to extend the elbow, biceps brachii will act as antagonist.

Synergists: When prime movers cross more than one joint, the undesired action at the proximal joint is prevented by certain muscles called synergists, e.g. when making a tight fist by long flexors, the wrist is kept fixed in extension by the synergists (extensors of wrist).

Clinical Notes

Muscle pull: Skeletal muscles are limited in their ability to lengthen. Muscle cannot elongate beyond 1/3rd of its resting length with its bony attachments, beyond which the muscle sustain damage, which is often referred as muscle pull. A **muscle cramp** is a sudden, hard, uncontrolled contraction that is usually quite painful. The muscle gets very hard and often feels stiff even after the cramp subsides.

The **muscle spasm** is a jerky, uncontrolled minor contraction of the muscle. It is usually not painful.

Rigor mortis: When death occurs, circulation ceases, and the skeletal muscles are deprived of nutrients and oxygen. The calcium ions accumulate inside the sarcoplasm, which results in locking of the muscles in contracted position. All the skeletal muscles of the body are involved. This condition is called rigor mortis.

Muscle hypertrophy: An increase in size of muscle is called hypertrophy which occurs due to excessive muscular activity. An increase in number of muscle fibre is called hyperplasia. Hypertrophy occurs in muscles that have been repeatedly stimulated. A champion weightlifter or body builder is an excellent example of hypertrophied muscular development.

Muscle atrophy: When a skeletal muscle is not stimulated by a motor neuron on a regular basis, it losses muscle tone and mass. The muscle becomes flaccid, and the muscle fibre becomes smaller and weaker. This reduction in muscle size, tone and power is called atrophy.

Paralysis: The loss of power of contraction is called paralysis. It may be due to the injury to the nerve supplying it or the disease of the muscle itself. It is characterized by sudden and involuntary tightening of muscle fibres.

Polio: Progressive paralysis of muscles due to destruction of CNS motor neurons (ventral horn cells of the spinal cord) by the polio virus.

Fibrosis: A process in which excess amounts of connective tissue develops, making muscles less flexible.

JOINTS

The articulation between two or more bones is called a joint. Joints hold the skeleton together and support movement.

Joints are classified in different ways. Based on the movements which allow, they are classified into:

1. **Synarthroses:** These joints do not allow any movement. For example, the most of the skull bones are connected by sutures.
2. **Amphiarthroses:** These joints allow little movement. For example, inferior tibiofibular joint and the pubic symphysis.
3. **Diarthroses:** These joints allow wide range of movements. For example, shoulder and hip joints.

Based on structure, the joints can be classified into—fibrous, cartilaginous and synovial joints.

1. Fibrous Joints

In this type of joint the articulating surfaces of the bones are connected by fibrous tissue, and thus very little movement is possible. Following are the types of fibrous joints:

a. **Sutures:** Sutural ligament (fibrous connective tissue) connects the bones without allowing movement, e.g. many skull bones are held together by sutures (Fig. 2.14).
b. **Syndesmosis:** The articulating parts of the bones are connected by interosseus ligament, e.g. inferior tibiofibular joint.
c. **Gomphosis (peg and socket):** It is an immovable articulation in which one bone or part is received in a cavity in another. For example, tooth in its bony socket.

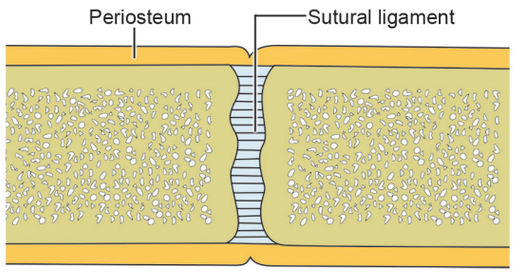


Fig. 2.14: Sutural variety of fibrous joint

2. Cartilaginous Joints

In these joints articulating surfaces are connected by a cartilage. There are two types of cartilaginous joints (Fig. 2.15A and B).

a. **Primary cartilaginous joint (synchondrosis):** The articulating ends of the bones are connected by a plate of hyaline cartilage. These joints are temporary because after certain age the cartilaginous plate is replaced by bone (it will ossify into a bone). These

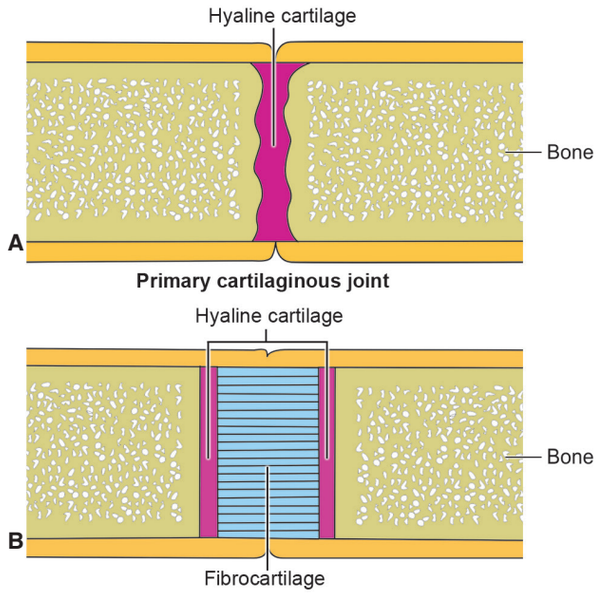


Fig. 2.15A and B: Cartilaginous joints

joints are immovable, e.g. (i) joint between the epiphysis and diaphysis of a growing long bone, (ii) joint between the body of the sphenoid and basilar part of the occipital bone.

b. **Secondary cartilaginous joint (symphysis):** The articulating surface is covered by hyaline cartilage. However, an articular disc is present between the articulating surfaces. This articular disc is a white fibrocartilage. These joints are permanent (except symphysis menti). These joints allow a limited movement, e.g. pubic symphysis, manubriosternal joint, intervertebral joints between the bodies of vertebrae.

3. Synovial Joint

In a synovial joint the articular surfaces of the bones are separated by a joint cavity filled with synovial fluid. Synovial joints are highly mobile.

Structure of a Typical Synovial Joint

Articular surface: The articulating surface is smooth and is covered by hyaline cartilage (in some cases by white fibrocartilage, e.g. temporomandibular joint). Periosteum being highly vascular and joint movement can cause rupture of capillaries, hence articulating surfaces are covered by cartilages which are avascular. This articular cartilage is nourished by synovial fluid. These articular cartilages provide slippery surface for the free movement.

Joint cavity: The space between the articulating surfaces is called joint cavity, which is filled with synovial fluid. In some joints, the cavity is divided into two compartments by the presence of an articular disc or meniscus (complex joint). A fibrous capsule externally closes the joint cavity (Fig. 2.16).

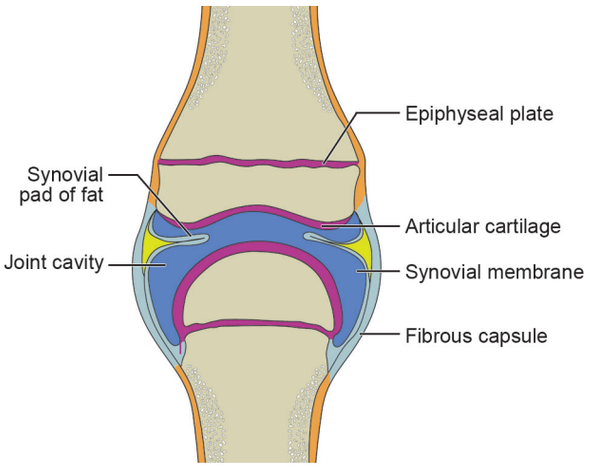


Fig. 2.16: Typical synovial joint

Fibrous capsule/capsular ligament: Structurally, it is made up of collagen and elastic fibres, which provide strength and elasticity respectively. Functionally, it holds the two bones and prevents their dislocation. It is attached to the margins of the articulating surfaces. It has stretch receptors, which are innervated by nerve fibres. They carry the information from the joint (proprioceptive information) and also execute reflexes to protect the joint from any sprain. Fibrous capsule has rich vascular plexus.

Synovial membrane: The fibrous capsule is lined by synovial membrane on its inner aspect. It is a highly vascular and cellular connective tissue membrane. They secrete synovial fluid and also hyaluronic acid, which maintains viscosity of the fluid.

Synovial fluid: It is a viscous fluid presents in the joint cavity. It contains hyaluronic acid, monocytes, lymphocytes, macrophages and traces of protein. It provides nutrition to the articular cartilage and also lubrication to the joint.

Ligaments: The synovial joint is stabilized by ligaments outside or inside the fibrous capsule. They may be thickened portions of the fibrous capsule or separate structures. These ligaments permit desirable movements and prevent undesirable ones. Their main function is to maintain stability of the joint. The tone of the muscles around the joint is an important factor in maintaining the stability.

Types of Synovial Joint

Synovial joints are classified into many subtypes according to the shape of the articular surfaces and types of movement occurring in them (Fig. 2.17).

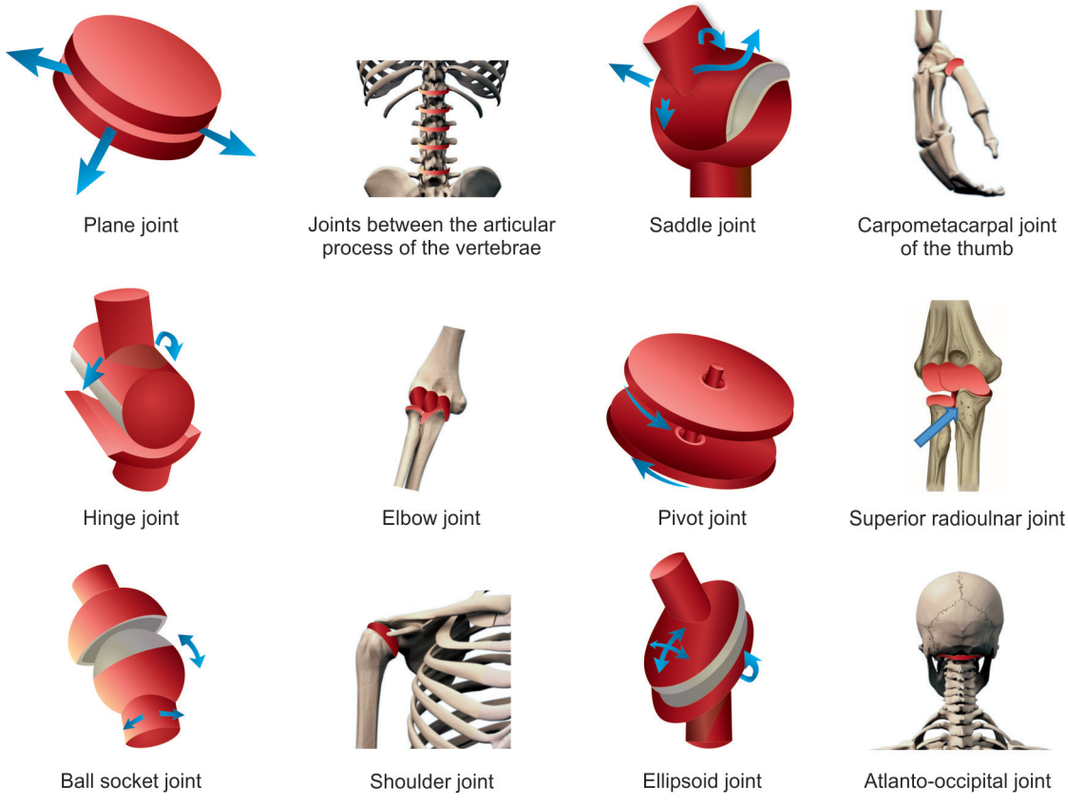


Fig. 2.17: Types of synovial joint

Plane joints: In these joints, the articular surfaces are flat permitting only sliding movement, e.g. acromioclavicular joint and joints between the articular processes of the vertebrae.

Hinge joints: These joints resemble the hinge on a door. Only flexion and extension movements are possible, e.g. elbow joint, knee joint (modified hinge), and ankle joint.

Pivot joints: In these joints, there is a central pivot, or an axis surrounded by a bony or ligamentous ring. In this joint either the pivot or the ring rotates. Rotation is the only movement possible, e.g. atlanto-axial joint, superior radioulnar joint.

Condylar joints: A condylar articulation is structured so that an oval, convex articular surface of one bone fits into an elliptical, concave depression on another bone. This permits angular movement in two directions as in an up-and-down and side-to-side motion, e.g. temporomandibular joint, knee joint.

Ellipsoid joints: In these joints, there is an elliptical convex articular surface that fits into an elliptical concave articular surface. The movements are flexion, extension, abduction and adduction, but rotation is not possible. e.g. Wrist joint and atlanto-occipital joint.

Saddle joints: In these joints, the articular surfaces are reciprocally concavo-convex and resemble a saddle on a horse's back. This joint permits flexion, extension, abduction and rotation, e.g. Carpometacarpal joint of the thumb.

Ball and socket joints: In these joints, a ball-shaped head of one bone fits into a socket-like concavity of another. This arrangement permits very free movements, including flexion, extension, abduction, adduction, medial and lateral rotation and circumduction, e.g. Shoulder joint and hip joint.

Blood Supply to a Synovial Joint

The epiphyseal branches of the artery supplying the bone form a periarticular plexus close to the attachment of fibrous capsule. Numerous minute vessels arising from this plexus pierce the fibrous capsule and form a rich vascular plexus on the outer surface of the synovial membrane. The blood vessels of the synovial membrane supply capsule, synovial membrane and the epiphysis. Before the fusion of epiphysis with metaphysis these vessels do not anastomose with metaphyseal arteries. However, after fusion, the communications between epiphyseal and metaphyseal arteries are established.

Nerve Supply to a Synovial Joint

The nerve supplying the joint contains sensory and autonomic fibres. The sensory fibres are proprioceptive in function. They provide the information regarding position and movement of the joint. They are concerned with reflex control of posture and locomotion. They also convey pain sensation from the joint. The autonomic fibres provide motor fibres to the blood vessels. The capsule and ligaments possess a rich nerve supply and specialized receptors (Golgi tendon end organs).

Hilton's law: It states that a motor nerve supplying a muscle which acts on a joint also supplies skin covering that particular joint.

Movements at Synovial Joints

Movements at synovial joints are produced by the contraction of skeletal muscles that span the joints and attached to the bones articulating. In these actions, the bones act as levers, the muscles provide the force, and the joints are the fulcra or pivots. Our bodies are composed of a variety of synovial joints that function as lever systems. The lever has three parts—effort, fulcrum and a load.

a. An effort or force applied to the lever (a muscle's applied force at the insertion site of a bone)
b. A fulcrum (the joint axis)
c. A load (the body part/weight to be moved).

The range of movement at a synovial joint is determined by the structure of the individual joint and the arrangement of the associated muscle and the bone. The movement at hinge joint, for example, occurs in only one plane, whereas the structure of a ball and socket joint permits movements around many axes. Joint movements are broadly classified as angular and circular.

Angular Movements

Angular movements increase or decrease the joint angle produced by the articulating bones. Following are the types of angular movements.

Flexion: Flexion is a movement that decreases the joint angle on an antero-posterior plane. Examples of flexion are the bending of the elbow or knee. Flexion of the elbow joint is a forward movement, whereas flexion of the knee joint is a backward movement. Flexion in most joints is simple to understand, such as flexion of the neck as the head is bowed. In the ankle joint the flexion occurs as the dorsum of the foot is elevated. This movement is frequently called dorsiflexion. Pressing the foot forward is plantar flexion.

Extension: In extension, which is the reverse of flexion, the joint angle is increased. Extension returns the body to the anatomical position. In an extended joint the joint angle between the articulating bones is 180°. The exception to this is the ankle joint, in which there is a 90° angle between the foot and leg in the anatomical position. Examples of extension are the straightening of the elbow or knee joints from flexion positions. Hyperextension occurs when a part of the body is extended beyond the anatomical position so that the joint angle is greater than 180°. An example of hyperextension is tipping the head backwards.

Abduction: Abduction is the movement of a body part away from the main axis of the body or away from the midsagittal plane, in a lateral direction. Examples of abductions are moving the arms sideward and away from the body or spreading the fingers apart.

Adduction: Adduction, the opposite of abduction is the movement of a body part towards the main axis of the body. In the anatomical position the arms and legs have been adducted towards the midplane of the body.

Circular Movements

Joints that permit circular movement are composed of a bone with a rounded or oval surface that articulates with a corresponding cup or depression on another bone. The two basic types of circular movements are rotation and circumduction.

- **Rotation:** Rotation is the movement of the body part around its own axis. There is no lateral displacement during this movement. Examples are turning the head from side to side in a 'no' motion.
- Supination (rotation of the forearm in which the palm of the hand being turned anteriorly) and pronation (rotation of the forearm in which the palm being turned posteriorly) are the specialized rotations of forearm.
- **Circumduction:** Circumduction is the circular, cone-like movement of a body segment. The distal extremity forms the circular movement and proximal attachment forms the pivot. The example for circumduction is the bowling action (in cricket) at shoulder joint.

Eversion, inversion, protraction, retraction, elevation and depressions are the special movements described in certain joints.

Clinical Notes

Dislocation (luxation): The articulating surfaces of the bones are forced out of position. This displacement can damage the articular cartilages, tear ligaments or distort the joint capsule. The capsule and ligaments are innervated by nerves and hence dislocation is very painful. The damage accompanying a partial dislocation or subluxation is less severe.

Sprain: It is ligamentous tear in a joint which causes severe pain in the joint.

Age-related structural changes in the articular cartilages are main cause of joint problems in elderly people often affecting the weight-bearing joints like knee and hip. The articular cartilage becomes less effective shock absorber as a result the articulation becomes vulnerable to repeated friction that occurs during joint movement. This can cause severe pain.

Arthritis: It is the inflammation of the joint(s). It can be caused by a variety of diseases. The joint is swollen, and movements are restricted and painful (rheumatic arthritis, rheumatoid arthritis). Osteoarthritis is a degenerative joint disease in elderly people characterized by stiffness, discomfort, and pain. It usually affects the weight-bearing joints like hip and knee.

Arthroscopy: It is a procedure by which the joint cavity can be examined through an arthroscope. This procedure not only helps in identifying joint abnormalities (such as torn menisci) but some surgical procedures can also be performed during this procedure.

CIRCULATORY SYSTEM

The circulatory system consists of the heart and the arteries and veins that convey blood throughout the body. Blood must always circulate to sustain life. The blood gets oxygenated in the lungs from the air we breathe. The oxygenated blood is pumped to all parts of the body through the pumping action of the heart. The pumping of the heart drives the blood flow through the arteries, capillaries, and veins. One set of blood vessels circulates blood through the lungs for gas exchange (pulmonary circulation). The other vessels which carry oxygenated blood to the tissues and bring back less oxygenated blood back to the heart (systemic circulation).

Pulmonary and Systemic Circulation

Pulmonary circulation moves blood between the heart and the lungs. It transports deoxygenated blood to the lungs to absorb oxygen and release carbon dioxide. The oxygenated blood then flows back to the heart. The right atrium of the heart receive venous or less oxygenated blood which then enters to the right ventricle. From the right ventricle, it enters the pulmonary trunk which divides into right and left pulmonary arteries to end in right and left lungs respectively. The oxygenated blood enters back to the left atrium of the heart through pulmonary veins. From the left atrium, blood enters the left ventricle. The left ventricle pumps the blood by powerful contraction to the aorta and its branches. The systemic circulation moves blood between the heart and the rest of the body. It sends oxygenated blood out to cells and returns deoxygenated blood to the heart (Fig. 2.18).

Portal Circulation

A portal circulation occurs through connecting veins, which are an additional network of vessels between arterial and venous circulation. The veins between the

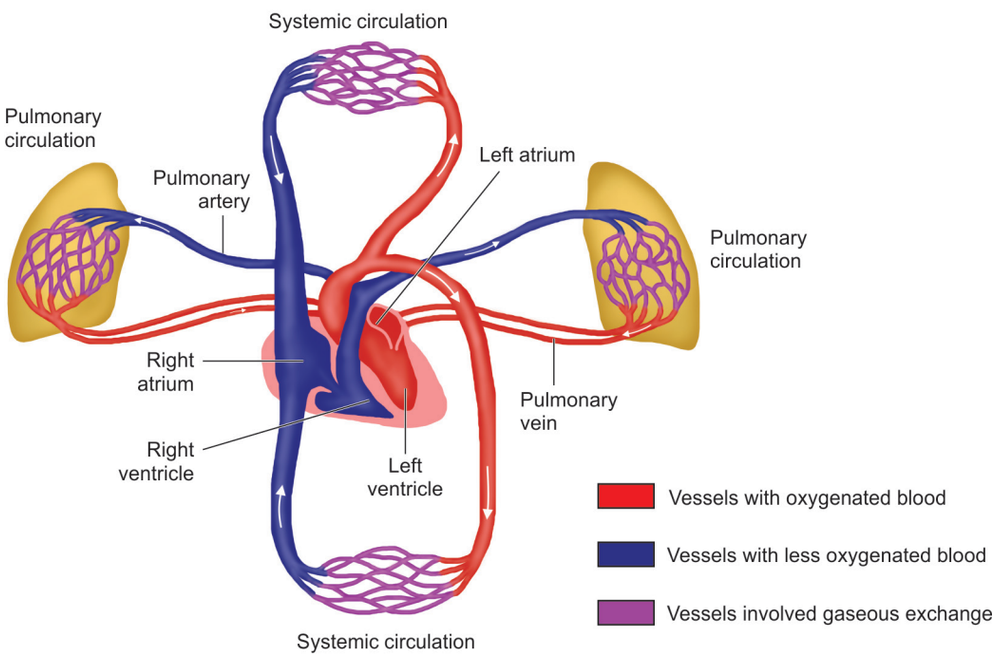


Fig. 2.18: Pulmonary and systemic circulation

connected capillaries are called portal veins. These portal vessels begin as capillaries and end as capillaries. For example, capillaries which arise from the wall of the stomach and intestine (venous blood having all the absorbed materials) form portal vein which ends in the liver by forming capillaries. It constitutes hepatic portal system. The master endocrine gland pituitary is supplied by portal vessels.

Blood Vessels

Blood vessels and lymphatic vessels are tubular channels, which carry nutrients to the tissue and metabolites back from the tissue into circulation. During cadaveric dissection arteries appear more bright, thick walled with patent lumen. The veins accompanying them appear darker in colour with thin wall and lumen is often collapsed (Fig. 2.19).

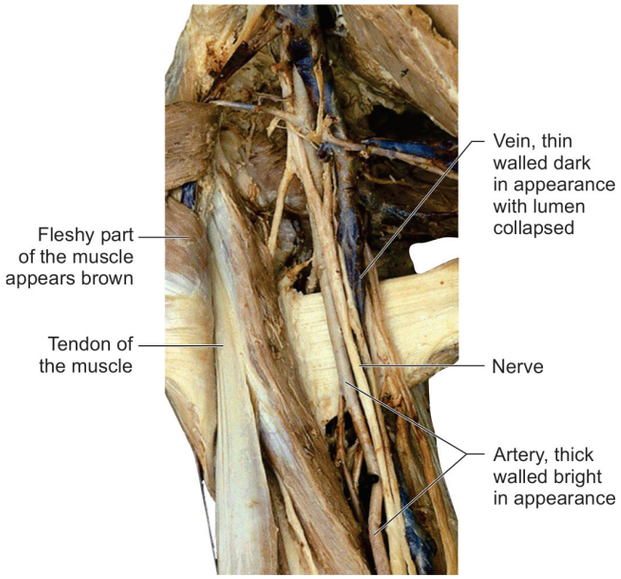


Fig. 2.19: Muscles, arteries and veins in a cadaveric specimen

Heart acts as a pumping organ which pumps oxygenated blood (arterial blood) to all the parts of the body through arteries. The pumping action of the artery maintains the pressure required for the arteries to carry the blood far away structures. The deoxygenated blood (venous blood) is brought back to the heart by veins, which is later carried to the lungs for oxygenation. The pulmonary arteries and umbilical arteries are exception that they carry venous (less oxygenated) blood.

Vascular Tree

The blood flows from heart through series of arteries. Which includes **large elastic arteries** (having diameter more than 10 mm). These large arteries divide into many **medium-sized muscular arteries** (diameter ranging between 2 to 10 mm). These medium sized artery gives many **small arteries** (diameter ranging between 0.1 and 2 mm). These small arteries give **arterioles** (diameter 10 to 100 πm) which finally ends in **capillaries** (diameter ranging between 4 and 10 πm). The capillaries give blood into the tissue. The blood flow in the capillaries is regulated by arterioles. The capillaries have arterial and venous ends. The venous end of the capillaries continues as venules which collect the blood from the tissue. They are also referred as **postcapillary venules** (diameter ranging between 10 and 15 πm). The postcapillary venules joins to form **muscular venule** (diameter ranging between 50 and 100 πm). The muscular venule joins to form small vein (diameter ranging between 0.1 and 1 mm). These small veins join to form **medium veins** (diameter ranging between 1 and 10 mm). These medium veins join to form **large veins** like superior and inferior vena cava (diameter greater than 10 mm). The wall of the blood vessels is made up of connective tissue fibres and smooth muscles. The lumen of the vessels is lined by cells called endothelial cells.

Arteries

- They carry blood away from the heart.
- They branch-like trees on their way to different parts of the body.
- The tiny branches of arteries are called arterioles.
- Arteries are thick walled, being uniformly thicker than the accompanying veins.
- The lumen is smaller than that of the veins accompanying it.
- Arteries do not have any valves.

Veins

- They bring blood from various tissues of the body back into the heart.
- The veins are formed by the union of many tributaries (like a river).
- The small veins are called 'venules', they join to form veins, which further form large veins and finally vena cavae before entering the heart.
- Veins are thin walled, being thinner than the arteries.
- Their lumen is larger.
- Veins have '**valves**' which are reduplications of endothelium. They maintain the unidirectional flow of blood even against gravity (Fig. 2.20). However, some of the veins do not have valves, e.g. emissary veins and veins of the vertebral column.

Venae comitantes: These are pair of veins that closely accompany an artery in such a manner that the pulsations of the artery aid venous return. This arrangement serves as a countercurrent heat exchanger. The warm arterial blood warm the cooler venous blood.

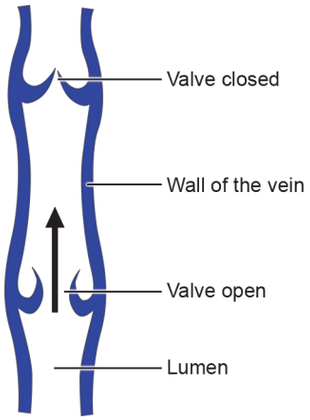


Fig. 2.20: Valves inside the veins

Capillaries (*capillus* = hair): These are microscopic blood vessels within the tissue. They have single layer of endothelial cells resting on a basement membrane, without any outer coats (Fig. 2.21A). Capillaries have arterial and venous ends. The diameter of a capillary is 6–8 microns; however, the capillaries of skin and bone marrow have larger diameter. Three types of capillaries in the body: Continuous capillaries (present in muscle and brain), fenestrated capillaries (present in kidney, intestine and endocrine glands) and sinusoids (present in lymphoid organs).

Sinusoids: Sinusoids (also called discontinuous capillaries) are located in certain organs like liver, spleen, bone marrow and endocrine glands. The lumen of the sinusoid is large and irregular. Their wall is thinner and incomplete with spaces within the endothelial cells. The basal lamina of endothelial cells is replaced by fine reticular fibres (Fig. 2.21B). The functional aspect of the capillaries and sinusoids are discussed in histology of the blood vessels.

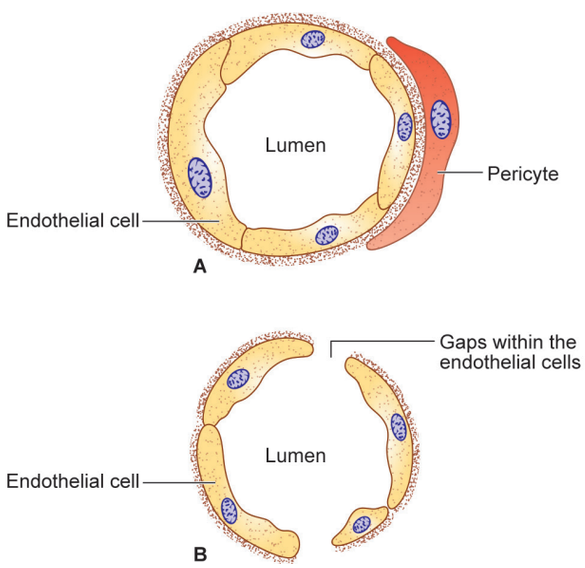


Fig. 2.21: **A**: Capillary; **B**: Sinusoidal capillary

Anastomosis

A precapillary or postcapillary communication between the neighboring vessels is called anastomosis.

Types

1. **Arterial anastomosis:** The terminal branches of arteries or arterioles join with each other to form anastomosis, e.g. Palmar arch, plantar arch, circle of Willis (arteries supplying the brain), intestinal arcades. On sudden occlusion of a main artery, the anastomosis may facilitate a collateral circulation.
2. **Venous anastomosis:** It is the communication between the veins or tributaries of the vein, e.g. dorsal venous arch of hand and foot.
3. **Arteriovenous anastomosis:** It is the direct communication between the arteries and veins. There will be a network of capillaries between the arteriole and venule. When the organ is at rest the blood bypasses these capillaries (Fig. 2.22). The arteriovenous anastomosis (AV) is observed in skin of the fingertips, nasal cavity, lips, mucous membrane of the alimentary canal, erectile tissue (penis and clitoris), tongue, thyroid gland, etc. Contraction of the arteriole smooth muscle of the AV shunts send blood to a capillaries bed while relaxation of the smooth muscle sends blood to a venule, bypassing capillary bed. AV shunt serves in thermoregulation at the body surface. Closing the AV shunt in the skin causes blood to flow through the capillary bed, enhancing heat loss. Opening AV shunt in the skin reduces the blood flow in the capillaries, conserving the body heat.

End-arteries

Arteries which do not anastomose with their adjacent arteries are called end arteries. Occlusion of an end artery causes severe ischemia resulting in death of

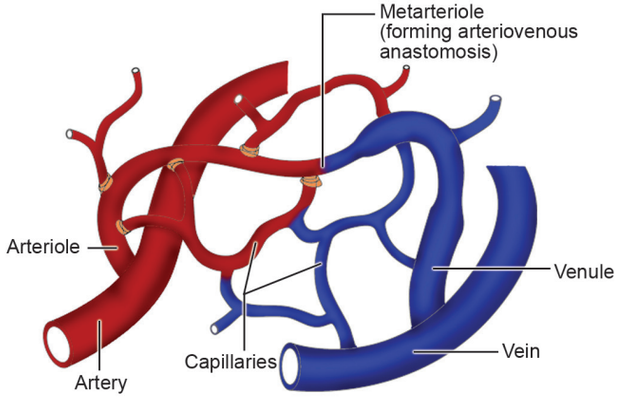


Fig. 2.22: Microcirculation at capillary level

the tissue. Occlusion of central artery of retina results in permanent blindness.

Examples: (i) Central artery of retina, (ii) central branches of cerebral arteries, (iii) vasa recta of the mesenteric arteries.

Clinical Notes

Haemorrhage (bleeding) is a flow of blood (bleeding). Arterial haemorrhage causes spurting of bright red blood and venous haemorrhage cause oozing (steady stream) of dark blood.

Arteriosclerosis: In old age the arteries become stiff. It is a thickening and toughening of arterial wall. The amount of blood flow through these arteries is reduced which can rise the systolic blood pressure.

Atherosclerosis is a type of arteriosclerosis characterized by changes in the endothelial lining. A fatty mass of tissue is projected into the lumina of the vessels.

Ischemia: It refers to reduction of blood supply to an organ or region as consequences of atherosclerosis or a thrombus formation or occlusion of a vessel by adjacent structure. Arterial occlusion resulting in ischemia is characterized by **5 Ps—pallor (pale), pain, puffiness, pulselessness and paralysis** (involving muscles).

Infarction: It refers to death or necrosis of an area of tissue or an organ resulting from reduced blood supply. Such infarction in heart causes heart attack, stroke in brain and gangrene in distal parts of the limbs.

Arteritis: An inflammation of an artery is called arteritis. Inflammation of a vein is called phlebitis.

Thrombosis: It is the coagulation of blood in the vessels. The clot thus formed is termed thrombus.

Embolism: An obstruction of blood vessel, usually in an artery by a thrombus (blood clot), fat cells, air, etc.

Aneurysm: A permanent dilatation of an artery usually with rupture of the internal and middle coats. The thoracic aorta and the innominate artery (brachiocephalic trunk) are usually affected.

Varicose veins: These refer to abnormally dilated and twisted superficial veins, which more frequently affect the limbs. The walls of the vein become weak and do not withstand the pressure resulting in its dilation. The valves become incompetent, thus causing regurgitation of the blood. Varicose vein can also occur due to inflammation of valves.

Arteriovenous (AV) fistula: An arteriovenous (AV) fistula is an abnormal connection between an artery and a vein. With an arteriovenous fistula, blood flows directly from an artery into a vein, bypassing some capillaries. Arteriovenous fistulas usually occur in the legs but can develop anywhere in the body. Arteriovenous fistulas are often surgically created for use in dialysis in people with severe kidney disease.

LYMPHATIC SYSTEM

Lymphatic system is a drainage system, which removes larger particles from the tissue fluid.

The lymphatic system consists of lymph vessels, lymphoid organs and circulating lymphocytes.

Lymph formation: The nutrients to the tissue are given by artery, arteriole and finally capillaries at tissues. The fluid from the tissue is taken up by venous end of the capillaries and then circulates through venules and veins. This is what you have studied before. However, lymphatic vessels absorb about 10–20% of the tissue fluid, which begins at the tissue spaces. The tissue fluid flowing through these vessels is called **lymph**. This lymph fluid finally drains into larger veins through lymphatic vessels (Fig. 2.23).

Lymphatic vessels: The lymphatic capillaries begin blindly in the tissue spaces. Lymphatic vessels are connected to each other forming a network. The superficial lymphatic vessels accompany veins while deep lymphatic vessels usually accompany arteries. Larger lymphatic vessels are named, for example thoracic duct. Lymph nodes are present in relation to the lymphatic vessels. The caliber of lymphatic capillary is greater and less regular than blood capillaries. Lymph fluid is colourless but, in the intestine, it is milk-white due to absorption of fat. It is called **chyle**. Lymphatic capillaries are absent in brain, spinal cord, bone marrow and other avascular structures.

Lymphoid Organs

Lymphatic organs are classified into central and peripheral lymphatic organs.

- **Central lymphatic organs** are bone marrow and thymus. The lymphoid stem cells are produced by bone marrow except during early foetal life (produced by spleen and liver). The stem cell undergoes differentiation in these central lymphatic organs and becomes competent. Bone marrow differentiates the B lymphocytes, which are capable of synthesizing antibodies. Thymus differentiates immunologically competent but uncommitted T lymphocytes.
- **Peripheral lymphatic organs** include lymph nodes, spleen, tonsil and lymphoid tissue present in the wall of the gastrointestinal and respiratory tracts. The

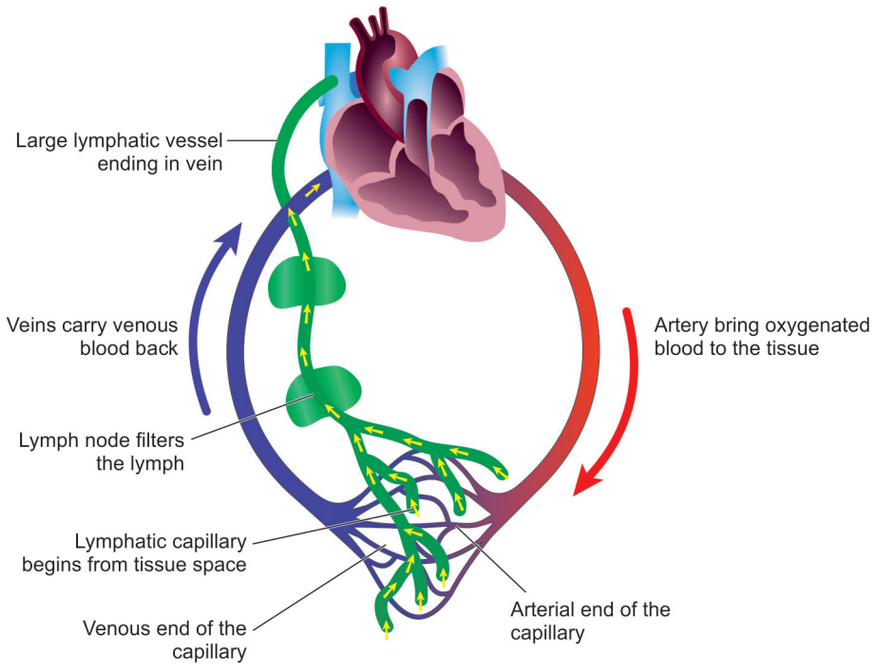


Fig. 2.23: Lymphatic system schematic

B and T lymphocytes reach peripheral lymphatic organs where they proliferate and mature into immunocompetent cells (Fig. 2.24).

Lymph Nodes: Lymph nodes are oval, or bean-shaped structures present in the course of small lymphatic vessels. They filter the lymph and multiply lymphocytes. Lymph nodes are present in-groups. The superficial lymph nodes are arranged along the veins and the deep nodes along the arteries. Each lymph node has a hilum. The artery enters the node and vein and one efferent lymphatic vessel emerge at this place. However, afferent lymphatic vessels are many in number, which enter the lymph node at many points along its periphery. Further microscopic details are discussed under histology section.

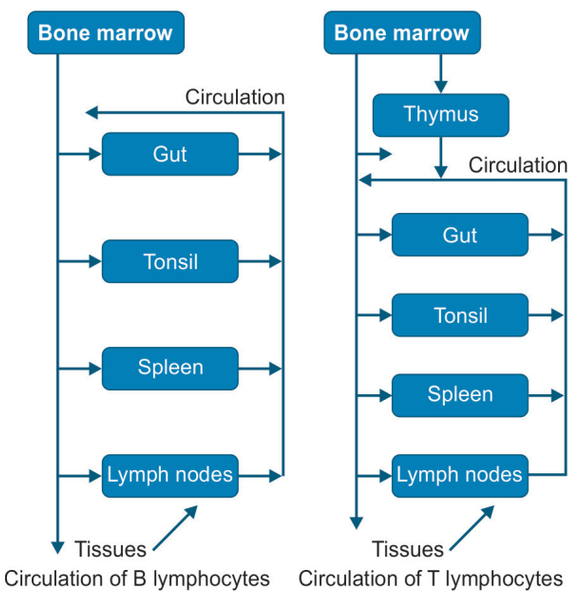


Fig. 2.24: Circulation of lymphocytes

Functions of the Lymphoid System

- Lymphatic vessels drain large protein molecules from the tissue places. Thus, cellular debris and foreign particles (dust particles inhaled into the lungs, bacteria and other micro-organisms) are drained by this system.
- Lymphatic vessels help in transportation of fat from the gut.
- Lymph node serves the following functions:
  a. They filter the lymph and prevent the foreign particles entering into the bloodstream.
  b. The foreign particles are phagocytosed by macrophages.
  c. These lymphocytes multiply in the lymph nodes.
  d. These lymphocytes provide both humoral and cellular immunity against the antigens.

Further details were discussed in Chapter 12: 'Lymphatic System'.

Clinical Notes

Lymphadenopathy: It refers to chronic or excessive enlargement of lymph node.

Lymphomas: A malignant cancer consisting of abnormal lymphocytes or lymphocytic stem cells.

Autoimmune disorder: A disorder that develops when the immune response mistakenly targets normal body cells and tissues.

Lymphangitis: Inflammation of the lymphatic vessels can occur while draining an infected area. The lymphangitis is marked on the skin as painful red lines and swollen lymph nodes.

Elephantiasis: The filarial parasite in the lymphatic vessel may block it and results in oedema (elephantiasis) in the peripheral area of the drainage.

Cancer spread through lymphatic vessels: Cancer can invade the adjacent tissue by direct contact and spread into distant sites (metastasis) by lymphatic vessels or blood vessels. Lymphatic route is the most common way of metastasis. Hence, lymphatic drainage of those organs which are commonly involved in cancer should be studied in greater detail which is helpful in the diagnosis of the primary site of the cancer. From the affected organ the cancer spread in the direction of lymph flow from that organ, hence it is important to know proximal and distal sets of lymph nodes for each organ. Understanding of lymphatic drainage of an organ helps in:

- To know what nodes are likely to be affected when a tumor is identified in an organ or a tissue.
- To be able to locate the likely sites of primary cancerous sites, when enlarged node is detected.

NERVOUS SYSTEM

The human nervous system is the most complex physical system known to mankind. At present our understanding of this complex system seems to be very rudimentary. This system provides a complex mechanism by which the living organism can react to the ever-changing external and internal environment and thus enabling the survival of human species. The nervous system is divided into the **central nervous system (CNS)**, which consists of brain and the spinal cord and the **peripheral nervous system (PNS)** which consists of cranial and spinal nerves with their associated ganglia.

Nervous tissue: Nervous tissue consists of two types of cells: Neurons and neuroglial cells.

Neurons

Neurons are basic structural and functional units of the nervous system. These are excitable cells of nervous tissue. They respond to physical and chemical stimuli. They conduct the impulses and release specific chemical regulators. In adults, the neurons cannot divide mitotically, but some neurons can regenerate.

Microscopic structure of a neuron: The principal components of the neurons are—cell body, dendrites and axon (Fig. 2.25).

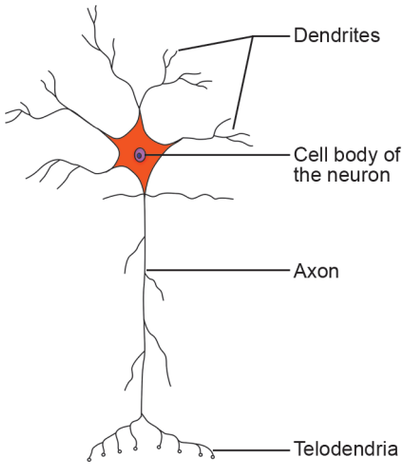


Fig. 2.25: Parts of the neuron

Cell body: The cytoplasm of the cell body is covered by a cell membrane with centrally placed nucleus. The cytoplasm presents numerous mitochondria, Golgi complex, ribosomes and lysosomes. It has been said that centrioles are absent in neurons, however, recent electron microscopic studies have confirmed the presence of centriole. The most characteristic feature of the cytoplasm of the neuron is presence of granular material called '**Nissl substance**' (Nissl bodies/granules). This Nissl substance is composed of rough endoplasmic reticulum. The cytoplasm of the neuron also shows 'neurofibrils' which consist of microfilaments and microtubules (Fig. 2.26). The

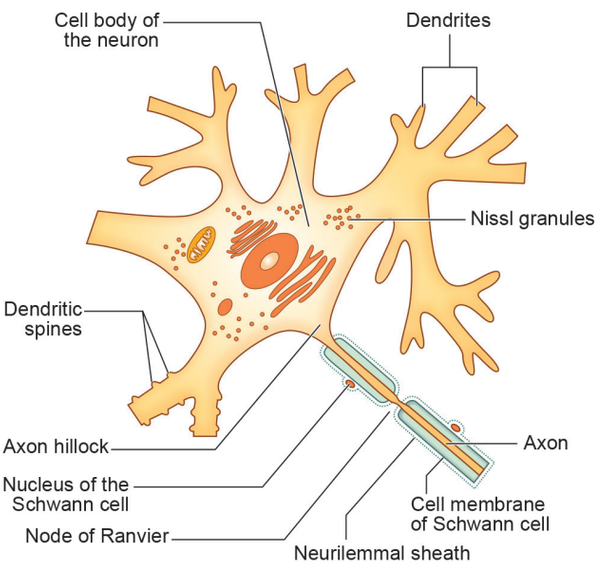


Fig. 2.26: Cell body of the neuron

cytoplasmic processes of neurons are of two types: Dendrites and axons.

Dendrites: These are branched processes that extend from the cytoplasm of the cell body. Their function is to **receive stimuli** and conduct impulses to the cell body. Some dendrites present minute 'spines' that increase their surface area. The dendrites contain 'Nissl substance' which is absent in the axons. The Nissl-free zone extends partly to the cell body and is called axon hillock.

Axon: Axon is the long cytoplasmic extension from the cell body. The term 'nerve fibre' is commonly used with reference to either an axon or an elongated dendrite. Axons conduct **impulses away** from the cell body. Their length varies from few millimeters in the CNS to over meter in the PNS. The side branches called collateral branches extend for a short distance from the axons.

Classification of Neurons

Neurons are classified in different ways. Based on functions they are classified into:

1. **Sensory neurons:** They carry impulses from the receptors through peripheral nerves into the CNS. These nerve fibres constitute somatic afferent (sensation of pain, temperature, touch, and pressure from the body surface) and visceral afferent (transmit pain impulses and other sensations from internal organs).
   Example: Bipolar neurons which bring information from ear (for hearing and balancing through eighth cranial nerve), pseudounipolar neurons of dorsal root ganglion of spinal nerves, rods and cones of retina.
2. **Motor neurons:** They convey impulses from the CNS or ganglia to effector cells. Somatic efferent neurons send impulses to skeletal muscles (induce or inhibit muscle contraction). Visceral efferent neurons send impulses to smooth muscle, cardiac muscles and glands (induce or inhibit glandular secretion).
   Example: Multipolar neurons of spinal cord, grey matter and autonomic ganglia. Pyramidal cells of the cerebral cortex, Purkinje cells of the cerebellar cortex.
3. **Interneurons:** They carry signals between motor neurons and sensory neurons. It is estimated that more than 99.9% of all neurons belong to this integrated network.

According to the number of cytoplasmic processes they may be classified into (Fig. 2.27):

1. **Unipolar neurons/pseudounipolar neurons:** One process arising from the cell body dividing into two—one central process (axon) and the other peripheral process (dendrite). For example, mesencephalic nucleus and dorsal root (posterior root) ganglia of spinal nerves.
2. **Bipolar neurons:** Two processes arise from the cell body separately and one of them acts as axons and the other as dendrite, e.g. spiral and vestibular ganglion of the internal ear.
3. **Multipolar neurons:** The cell body presents many cytoplasmic processes, one acting as axon and the rest as dendrites. Majority of the neurons are multipolar.

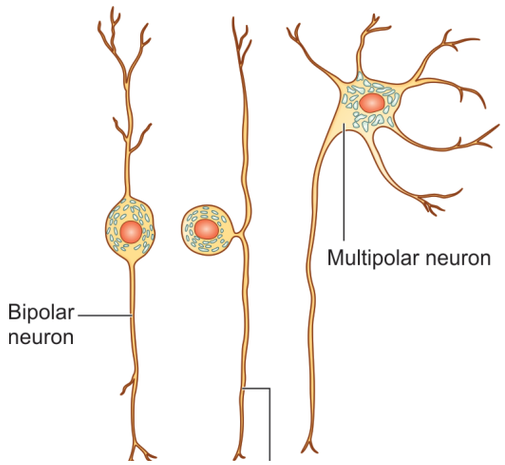


Fig. 2.27: Types of neurons

According to the length of axon, the neurons are classified into:

1. **Golgi type I:** They have long axons that may be 1 m or more in length. The axons of these neurons form long fibre tracts of the brain and spinal cord and the nerve fibres of the peripheral nerves.
2. **Golgi type II:** They have short axons that terminate in the neighborhood of the cell body, or it is entirely absent. They are more numerous than Golgi type I. Because of short dendrites arising from the cell body, the neurons appear to be star-shaped (stellate). They are found in cerebral and cerebellar cortex and often inhibitory in function.

Based on the neurotransmitter the neurons are classified into cholinergic, adrenergic, noradrenergic, serotonergic, dopaminergic, GABAergic neurons. These are discussed in Chapter 13.

Neuroglia (Glial Cells)

These are non-excitable supporting cells of the nervous tissue. They are more numerous than neurons and have limited mitotic capacity. There are many varieties of neuroglial cells (Fig. 2.28).

Astrocytes: These cells are stellate in appearance. They are present at the site of blood–brain barrier.

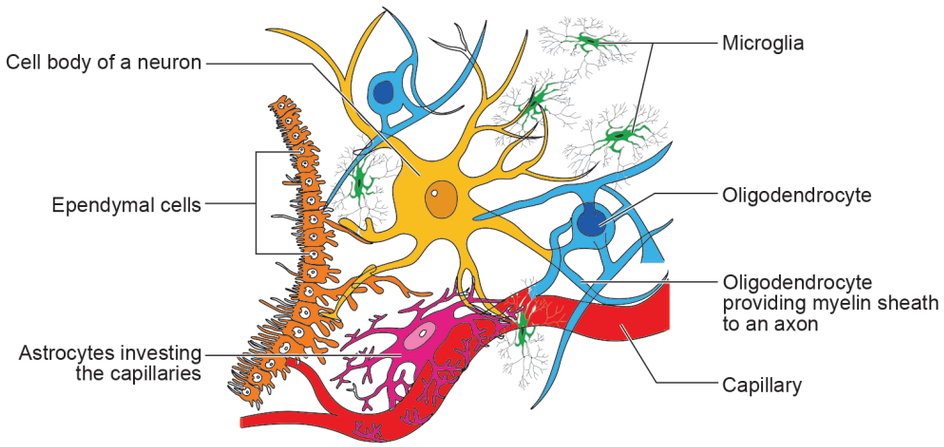


Fig. 2.28: Glial cells

They regulate the passage of molecules from the blood to brain. Astrocytes are the primary glycogen stores in the CNS. Further details are explained in microscopic structure of nervous tissue.

Oligodendrocytes: They have small cell bodies and few delicate processes. These cells form myelin sheath around the axons in CNS.

Microglial cells: These are small cells with flat cell body and few short cellular processes. They are found along the perivascular coat of blood vessels in CNS. They are phagocytic in function and act as macrophage cells of the CNS.

Ependyma: These are simple columnar or cuboidal cells with non-motile cilia, lining the cavities of the brain (ventricles) and central canal of the spinal cord.

Schwann cells: These cells provide myelin sheath for the PNS.

Synapse

The junction between the neurons is called synapse. Synapses may be of various types depending on the parts of neurons that come in contact (Fig. 2.29). Further details about the synapse will be discussed in Chapter 13, under "Nervous tissue".

What is a Nerve or a Nerve Fibre?

A nerve fibre or a nerve can be defined as 'collection of cytoplasmic processes (mainly axons) of neurons'. Functionally, nerves resemble like electric wires. Like the electric current flowing through the wires, the impulses (sensory and motor) are conducted through the nerves.

Myelination

Myelination is a process in which a neuroglial cell surrounds a portion of the axons or dendrite to provide support and to facilitate the conduction of impulses. If the axons are covered with concentric layers of myelin sheath, then the nerve is **myelinated**. Myelinated nerve fibres are found in peripheral nerves and in the white matter of the CNS. The grey matter of the brain and spinal cord is mostly composed of non-myelinated fibres (Fig. 2.30A). The myelin sheaths act as an insulator of nerve fibre and reduce the loss of electrical activity into the surrounding tissue by dispersion. The node of Ranvier helps in faster conduction of impulses (Fig. 2.30B).

Spinal Nerves

These nerves arise directly from the spinal cord. There are 31 pairs of spinal nerves.

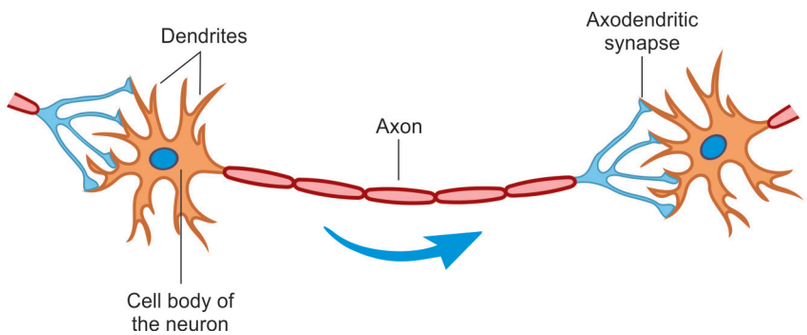


Fig. 2.29: Schematic representation of a synapse

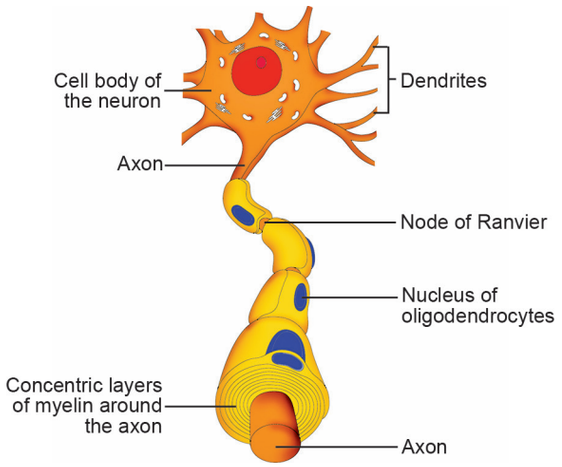


Fig. 2.30A: Myelination

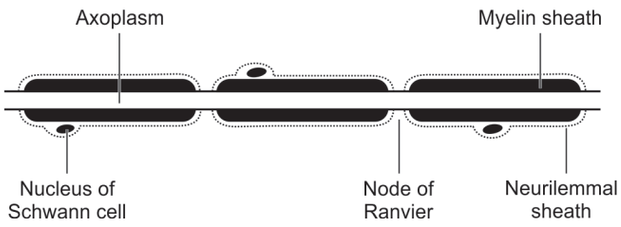


Fig. 2.30B: Myelinated nerve fibre showing node of Ranvier

It includes 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal nerves.

Formation of a Typical Spinal Nerve

- Each spinal nerve arises from the spinal cord by two roots (Fig. 2.31).
- Ventral root is motor, which arises from the anterior grey horn of the spinal cord. These are axons arising from the cell bodies of the motor neurons located in the anterior grey horn. The impulses arise from the cell body and pass through their axons which form ventral root. Hence, ventral root is motor.
- Dorsal root is sensory which shows a ganglion called 'dorsal root ganglion'. The ganglion contains many pseudounipolar neurons. The peripheral process (dendrites) of these neurons ends in receptors. They bring sensation from these receptors to cell body located in the dorsal root ganglion. The central process (axons) of the pseudounipolar neurons enters the spinal cord as dorsal root. Hence, dorsal root is sensory.
- The ventral and dorsal roots join to form mixed spinal nerve trunk, which again divides into ventral (anterior primary rami) and dorsal rami (posterior primary rami).
- At certain places, ventral rami of the spinal nerves join together and branch to form **nerve plexus**.

For example, cervical plexus, brachial plexus, lumbar plexus, sacral plexus of nerves.

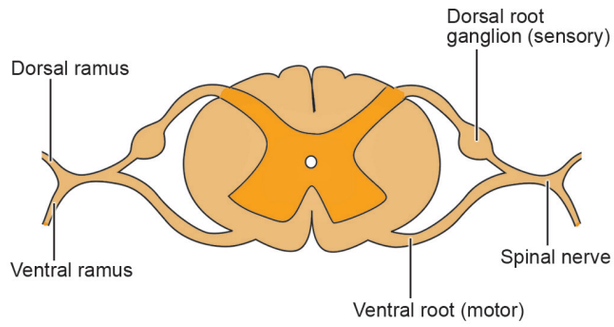


Fig. 2.31: Formation of a typical spinal nerve

Nerve Plexus

The human body is supplied by 12 pairs of cranial nerves and 31 pairs of spinal nerves. The distribution of cranial nerves is mainly confined to the head and neck region except for vagus nerve (which extends up to the abdomen). The remaining major part of the body is supplied by spinal nerves in a sequential manner. Some of these spinal nerves anterior primary rami form nerve plexus after emerging from the spinal cord outside the vertebral canal. They include cervical, brachial, lumbar and sacral nerve plexus. The limbs are often considered as extensions from the body. In order to reach the limbs, the spinal nerves form plexus.

The **cervical plexus** is formed from the anterior primary rami of C1–C4 nerves.

The **brachial plexus** is formed by anterior primary rami of C5 to T1 spinal nerves and it supplies upper limb.

The **lumbar plexus** is formed by anterior primary rami of L1 to L4 spinal nerves. It mainly supplies lower limb.

The **sacral plexus** is formed by anterior primary rami of L4 to S4 spinal nerves. It supplies lower limb.

Reflex Arc

It is a neuronal pathway that controls the action reflex. A simple monosynaptic reflex pathway consists of only two neurons. For example, touching a fire and reflex withdrawal of the hand. The pain fibres from the receptors in the skin are carried by neurons present in the dorsal root ganglion (afferent pathway) to the spinal cord, where it stimulates the motor neurons. The impulses from the motor neurons pass through the nerve fibres (efferent pathway) and end in the muscle (effector organ) required to act for withdrawal of the hand. These reflex pathways do not involve brain but are mediated through the spinal cord for relatively quicker action. The reflex arc has an afferent and an efferent limb (Fig. 2.32A and B). If the reflex

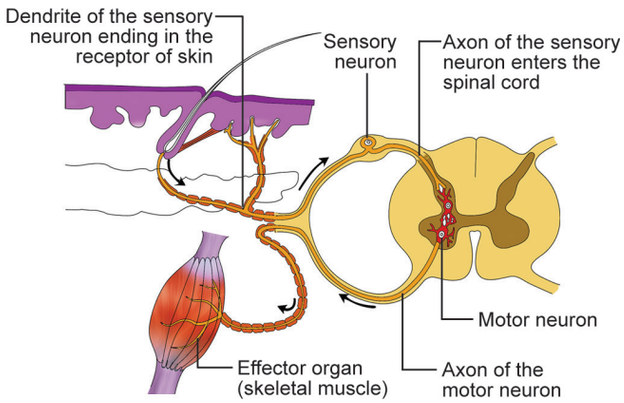


Fig. 2.32A: Components of a reflex arc

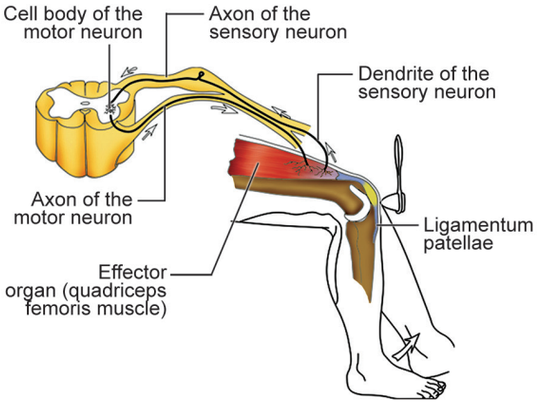


Fig. 2.32B: Reflex arc

arc consists of more than two neurons, it is referred as polysynaptic reflex arc, e.g. light reflex.

Some of the Important Terminologies used in the Nervous System

Nerve is a collection of nerve fibres outside the central nervous system.

Sensory nerves carry information from the peripheral part to the CNS, e.g. cutaneous nerve, optic nerve, vestibulocochlear nerve.

Motor nerve is the nerve which carries impulses from the CNS to the target muscle (Fig. 2.33).

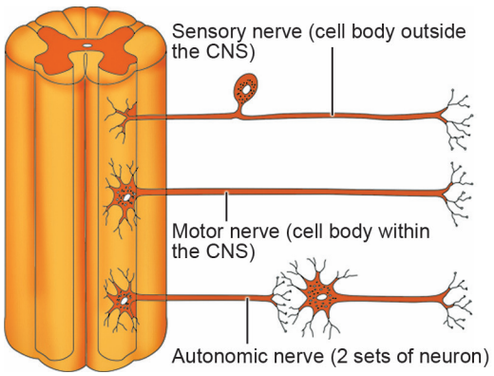


Fig. 2.33: Motor, sensory and autonomic nerves

Grey matter is the collection of cell bodies of neurons within the central nervous system. Such aggregation, when it is smaller in size is referred as 'nucleus' (not to be confused with nucleus of a cell) in the brainstem.

White matter is mainly collection of nerve fibres with few supporting glial cells in the central nervous system.

Ganglia are a collection of cell bodies of neurons outside the central nervous system.

Root value: The root value of a nerve refers to its segmental origin from the spinal cord. For example, the root value of axillary nerve is C5 and C6. It means the axillary nerve is derived from fifth and sixth cervical segments of the spinal cord.

Cranial Nerves

There are 12 pairs of cranial nerves, which arise directly from the brain. Following are the cranial nerves.

Olfactory: It is the first cranial nerve concerned with carrying smell sensation from the nasal cavity.

Optic: It is the second cranial nerve concerned with vision. It carries visual information from the retina.

Oculomotor: It is the third cranial nerve and is motor. It supplies many muscles moving the globe of the eye (extraocular muscles).

Trochlear: It is the fourth cranial nerve and is motor. It supplies superior oblique muscle which acts on globe of the eye.

Trigeminal: It is the fifth cranial nerve and is mixed (both sensory and motor). It has three divisions—ophthalmic, maxillary and mandibular. Through these branches it supplies head and neck region.

Abducent: It is the sixth cranial nerve and is motor. It supplies lateral rectus muscle which acts on the globe of the eye.

Facial: It is seventh cranial nerve and is motor. It mainly supplies muscles of face.

Vestibulocochlear: It is the eighth cranial nerve having two components; vestibular and cochlear. The vestibular component is concerned with maintaining the body balance and the cochlear component is concerned with hearing. It carries auditory information from the internal ear to the brain.

Glossopharyngeal: It is the ninth cranial nerve and is mixed. It mainly supplies posterior part of

the tongue and also a muscle of the pharynx called stylopharyngeus.

Vagus: It is the tenth cranial nerve and has the longest course compared to the rest of the cranial nerves. It has mainly parasympathetic fibres which supplies heart, lungs and abdominal organs. It also supplies larynx.

Accessory: It is the eleventh cranial nerve, and it has two parts; spinal and cranial. The spinal part of the accessory nerve supplies two muscles in the neck (sternocleidomastoid and trapezius) while cranial part has short course inside the cranial cavity, then it joins the vagus nerve and distributed through the vagus.

Hypoglossal: It is the twelfth cranial nerve and is motor. It supplies muscles of the tongue.

AUTONOMIC NERVOUS SYSTEM

Autonomic nervous system along with endocrine glands maintains the constant internal environment (both of them are under the influence of hypothalamus). The maintenance of the constant internal environment (homeostasis) is performed by regulating the body temperature, blood pressure, cardiorespiratory rate, gastrointestinal motility and glandular secretion. They supply cardiac and smooth muscles (e.g. smooth muscles of the viscera, blood vessels, arrector pili (erector pylorum) muscle and intrinsic muscles of the eye and many glands).

Autonomic nervous system has two components:
a. Sympathetic
b. Parasympathetic

Sympathetic System

Functionally this system is 'sympathetic' to the body and its nerve is considered as 'nerve of emergency'. It prepares the body for fight or flight.

The pre-ganglionic sympathetic neurons are derived from intermediate (or lateral) horn cells of all thoracic and upper two lumbar segments of the spinal cord. This is often referred as '**thoracolumbar outflow**'. The fibres from these neurons pass through ventral motor root of the spinal nerve, then into the mixed spinal nerve. They leave the spinal nerve and reach sympathetic ganglion by white rami communicantes (pre-ganglionic) and relay in the sympathetic ganglion. It is referred white because they are slightly myelinated. Neurons of sympathetic ganglion act as post-ganglionic neurons. Postganglionic fibres from the sympathetic ganglion (Fig. 2.34).

a. Joins the spinal nerve again through grey rami communicantes (post-ganglionic). This is unmyelinated.

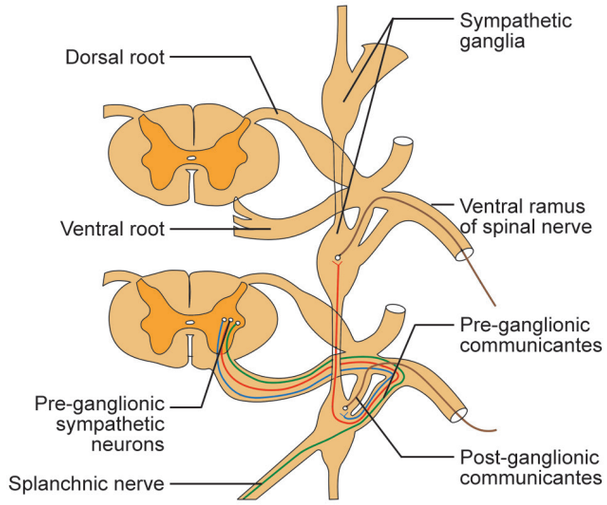


Fig. 2.34: Sympathetic outflow

b. Post-ganglionic sympathetic fibres emerge as 'splanchnic nerves' from the ganglia. They finally reach the target structures by forming plexus around the blood vessels.

The sympathetic fibres also carry visceral pain sensation to the spinal cord through dorsal root ganglia.

Ganglionated Sympathetic Chain

- There are two sympathetic chains (right and left), which are located in front of the vertebral bodies (Fig. 2.35).
- They extend from the base of the skull to the first piece of coccygeal vertebra where both chains unite to form a median ganglion called 'ganglion impar'.
- Each chain presents about 22 ganglia (3 cervical, 11 thoracic, 4 lumbar and 4 sacral).

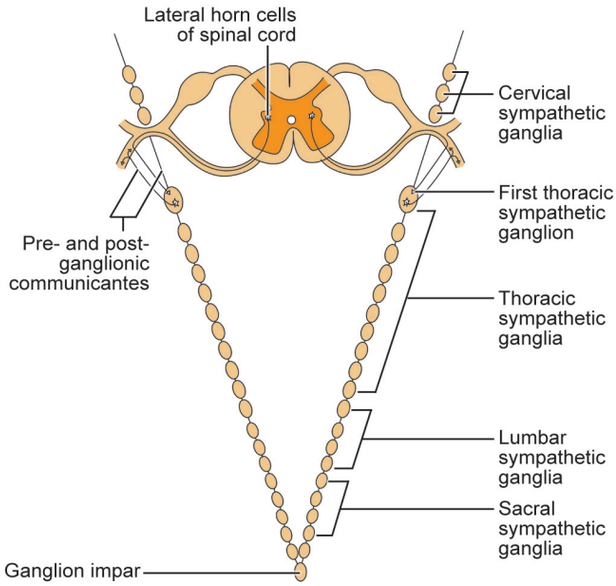


Fig. 2.35: Ganglionated sympathetic chain (schematic)

- All the thoracic and upper two lumbar sympathetic ganglia are connected with corresponding spinal nerves by both pre- and post-ganglionic communicantes. However, other ganglia send only post-ganglionic communicantes to the corresponding spinal nerve (hence 31 pairs of grey rami communicantes but only 14 pairs of white rami communicantes).
- Structurally the ganglia consist of multipolar neurons with supporting cells.
- Sympathetic system secretes non-adrenaline at the post-ganglionic endings.
- Sensory component of the sympathetic system conveys visceral pain sensation.

Parasympathetic System

The pre-ganglionic parasympathetic neurons are located mainly in few cranial nerve nuclei and also in sacral segments of the spinal cord (**craniosacral outflow**). Parasympathetic fibres are distributed through third, seventh, ninth and tenth cranial nerves. The parasympathetic system liberates acetylcholine at the post-ganglionic endings.

The pre-ganglionic parasympathetic fibres end in a ganglion (peripheral parasympathetic ganglion), which are located close to the target structure.

The pre-ganglionic parasympathetic fibres, of the oculomotor nerve relays in ciliary ganglion, of the facial nerve relays in pterygopalatine and submandibular ganglia, of the glossopharyngeal nerve relays in otic ganglion and of the vagus nerve in many unnamed ganglia located near the viscera. Further details will be discussed in Head and Neck section.

The pelvic splanchnic nerve carries fibres from ventral horn cells of second to fourth sacral segments of the spinal cord. These parasympathetic fibres supply pelvic organs like urinary bladder, uterus, uterine tubes, rectum, anal canal, etc.

Neurotransmitters in ANS

- **Acetylcholine** is liberated at all pre-ganglionic endings of both sympathetic and parasympathetic nerves.
- **Acetylcholine** is liberated at all post-ganglionic endings of parasympathetic nerves.
- **Norepinephrine**, a catecholamine, is the neurotransmitter at most sympathetic post-ganglionic endings. The exception includes sympathetic post-ganglionic neurons to eccrine sweat glands, and sympathetic vasodilator neurons to blood vessels in skeletal muscle which like parasympathetic secretes acetylcholine.
- Nitric oxide as their neurotransmitter in parasympathetic system for penile erection.

Table 2.2: Difference between sympathetic and parasympathetic nervous system

Sympathetic system	Parasympathetic system
• Increase the heart rate	• Decrease the heart rate
• Bronchodilator	• Bronchoconstriction
• Generally vasoconstriction (in coronary vessels, the vessels of the skeletal muscles and external genitalia, it causes vasodilation)	• Vasodilatation
• Inhibitory to GIT motility and secretion	• Stimulate the GIT motility and secretion
• Motor to sphincter of GIT	• Inhibitor to the sphincter GIT
• Dilates the pupil	• Constrict the pupil

- Sympathetic cholinergic activation releases acetylcholine that binds to muscarinic receptors, which stimulates sweating and dilates arteries in some tissues, most notably in the skin and skeletal muscle.

Clinical Notes

Irritation of a Nerve or Nerve Injury

- Irritating lesions (compression) of sensory nerve result in reduced sensation (hypesthesia) or altered sensation (paresthesia).
- Destructive lesions of sensory nerve result in a loss of sensory modality.
- Irritating lesions of motor nerve result in weakness of skeletal muscle (paresis).
- Destructive lesions of motor nerve result in paralysis of skeletal muscle.

When nerves are stretched, severed or crushed, their axons degenerate distal to the lesion because they depend on the cell bodies for survival. **If the axon is damaged with intact cell body, regeneration and restoration of function is possible.** In crushing type of injury, the connective tissue coverings of the nerve is intact, which guides the cut ends of the axons to grow to their destination. But a cutting nerve injury requires surgical intervention because regeneration of axons requires apposition of the cut ends by suture through epineurium. Compression of blood vessels supplying the nerve can also cause nerve degeneration.

CNX axons with myelin sheath formed by oligodendrocytes do not regenerate if cut. Myelinated axons in the PNS have the capacity to regenerate due to neurilemmal sheath of Schwann cells.

Demyelination: The progressive destruction of myelin sheath in the CNS and PNS, leading to a loss of sensation and motor control. Demyelination is associated with heavy metal poisoning, diphtheria and multiple sclerosis.

Neuralgia: A severe pain along the distribution of a nerve.

Neuritis: It refers to an inflammation of a nerve with neuralgia and is also associated with the loss of sensory and motor functions.

MCQs

1. Which of the following refers to the skin folds present opposite to the joint?
A. Papillary ridges B. Langer's lines
C. Voight lines D. Flexure lines

2. Which of these tissues mainly presents in the superficial fascia?
A. Loose connective tissue
B. Adipose tissue
C. Dense connective tissue
D. Elastic tissue

3. Which of the following tissue connects the anterior ends of the ribs with the sternum?
A. Fibrous cartilage B. Hyaline cartilage
C. Compact bone D. Spongy bone

4. Which of the following structure is not a hyaline cartilage?
A. Epiphyseal plate B. Tracheal rings
C. Thyroid cartilage D. Epiglottis

5. Which of the following bones is an example for pneumatic bone?
A. Parietal bone B. Mandible
C. Hyoid bone D. Maxilla

6. Which of the following is not a sesamoid bone?
A. Malleus B. Fabella
C. Pisiform D. Patella

7. Which of these parts of the developing long bone develops from secondary centre of ossification?
A. Epiphysis B. Diaphysis
C. Metaphysis D. Symphysis

8. Which of the following bones is an example for dermal bone?
A. Femur B. Hip bone
C. Clavicle D. Humerus

9. Which of the following bones violates the laws of ossification?
A. Tibia B. Fibula
C. Radius D. Ulna

10. Which of the following muscles is an example for bipennate muscle?
A. Middle fibres of deltoid B. Rectus femoris
C. Palmar interossei D. Flexor carpi ulnaris

11. Which of the following statement is incorrect regarding the smooth muscles?
A. They are present in the wall of the stomach
B. They do not exhibit cross striations
C. They are made up of actin and myosin filaments
D. They respond quickly to stimuli

12. The inferior tibiofibular joint belongs to which of these variety of joint?
A. Primary cartilaginous B. Syndesmosis
C. Gomphosis D. Secondary cartilaginous

13. Which of the following joints is an example for pivot variety of synovial joint?
A. Median atlanto-axial joint B. Elbow joint
C. Ankle joint D. Inferior tibiofibular joint

14. Which of the following arteries is an example of an end artery?
A. Superficial palmar arch B. Mesenteric artery
C. Central artery of retina D. Middle cerebral artery

15. Which of the following structures is an example for a lymphatic vessel?
A. Thoracic duct B. Bile duct
C. Cystic duct D. Parotid duct

16. Which of the following structures presents unipolar neurons?
A. Mesencephalic nucleus B. Spiral ganglion
C. Sympathetic ganglion D. Vestibular ganglion

17. Which of the following cells in CNS are phagocytic in function?
A. Oligodendrocytes B. Astrocytes
C. Ependymas D. Microglial cells

18. Which of these cells provide myelin sheaths in the peripheral nervous system?
A. Astrocytes B. Schwann cells
C. Microglial cells D. Oligodendrocytes

19. Which of these arteries carry less oxygenated blood?
A. Plantar arch B. Renal arteries
C. Pulmonary arteries D. Palmar arch

20. Nissl bodies correspond to which of the following cytoplasmic organelles?
A. Golgi apparatus
B. Mitochondria
C. Nucleoli
D. Rough endoplasmic reticulum

21. Which of this neurotransmitter is released at the post-ganglionic endings of parasympathetic nerves?
A. Acetylcholine B. Norepinephrine
C. Nitric oxide D. Serotonin

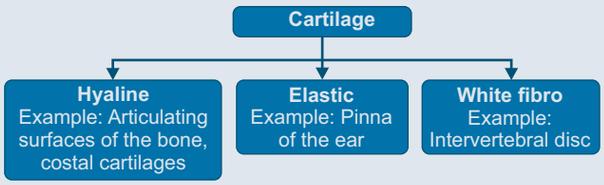
22. Which of these cranial nerves carries parasympathetic fibres?
A. Trigeminal B. Oculomotor
C. Abducent D. Trochlear

23. What is the source of origin of sympathetic nerve fibres?
A. Anterior horn of the cervical spinal segments
B. Anterior horn of the S2, S3, S4 spinal segments
C. Lateral horn of the thoracic spinal segments
D. Posterior horn of the thoracic spinal segments

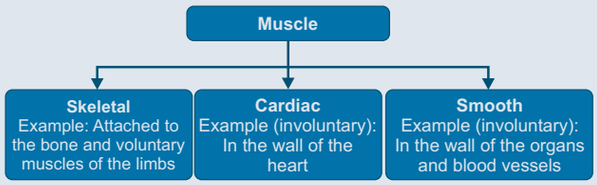
ANSWERS TO MCQs

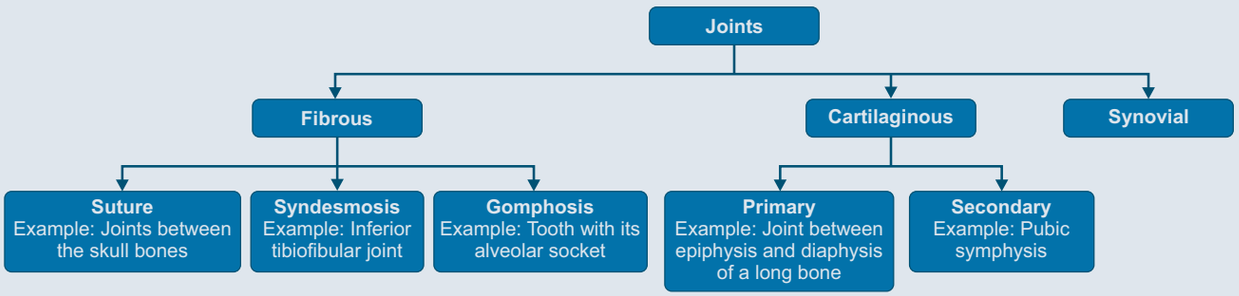
1. D	2. B	3. B	4. D	5. D
6. A	7. A	8. C	9. B	10. B
11. D	12. B	13. A	14. C	15. A
16. A	17. D	18. B	19. C	20. D
21. A	22. B	23. C		

JUST BEFORE THE EXAM



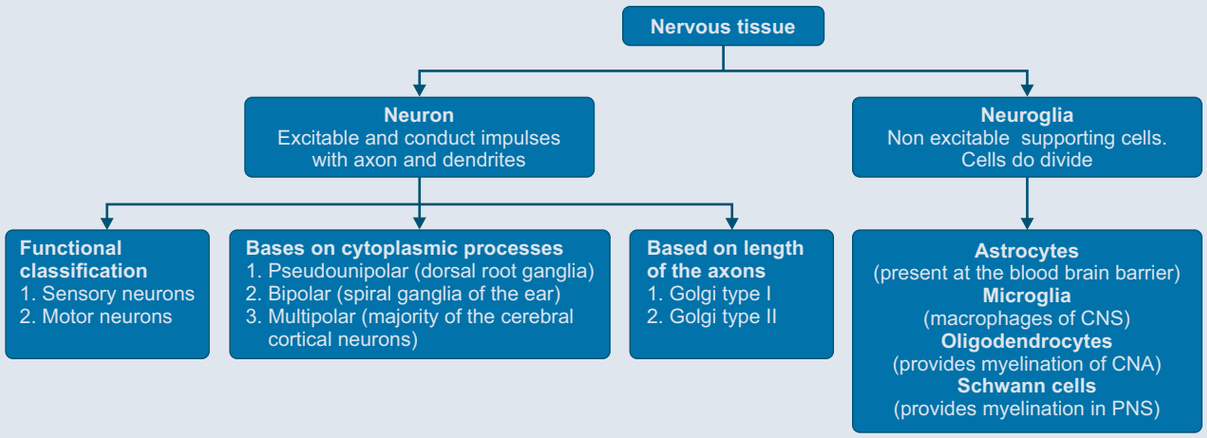
- **Sesamoid bones** are the bones develop within the tendon of the muscle, e.g. pisiform bone and patella. Sesamoid bone does not have periosteum and Haversian system.
- **Epiphysis** is the part of the long bone which develops from secondary centre of ossification (ossification centre appears after birth). Ends of the long bones are epiphysis.
- **Diaphysis** is the part of the long bone which develops from primary centre of ossification (ossification centre appears before birth). Shafts of the long bones are diaphysis. The growing end of the diaphysis is called **metaphysis**.
- Bones can ossify through either **membranous or cartilaginous ossification**. Clavicles ossify through membrane and most of the long bones ossify through cartilaginous ossification.
- **Laws of ossification states** that the epiphysis which ossifies first (or appears first) unites (fuses) with the diaphysis last and the epiphysis which ossifies last fuses first. Exception: Lower end of the fibula. The end of a long bone where epiphysis appears first and fuses last is called the 'growing end' of the bone (upper end of the humerus, lower ends of the radius and ulna, lower end of the femur and upper ends of the tibia and fibula are the growing ends).
- The direction of nutrient artery is always away from the growing end.





- **Hilton's** law states that a motor nerve supplying a muscle which acts on a joint also supplies skin covering that particular joint.
- **Arteries** are thick walled with smaller lumen and carry oxygenated blood. They give branches.

Veins are thin walled with larger lumen with valves inside and carry deoxygenated blood. Veins have tributaries.



Short Note Questions in General Anatomy

1. Primary cartilaginous joint
2. Secondary cartilaginous joint
3. Fibrous joint
4. Epiphysis
5. Blood supply to a long bone
6. Laws of ossification
7. Arterial anastomoses
8. Capillaries and sinusoids
9. Periosteum
10. Dermatome
11. Structure of a typical synovial joint
12. Centre of ossification
13. Growing end of the long bone
14. Diaphysis