Locomotion and Movement

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MOVEMENT

Movement is one of the most important characteristics of living organisms.

Nonliving objects do not move.

Types of Movement

Cells of the human body exhibit three main types of movements which are followings :-

(i) Amoeboid (ii) Ciliary (iii) Muscular.

(i) Amoeboid movement :

Some specialised cells in our body like **macrophages and leucocytes** in blood exhibit amoeboid movement. It is effected by pseudopodia formed by the streaming of protoplasm **(as in Amoeba)**. Cytoskeletal elements like micro filaments are also involved in amoeboid movement.

(ii) Ciliary movement :

Ciliary movement occurs in most of our internal tubular organs which are lined by ciliated epithelium. The coordinated movements of cilia in the **trachea** help us in removing dust particles and some of the foreign substances inhaled alongwith the atmospheric air. **Passage of ova** through the female reproductive tract is also facilitated by the ciliary movement.

(iii) Muscular movement :

Movement of our limbs, jaws, tongue, etc, require muscular movement. The contractile property of muscles are effectively used for locomotion and other movements by human beings and majority of multicellular organisms.

Note : Locomotion requires a perfect coordinated activity of muscular, skeletal and neural systems.

LOCOMOTION

(locus = place + moveo = to move) : Locomotion is the movement of an animal as a whole from one place to another.

Locomotion in different animals

(i) **Locomotion in Protozoa :** Locomotion in protozoans by the help of cilia, flagella and pseudopodia.

(ii) **Locomotion in Porifera :** Sponges are sedentary or fixed animals which are attached to some substratum.

(iii) **Locomotion in Coelentrates :** Locomotion in coelentrates is largely due to the contraction of the epidermal muscle fibres following type of movements take place in coelentrates –

(a) Swimming (b) Floating (c) Climbing

(d) Walking (e) Gliding

(iv) **Locomotion in Helminths :** In helminths (platyhelminthes and aschelminthes) locomotion not required by adult due to parasitic adaptations. In planaria locomotion by **cilia and muscles**.

(v) **Locomotion in Annelids :** Leech, Earthworm and Nereis have well developed circular and longitudinal muscles in the body wall that help these animals to move about. **Parapodia and setae** helpful for locomotion in nereis. In earthworm also locomotion by **setae**.

(vi) **Locomotion in Arthropods :** In arthropods locomotion takes place with the help of jointed legs, and a pair of wings.

(vii) **Locomotion in Mollusca :** In all the molluscs, the locomotory organ is a thick walled, muscular, broad or laterally compressed foot. In some molluscs, the foot is modified into eight or ten arms

(viii) **Locomotion in Echinodermata :** In echinoderms such as starfish, the locomotory organs are **tubefeet.**

(ix) **Locomotion in vertebrates :** In vertebrates, locomotion takes place with the help of skeletal muscles, and skeleton. The locomotory organs are a pair of legs.

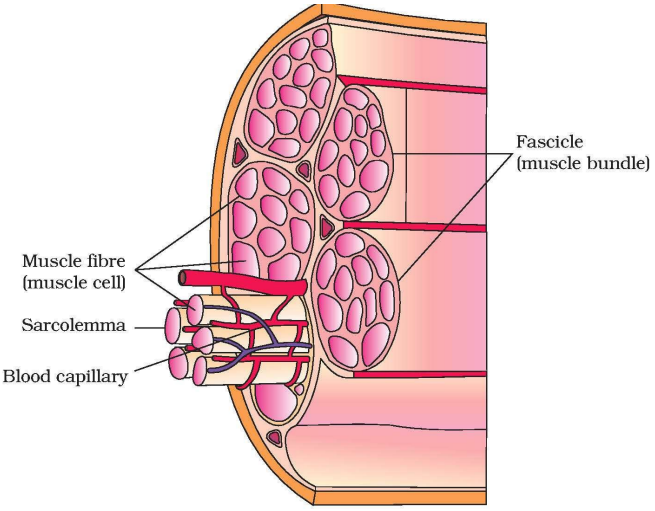
MUSCULAR TISSUES

- Contraction for motility in the cells results essentially from the interaction of two contractile proteins, **actin and myosin**. These tissues are obviously responsible for movements of organs and locomotion of the body in response to stimuli.
- These develop from embryonic **mesoderm** except for those of the iris and ciliary body of eyes, which are **ectodermal** in origin.
- The muscle cells are always elongated, slender and spindle-shaped, fibre-like cells, These are, therefore called muscle fibres. These possess large numbers of myofibrils formed of actin and myosin. Muscle cells lose capacity to divide, multiply and regenerate to a great extent.
- Study of muscle is called myology.
- Based on their location, three types of muscles are identified:

  (i) Skeletal (ii) Visceral and (iii) Cardiac.

SKELETAL OR STRIATED OR STRIPED MUSCLES

- Most muscles of body are striated. These generally bring about voluntary movements under conscious control of brain and, hence, called **voluntary muscles**.
- Most of these are inserted at both ends upon bones in different parts of the body depend upon these muscles. Hence, these are also called **skeletal muscles**.
- Movements of limbs and the body solely depend upon these muscles. Hence these are also called **somatic muscles**.
- These are also called **phasic type of muscles**, because contraction in these is rapid, but brief and fatigue occurs quickly.
- Each organised skeletal muscle in our body is made of a number of **muscle bundles or fascicles** held together by a common collagenous connective tissue layer called **fascia.** Each muscle bundle contains a number of muscle fibres.



Diagrammatic cross sectional view of a muscle showing muscle bundles and muscle fibres

(i) Fine structure of striated muscle fibres :

- Striated muscle fibres shows **transverse striation** in the form of regular alternate dark A (anisotropic) and light I (isotropic) bands.

(a) **A- band :** The **'A' band** contains about 120Å thick and 1.8 μ long "myosin filaments". A slender transverse line, the **'M' or Hansen's line** is visible in middle of each 'A' band. The major, middle region of **'A' band** is comparatively lighter, but its terminal parts appear darker. The middle lighter region is called **'H' zone**.

(b) **I-band :** The **I band** contains about 60Å thick and 1.0 μ long "actin filament" which are twice as many as myosin filaments. Each I band is divided into two equal halves by a thin, fibrous and transverse zig-zag partition, called **'Z' band (' Z' disc) or Krause's membrane**. Each segment of a fibril between two adjacent 'Z' bands is called a **sarcomere**. It is 2.3 μ long in uncontracted mammalian striated fibres.

(ii) **Ultrastructure of myofilaments :**

- At the molecular level, each myosin filament is composed of about 500 thread-like myosin molecules.
- Three different kinds of proteins participate in the composition of actin filaments. The major part of an actin filament is a coiled double helical strand whose each arm is a linear polymer of small and globular molecules (monomers) actin protein. Another coiled double helical, but thiner, strand runs along the whole length of actin strand. Each arm of this strand is a polymer of fibre-like molecules of tropomyosin protein. The third protein is troponin.

(iii) **Structure of Contractile Proteins :**

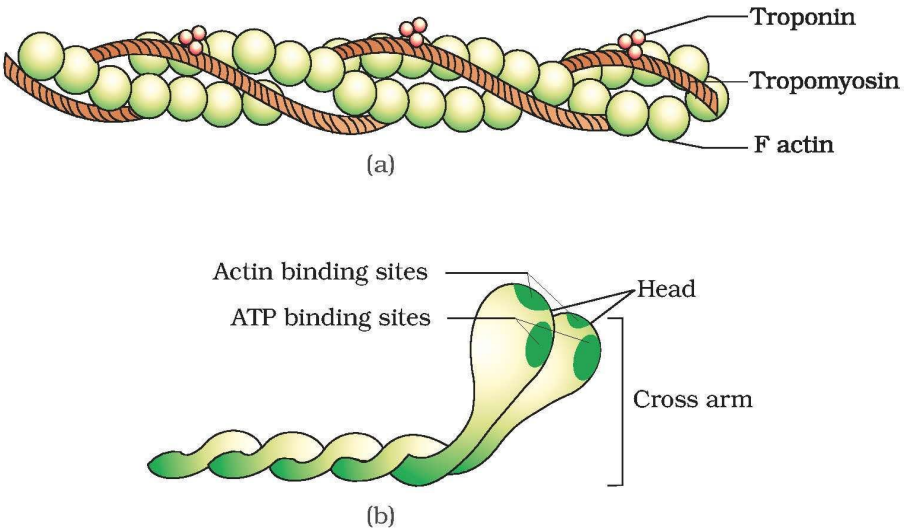
(a) **Actin :** Each actin filament is made up of the following components-

(A) **F- actin : In** each actin filament, two 'F' (filamentous) actins helically wound to each other. Each 'F' actin is a polymer of monomeric **'G' (Globular) actins**.

(B) **Tropomyosin :** Two filaments of another protein, **tropomyosin also** run close to the 'F' actins throughout its length.

(C) **Troponin :** It is a complex protein which is distributed at regular intervals on the tropomyosin. In the resting state a subunit of troponin masks the active binding sites for myosin on the actin filaments.

(b) **Myosin :** Each myosin (thick) filament is also a polymerised protein. Many monomeric proteins called **Meromyosins** constitute one thick filament. Each meromyosin has two important parts, a globular head with a short arm and a tail, the former being called the **heavy meromyosin (HMM)** and the latter, the **light meromyosin (LMM)**. The HMM component, i.e.; the head and short arm projects outwards at regular distance and angle from each other from the surface of a polymerised myosin fllament and is known as cross arm. The globular head is an **active ATPase enzyme** and has binding sites for ATP and active sites for actin.



(a) An actin (thin) filament (b) Myosin monomer (Meromyosin)

(iv) Working of striated muscles :

- **H.E. Huxley** and **A.F. Huxley** in 1954 proposed a theory to explain the process of muscular contraction. This theory is known as **'sliding filament theory'**.
- **It was observed that when a fibril contracts :**

(a) Its 'A' bands remain intact,

(b) 'I' bands progressively shorten and eventually disappear when the fibril has shortened to about 65% of its resting length.

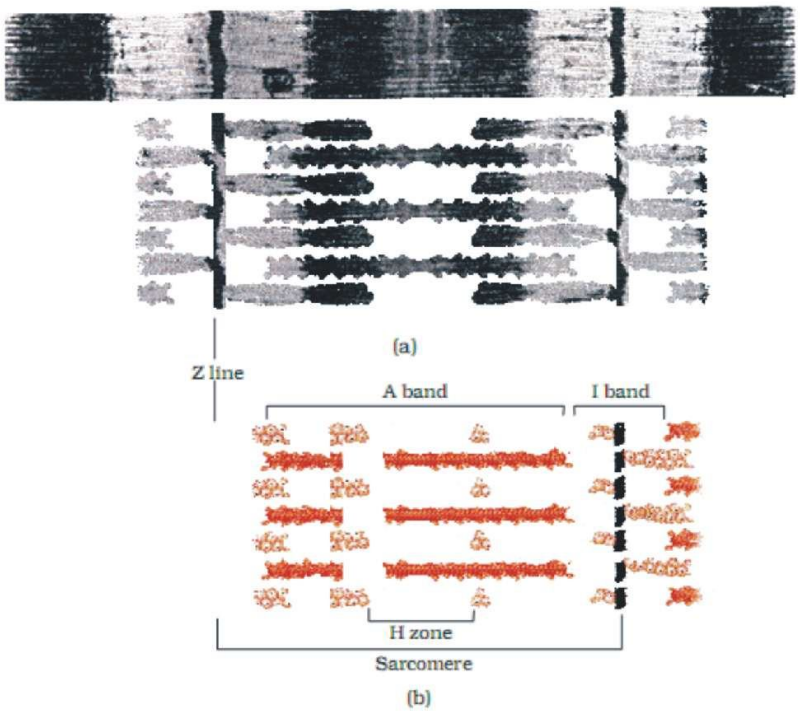
(c) At this stage, 'H' zones also disappear because the actin filaments of both sides in each sarcomere reach, and may even overlap each other at the "M" line, and the 'Z' lines now touch the ends of myosin filaments.

(d) Sarcomere shortens

Note: It was further observed that if a fibre is mechanically streched, the zones of overlap between thick and thin filaments are shorter than in resting condition, resulting in wider 'H' zones.

- **It was observed that when a fibril relax :** All the phenomenona occur in reverse way to relax the muscle i.e. the muscle comes in normal condition.

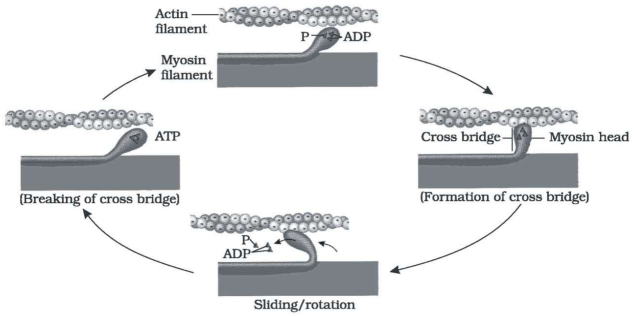
Note : These observations led Huxley to propose that shortening of the fibrils in contraction is brought about **by sliding movement of actin filaments over myosin filaments towards "M" line by** means of rapidly forming and breaking **cross bridges or rachets** at the spurs of myosin filaments. Thus, the sarcomere were recognised as the **'ultimate units of contraction'**.



Diagrammatic Representation of (a) anatomy of a muscle fibre showing a sarcomere (b) a sarcomere

(v) Mechanism of Muscle Contraction

- Mechanism of muscle contraction is best explained by the sliding filament theory which states that contraction of a muscle fibre takes place by the sliding of the thin filaments over the thick filaments.
- Muscle contraction is initiated by a signal sent by the central nervous system (CNS) via a motor neuron. A motor neuron along with the muscle fibres connected to it constitute a **motor unit**. The junction between a motor neuron and the sarcolemma of the muscle fibre is called the **neuromuscular junction or motor-end plate**.
- A neural signal reaching this junction releases a neurotransmitter (Acetyl choline) which generates an action potential in the sarcolemma. This spreads through the muscle fibre and causes the release of calcium ions into the sarcoplasm.
- Increase in Ca^{2+} level leads to the binding of calcium with a subunit of troponin on actin filaments and thereby remove the masking of active sites for myosin.
- Utilising the energy from **ATP hydrolysis**, the myosin head now binds to the exposed active sites on actin to form a cross bridge.



Stages in cross formation, rotation of head and breaking of cross bridge

- This pulls the attached actin filaments towards the centre of 'A' band. The 'Z' line attached to these actins are also pulled inwards thereby causing a shortening of the sarcomere, i.e., contraction. **It** is clear from the above steps, that during shortening of the muscle, i.e., contraction, the I bands get reduced, whereas the 'A' bands retain the length.
- The myosin, releasing the ADP and P_i goes back to its relaxed state. A new ATP binds and the cross-bridge is broken. The ATP is again hydrolysed by the myosin head and the cycle of cross bridge formation and breakage is repeated causing further sliding.
- The process continues till the Ca^{2+} ions are pumped back to the sarcoplasmic cisternae resulting in the masking of actin filaments. This causes the return of 'Z' lines back to their original position, i.e., relaxation.
- The reaction time of the fibres can vary in different muscles.

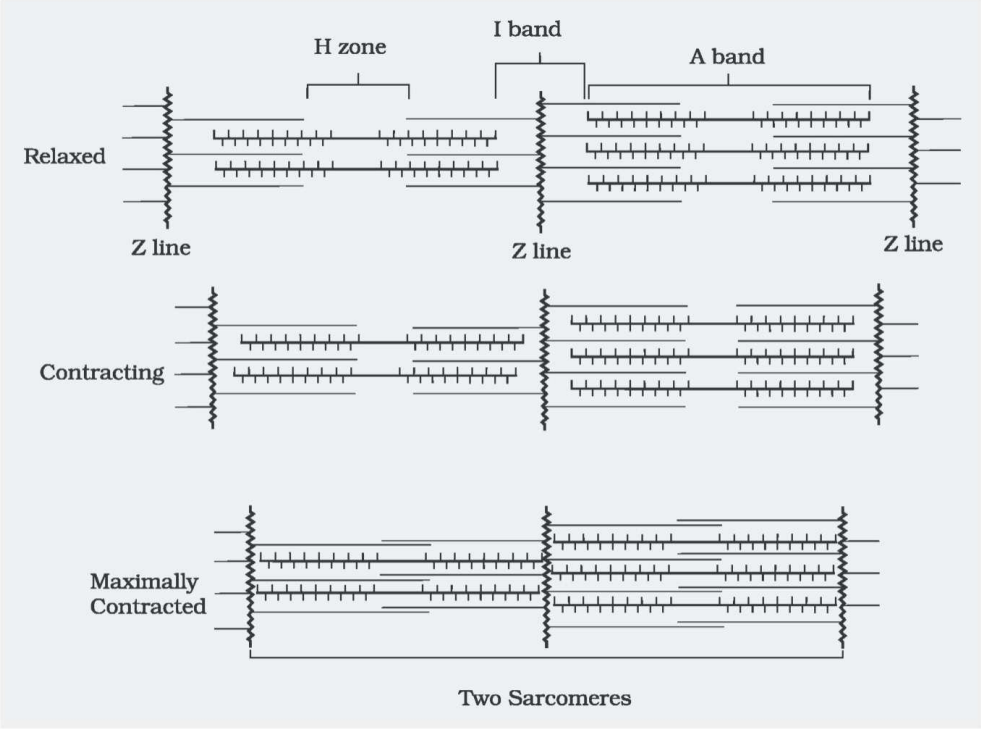
Note :

(1) Repeated activation of the muscles can lead to the **accumulation of lactic acid** due to anaerobic breakdown of glycogen in them, causing **fatigue**.

(2) On the basis of quantity of myoglobin pigment muscles are categories as

(A) **Red muscle fibre :** Muscle contains a red coloured oxygen storing pigment called **myoglobin**. Myoglobin rich muscles gives a reddish appearance. Such muscles are called the **Red fibres**. These muscles also contain plenty of mitochondria which can utilise the large amount of oxygen stored in them for ATP production. These muscles, therefore, can also be called aerobic muscles.

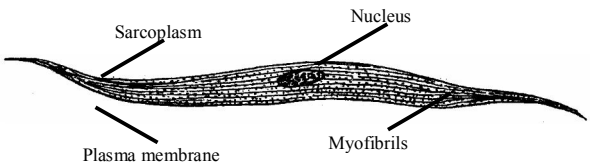
(B) **White muscle fibre :** Muscles possess very less quantity of myoglobin, appear pale or whitish. These are the **White fibres**. Number of mitochondria are also few in them, but the amount of sarcoplasmic reticulum is high. They depend on anaerobic process for energy.



Sliding-filament theory of muscle contraction (movement of the thin filaments and the relative size of the I band and H zones)

VISCERAL OR SMOOTH MUSCLES OR NON STRIATED

- These are called smooth, plain nonstriated involuntary or unstriped muscles due to absence of striations.
- These occur in the walls of hollow internal organs (alimentary canal, gall bladder, bile ducts, respiratory tracts, uterus, urinogenital ducts, urinary bladder, blood vessels, etc.), in capsules of lymph glands, spleen etc., in iris and ciliary body of eyes, skin dermis, penis and other accessory genitalia, etc.
- Smooth muscles of skin dermis, called **errector pilli** muscles, are associated with hair roots, and are responsible for flesh (erection of hairs). Those of penis form a muscular network which helps in its erection and limping.
- **Structure :** Smooth muscle fibre is unbranched goose-spindle shaped, uninucleated and has no sarcolemma. Contraction is slow, involuntary under the control of ANS.



smooth muscles

- Functionally smooth muscles are of two types –

(1) **Single-unit smooth muscle :** Single unit smooth muscle fibres are composed of muscle fibres closely joined together, contract as a single unit. e.g., urinary bladder, gastrointestinal tract, small arteries and small veins.

(2) **Multi-unit smooth muscles :** are composed of more independent muscle fibres, contract as separate units e.g. – hair root muscle, muscles on the wall of large blood vessels, ciliary muscles, muscles of iris and bronchi.

CARDIAC MUSCLES

- Heart wall (also the wall of large veins just where these enter into the heart) is made up of cardiac muscles and, hence, called myocardium.
- Structurally, these muscles resemble striated muscles but, functioning independently of the conscious control of brain, these are **involuntary** like the smooth muscles.
- Cardiac muscle cells of fibres are comparatively shorter and thicker, cylindrical, mostly uninucleate with a central nucleus, somewhat branched and covered by a sarcolemma.

SKELETAL SYSTEM

- Skeletal system consists of a framework of bones and a few cartilages. This system has a significant role in movement shown by the body.
- Bone and cartilage are specialised connective tissues. The former has a very hard matrix due to calcium salts in it and the latter has slightly pliable matrix due to chondroitin salts.
- Bones are made up of a protein called **ossein** and cartilage are made of a protein called **chondrin**. Hence study of bones is called **osteology** and study of cartilage is called **chondrology**.

SKELETON

The hardened tissues of the body together form the skeleton (*sclero* = hard). Skeleton of invertebrates is most often secreted on the surface, forming a lifeless or dead exoskeleton. Whereas skeleton of vertebrates develops most often underneath the surface forming a living or growing endoskeleton.

- Three types of skeletons develop in vertebrates :

(1) **Epidermal/Horny exoskeleton :** These include hard and horny of keratinized derivatives of epidermal layer of skin, such as claws, most reptilian's scales, bird feathers and mammalian hairs, horns, nails and hoofs, etc.

(2) **Dermal/Bony skeleton :** Dermal bony skeleton is derived from the dermis of skin. It includes bony scales and plates. In fishes, dermal scales become exposed due to wearing out of epidermis, and form exoskeleton.

(3) **Endoskeleton :** Greater part of vertebrate skeleton lies more deeply, forming the endoskeleton. Endoskeleton is formed by bones in vertebrates.

Functions of bony skeleton :

Chief function of vertebrate bony skeleton can be enumerated as follows –

(i) To provide physical support to body by forming a firm and rigid internal framework.

(ii) To give definite body shape and form.

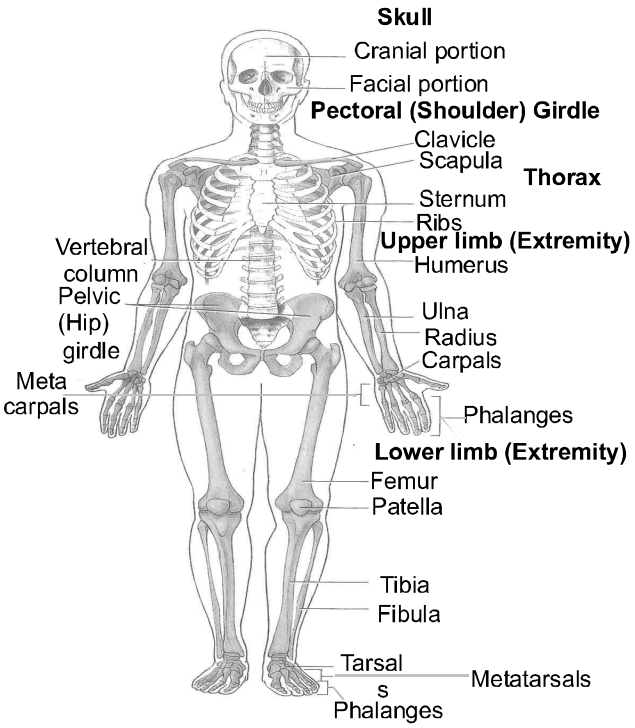
(iii) To protect by surrounding delicate internal organs like brain, heart, lungs etc.

(v) To provide surface for attachment of muscles.

(vi) To serve as levers on which muscles can act.

(vii) To manufacture blood corpuscles in bone marrow.

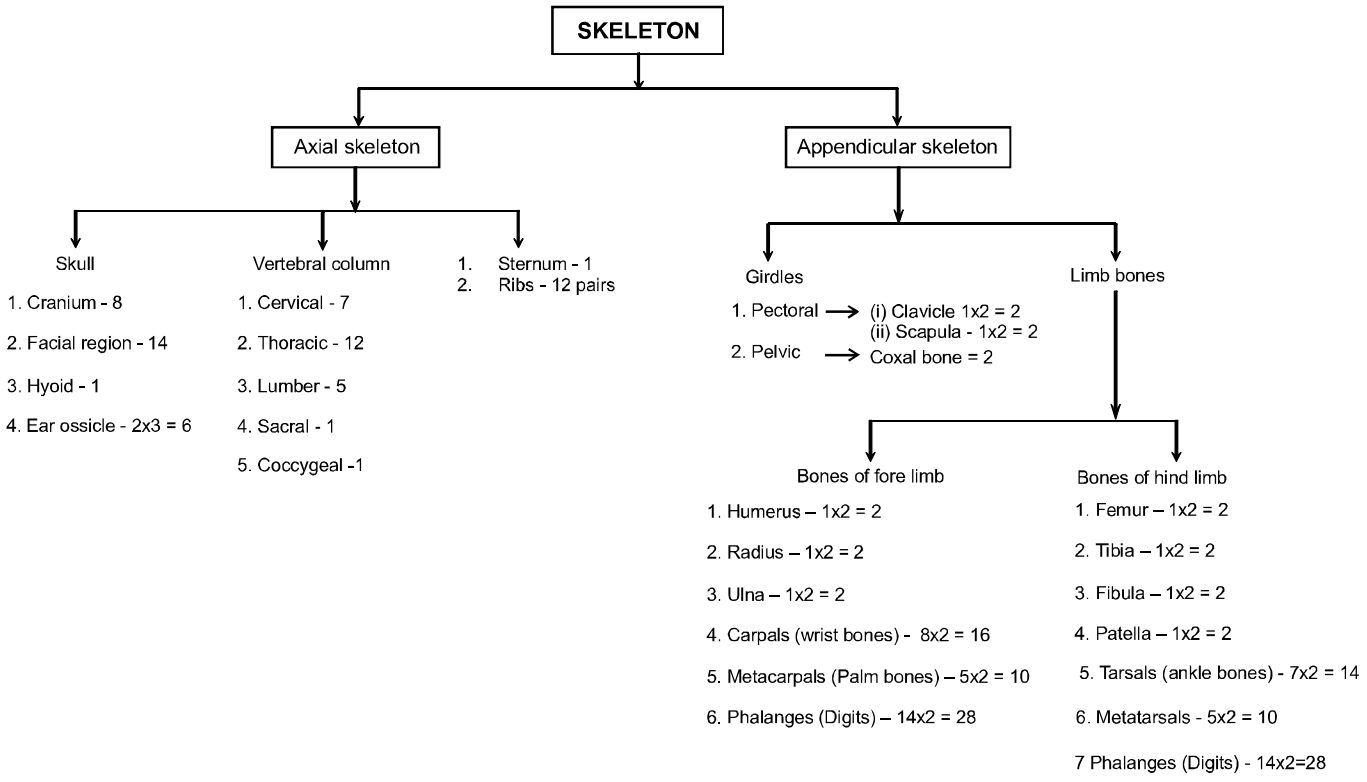
(viii) To help in breathing (tracheal rings, ribs).



Divisions of skeletal system

HUMAN SKELETAL SYSTEM

In human beings, this system is made up of **206 bones** and a few cartilages. It is grouped into two principal divisions - the axial and the appendicular skeleton.



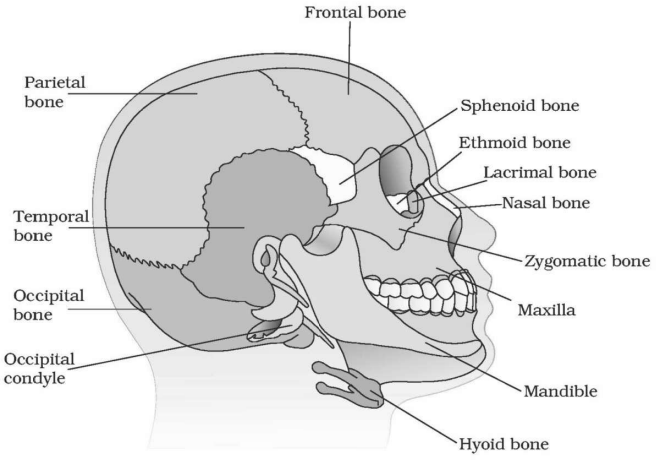
AXIAL SKELETON :

- **Axial skeleton** comprises 80 bones distributed along the main axis of the body. The skull, vertebral column, sternum and ribs constitute axial skeleton.

(a) **Skull :** The **skull** is composed of two sets of bones cranial and facial, that totals to 22 bones. Cranial bones are 8 in number. They form the hard protective outer covering, cranium for the brain.

- The facial region is made up of 14 skeletal elements which form the front part of the skull. A single U-shaped bone called hyoid is present at the base of the buccal cavity and it is also included in the skull. Each middle ear contains three tiny bones - Malleus, Incus and Stapes, collectively called **Ear Ossicles.**

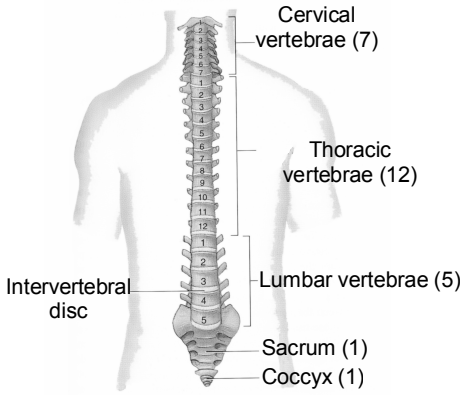
- The skull region articulates with the superior region of the vertebral column with the help of two occipital condyles (dicondylic skull).



Diagrammatic view of human skull

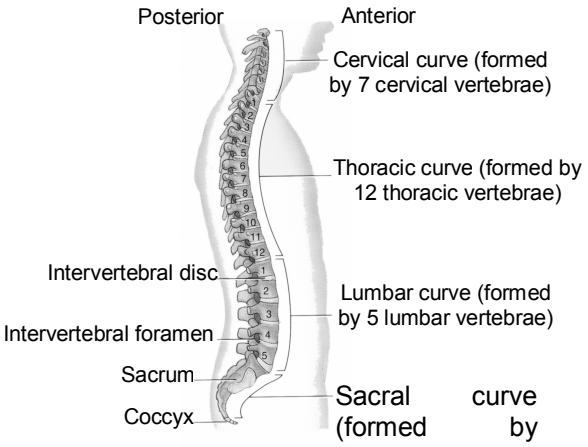
(b) Vertebral column :

- Our **vertebral column** is formed by 26 serially arranged units called vertebrae and is dorsally placed. It extends from the base of the skull and constitutes the main framework of the trunk.
- Each vertebra has a central hollow portion (neural canal) through which the spinal cord passes.
- First vertebra is the atlas and it articulates with the occipital condyles.
- The vertebral column is differentiated into cervical (7), thoracic (12), lumbar (5), sacral (1-fused) and coccygeal (1-fused) regions starting from the skull. The number of cervical vertebrae are seven in almost all mammals including human beings.
- The vertebral column protects the spinal cord, supports the head and serves as the point of attachment for the ribs and musculature of the back.
- **Sternum** is a flat bone on the ventral midline of thorax.

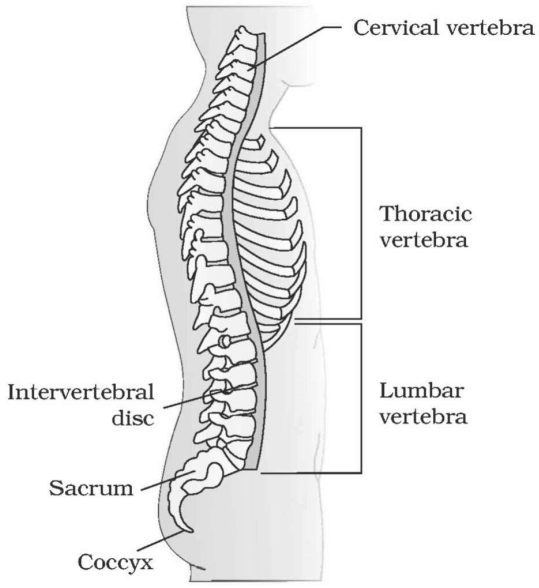


Anterior view showing regions of the vertebral column

- **Curvatures of vertebral column :** In a foetus, there is only a single anteriorly concave curve, in adult there are 4 curves like, cervical, thoracic, lumber, and sacral. Cervical and lumber are anteriorly convex, while thoracic and sacral are anteriorly concave.



Right lateral view showing four normal curves



Vertebral column (right lateral view)

- The curves of vertebral column are important because they increases its strength, help maintain balance in upright position absorb shock during walking and running and help protect the column from fracture. Certain abnormalities of curvature are :

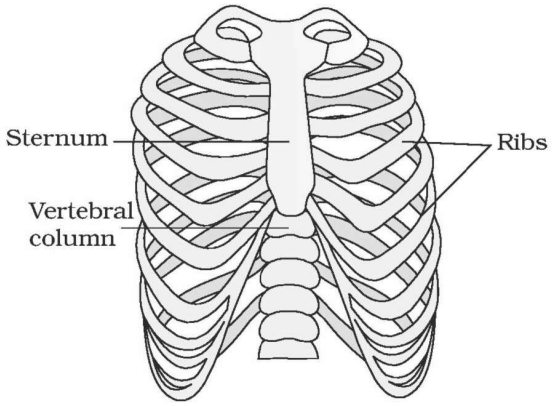
(i) **Kyphosis :** Exaggeration of thoracic curve, resulting in "round-shouldered" appearance, also called hunch back.

(ii) **Lordosis** : An exaggeration of lumber curve, also called sway back.

(iii) **Scoliosis :** An abnormal lateral curvature in any region of spine.

(c) Ribs & Sternum:

- There are 12 pairs of **ribs.** Each rib is a thin flat bone connected dorsally to the vertebral column and ventrally to the sternum. It has two articulation surfaces on its dorsal end and is hence called **bicephalic**.
- First seven pairs of ribs are called **true ribs**. Dorsally, they are attached to the thoracic vertebrae and ventrally connected to the sternum with the help of hyaline cartilage. The 8^{th}, 9^{th} and 10^{th} pairs of ribs do not articulate directly with the sternum but join the seventh rib with the help of hyaline cartilage. These are called vertebrochondral **(false) ribs**.
- Last 2 pairs (11^{th} and 12^{th}) of ribs are not connected ventrally and are therefore, called **floating ribs**. Thoracic vertebrae, ribs and sternum together form the **rib cage or thoracic cage.**



Ribs and rib cage

APPENDICULAR SKELETON

- The bones of the limbs along with their girdles constitute the **appendicular skeleton** which are followings

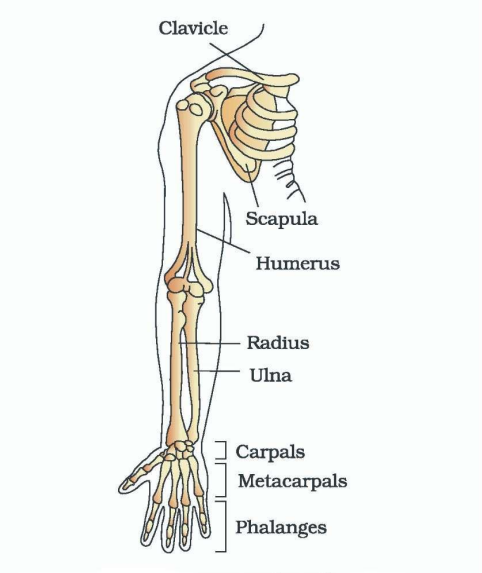
(a) Limb bone : Each **limb** is made of 30 bones.

(i) Fore limb bones : The bones of the hand (fore limb) are humerus, radius and ulna, carpals (wrist bones - 8 in number), metacarpals (palm bones - 5 in number) and phalanges (digits - 14 in number).

(ii) Hind limb bones : Femur (thigh bone - the longest bone), tibia and fibula, tarsals (ankle bones - 7 in number), metatarsals (5 in number) and phalanges (digits - 14 in number) are the bones of the legs (hind limb). A cup shaped bone called patella cover the knee ventrally (knee cap).

(b) Girdle bones : Pectoral and Pelvic girdle bones help in the articulation of the upper and the lower limbs respectively with the axial skeleton. Each girdle is formed of two halves.

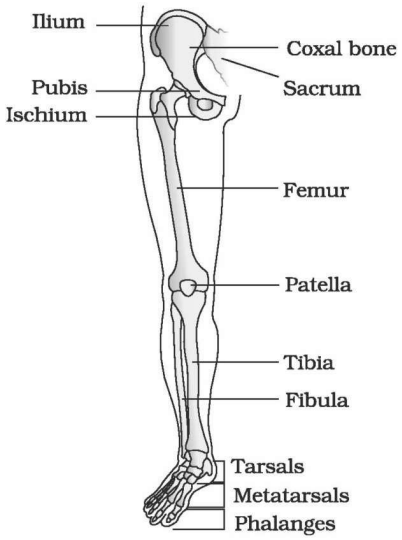
(i) Pectoral girdle : Each half of **pectoral girdle** consists of a clavicle and a scapula. Scapula is a large triangular flat bone situated in the dorsal part of the thorax between the second and the seventh ribs. The dorsal, flat, triangular body of scapula has a slightly elevated ridge called the spine which projects as a flat, expanded process called the **acromion**. The clavicle articulates with this. Below the acromion is a depression called the **glenoid cavity** which articulates with the head of the humerus to form the shoulder joint. Each clavicle is a long slender bone with two curvatures. This bone is commonly called the **collar bone**.



Rigth pectoral girdle and upper arm. (frontal view)

(ii) Pelvic girdle : It consists of two coxal bones. Each coxal bone is formed by the fusion of three bones - ilium, ischium and pubis. At the point of fusion of the above bones is a cavity called

acetabulum to which the thigh bone articulates. The two halves of the pelvic girdle meet ventrally to form the pubic symphysis containing fibrous cartilage.



Right pelvic girdle and lower limb bones (frontal view)

JOINTS

- Joints are essential for all types of movements involving the bony parts of the body. Locomotory movements are no exception to this. Joints are points of contact between bones, or between bones and cartilages.
- Force generated by the muscles is used to carry out movement through joints, where the joint acts as a fulcrum. The movability at these joints vary depending on different factors.
- Joints have been classified into three major structural forms, namely, fibrous, cartilaginous and synovial.

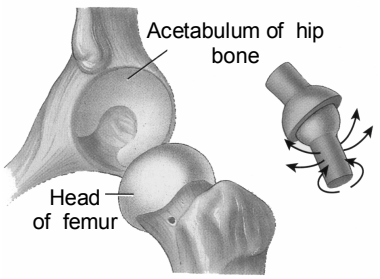
(a) **Fibrous joints :** These do not allow any movement. This type of joint is shown by the flat skull bones which fuse end-to-end with the help of dense fibrous connective tissues in the form of sutures, to form the cranium.

(b) **Cartilaginous joints :** In this, the bones involved are joined together with the help of cartilages. The joint between the adjacent vertebrae in the vertebral column is of this pattern and it permits limited movements.

(c) **Synovial joints :** These are characterised by the presence of a fluid filled synovial cavity between the articulating surfaces of the two bones. Such an arragement allows considerable movement. These joints help in locomotion and many other movements.

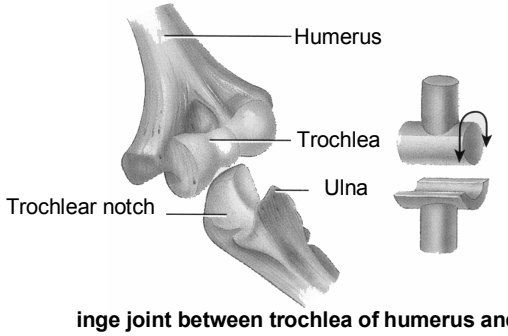
- **Synovial joints are classified as :**

(i) **Ball and socket joint :** Ball of one bone articulate in socket of another bone. *e.g.,* head of humerus and glenoid cavity of pectoral girdle, femur and acetabulum of pelvic girdle.



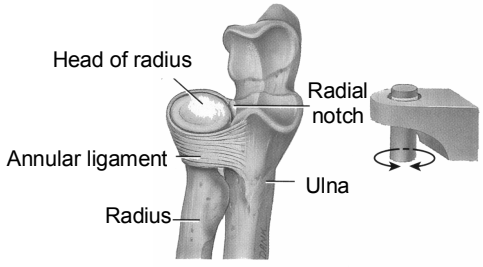
Ball-and-socket joint between head of the femur and acetabulum of the hip bone

(ii) **Hinge joint :** Movement is possible in one direction only. *e.g.,* Joint of malleus and incus, knee joint, elbow joint.



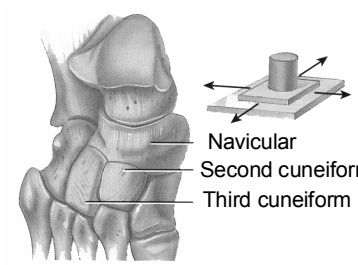
inge joint between trochlea of humerus and trochlear notch of ulna at the elbow

(iii) **Pivot joint :** Also known as rotatoria and helps in turning movement. e.g. between Atlas & Axis, Radius & Ulna



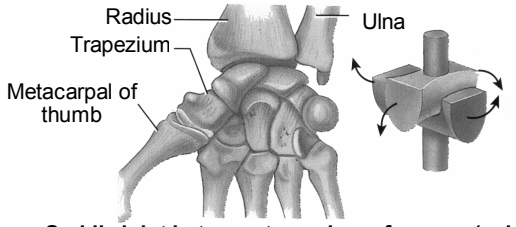
Pivot joint between head of radius and radial notch of ulna

(iv) **Gliding joint :** Limited movement in all direction. *e.g.,* Tarsals bones of ankle, between the carpals.



Gliding joint between the navicular and second and third cuneiforms of the tarsus in the foot

(v) **Saddle joint :** It is ball and socket like joint but not developed fully. *e.g.* between carpal & metacarpal of thumb.



Saddle joint between trapezium of carpus (wrist) and metacarpal of thumb

DISORDERS OF MOSCULAR & SKELETAL SYSTEM

1. **MYASTHENIA GRAVIS :** Auto immune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.

- Auto antibodies against ach receptors.

2. **MUSCULAR DYSTROPHY :** Progressive degeneration of skeletal muscle mostly due to genetic disorder.

3. **TETANY :** Rapid spasms (wild contractions) in muscle due to low Ca^{2+} in body fluid.

4. **ARTHRITIS :** Arthritis refers to inflammation of the joints. It is a common disease of the old age. Its common symptoms are pain and stiffness in the joints. It is differentiated in three given forms:-

(a) **Osteoarthritis :** Secretion of the lubricating synovial fluid between the bones at the joint stops.

(b) **Rheumatoid arthritis :** It is a chronic painful inflammation of the synovial membranes of many joints simultaneously.

(c) **Gout :** It is an inherited disorder of purine metabolism, occurring especially in men. Body forms excess amounts of uric acid and the crystals of sodium urate are deposited in the synovial joints, giving rise to a severe arthritis.

5. **OSTEOPOROSIS**

(a) **Meaning :** Osteoporosis is reduction in bone tissue mass causing weakness of skeletal strength (*G.osteon* = bone, *poros* = pore, *osis* = condition). It results from excessive resorption of calcium and phosphorous from the bone.

(b) **Causes :** Osteoporosis occurs in postmenopausal women and elderly men. It may result from defective intestinal calcium absorption and menopause. Possible environment factors include smoking, excessive drinking, and decreased exercise. Osteoporosis is more common in women than in men, and in older than in middle-aged persons.

(c) **Symptoms :** Symptoms of osteoporosis are pain in the bone, particularly the back.

(d) **Prevention :** Preventive measures in high-risk patients include supplementary calcium and exercise, and, in postmenopausal women, estrogen replacement therapy. Supplementary calcium and sex hormones decrease bone resorption and may arrest or reduce disease progression.