CHAPTER-20

LOCOMOTION AND MOVEMENT

Introduction

Movement is one of the important features of living beings. All the living beings including animals and plants exhibit a wide range of movements. Cyclosis streaming of protoplasm in the unicellular organisms like Amoeba is a simple form of movement. Movement of cilia e.g. as in Paramoecium, flagella, and tentacles e.g. as in Hydra are shown by many organisms. Human beings can move limbs, jaws, eyelids, tongue, etc. Some of the movements result in a change of place or location. Such voluntary movements are called locomotion. We use limbs to change in body postures and locomotion as well. Movement and locomotion may be linked by stating that all locomotion is movements but all movements are not locomotion. Methods of locomotion performed by animals vary with their habitats and the demand of the situation. In different animals, locomotion is generally for the search of food, shelter, mate, suitable breeding grounds, and favourable climatic conditions or to escape from enemies or predators.

Types of movement

In human being different cells shows three different types of movement.

(a) Amoeboid movement- In our body certain cells like leukocytes, macrophages show amoeboid movement. The amoeboid movement occurs by pseudopodia formation which is formed by protoplasmic streaming movement, at the same time pseudopodia formation also involves the cytoskeleton like microfilaments.

(b) Ciliary movement- In our body, several hollow structures are lined with ciliated epithelium, e.g. as in the trachea, fallopian tube, etc. In the trachea, the coordinated movement of the cilia results in the movement of dust particles towards the outside. Similarly, the fallopian tube is also lined with ciliated epithelium. Here the coordinated movement of cilia helps in the movement of ova from infundibulum to site of fertilization.

(c) Muscular movement- Movement of the jaw, tongue, limbs, etc is an example of muscular movement. Muscle is contractile tissue. Muscular movement is used in most of the multicellular organisms for movement and locomotion. Muscular movement requires properly coordinated.

Types of muscle

Muscle constitutes about 40 to 50% of total body weight. Muscle is a special type of cell having property excitability, contractility, extensibility, and elasticity. Muscle is mesodermal in origin. Based on location, the muscle may be of three types- (i) Skeletal (ii) Visceral, and (iii) Cardiac.

(i) **Skeletal muscles-** A muscle associated with our skeletal system is known as skeletal muscle. They are under the control of the voluntary nervous system hence it may be known as voluntary muscle. They have a striped appearance under the microscope and hence are called striated muscles. They are primarily involved in locomotory actions and changes of body postures.

(ii) **Visceral muscles-** These are located in the inner walls of hollow visceral organs of the body like the alimentary canal, reproductive tract, etc. Under a microscope, they appear smooth hence known as smooth muscle or non-striated muscle. Their activities are not under the voluntary control of the nervous system and are therefore known as involuntary muscles. These muscles are involved in involuntary activities like transportation of food through the digestive tract and gametes through the genital tract.

(iii) **Cardiac muscles-** It is a special type of muscle found in the heart hence known as cardiac muscle. Like skeletal muscles, they show striation in their structure but at the same time, they are not under the control of our voluntary nervous system. Hence it is intermediate between skeletal muscle and visceral muscle.

Structure of skeletal muscle

Each organized skeletal muscle in our body is made of several muscle bundles or fascicles held together by a common collagenous connective tissue layer called fascia. Each muscle bundle contains several muscle fibers. Each muscle fiber is lined by the plasma membrane called sarcolemma enclosing the sarcoplasm. A muscle fiber is a syncitium or multinucleated. The endoplasmic reticulum of muscle fiber is known as sarcoplasmic reticulum which is a storehouse of calcium ions.

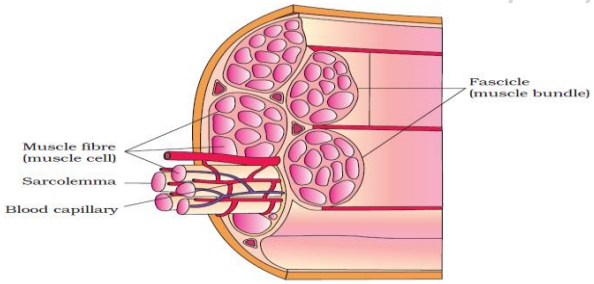

Figure Diagrammatic cross sectional view of a muscle showing muscle bundles and muscle fibres

A characteristic feature of the muscle fiber is the presence of a large number of parallelly arranged filaments in the sarcoplasm called myofilaments or myofibrils. Each myofibril has alternate dark and light bands on it. This is why it appears striated, and known as striated muscle. The dark band is known as an anisotropic band (A-band) while the light band is known as an isotropic band (I-band). In the middle of the I-band, there is a dark line known as Z-line or Krause's membrane, while in the A- band there is a central clear zone known as H-zone (Hensen zone). In the H-zone there is a dark line known as M-line. The space between two successive Z-

line is known as a sarcomere. The sarcomere is said as a unit of contraction of striated muscle. In a resting state, the edges of thin filaments on either side of the thick filaments partially overlap the free ends of the thick filaments leaving the central part of the thick filaments.
Each of the myofibrils consists of two types of filaments the primary and secondary filament. The primary filament may also be known as thick filament while the secondary filament is also known as thin filament. The A-band consists both of thick and thin filament while the I-band has consisted only of the thin filament. The thick filament is hexagonal in cross-section, while thin filament appears as globular. In A-band each of the thick filaments is surrounded by six thin filaments, while each of the thin filament is surrounded by three thick filaments.

Structure of contractile protein

Each of the thick filaments consists of Myosin protein while the thin filament consists of Actin protein, Tropomyosin protein, and Troponin protein.
Each actin (thin) filament is made of two 'F' (filamentous) actins helically wound to each other. Each 'F' actin is a polymer of monomeric 'G' (Globular) actins. Two filaments of tropomyosin also run close to the 'F' actins throughout its length. A complex protein Troponin 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.
Each myosin or thick filament is also a polymerized 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 a regular distance and angle from each other from the surface of a polymerized myosin filament and is known as a cross arm. The globular head is an active ATPase enzyme and has binding sites for ATP and active sites for actin.

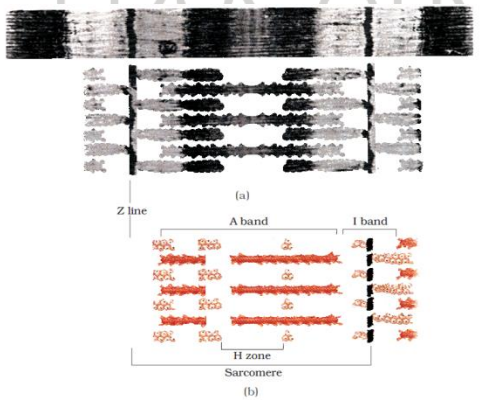

Figure Diagrammatic representation of (a) anatomy of a muscle fibre showing a sarcomere (b) a sarcomere

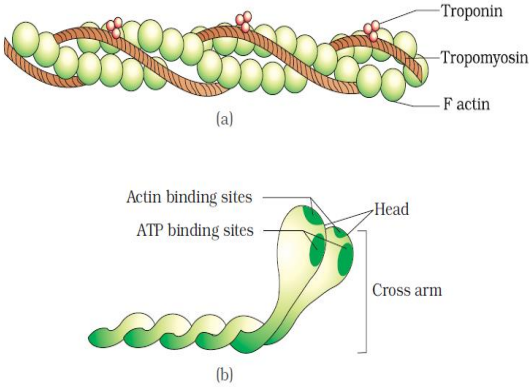

Figure (a) An actin (thin) filament (b) Myosin monomer (Meromyosin)

Mechanism of muscular contraction

Huxley and Huxley studied the mechanism of muscular contraction. They gave the "Sliding filament cross-bridge hypothesis" to explain the mechanism of contraction of striated muscle.

For this work, they were awarded by Nobel prize. This hypothesis states that contraction of a muscle fiber takes place by the sliding of the thin filaments over the thick filaments.

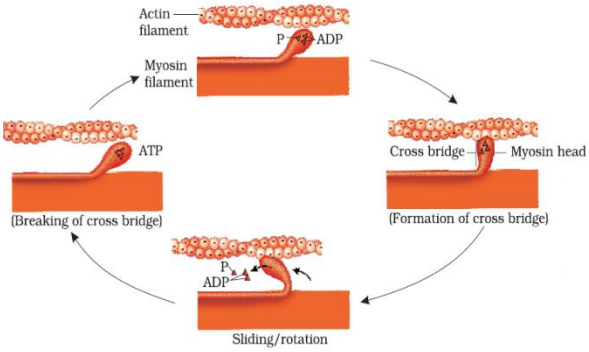

Figure Stages in cross bridge formation, rotation of head and breaking of cross bridge

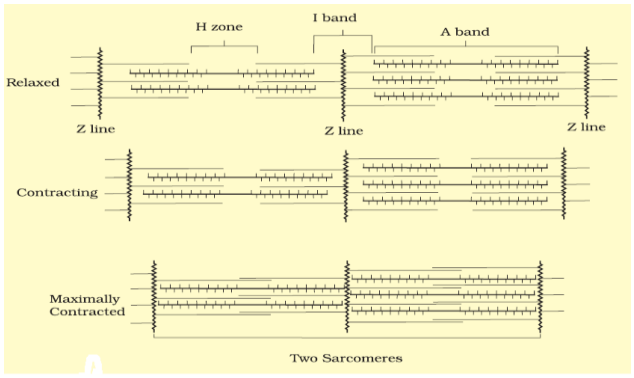

Figure Sliding-filament theory of muscle contraction (movement of the thin filaments and the relative size of the I band and H zones)

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 fibers connected to it constitutes a motor unit. The junction between a
motor neuron and the sarcolemma of the muscle fiber is called the neuromuscular junction or motor-end plate.
The overall process of the mechanism of contraction is as following

- A neural signal reaching to neuro-muscular junction releases a neurotransmitter Acetylcholine which generates an action potential in the sarcolemma. This action potential spreads through the sarcolemma of the muscle fiber, enters in muscle fiber through T-tubule, and then to the sarcoplasmic reticulum and causes the release of calcium ions into the sarcoplasm. It results in an increase in Ca++ concentration in the sarcoplasm.
- An increase in Ca++ 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.
- Utilizing the energy from ATP hydrolysis, the myosin head now binds to the exposed active sites on actin to form a cross bridge. This pulls the attached actin filaments towards the center of the 'A' band.
- The 'Z' line attached to these actions is also pulled inwards thereby causing a shortening of the sarcomere, i.e., contraction occurs. During the shortening of the muscle, i.e. during contraction, the 'I' bands get reduced, whereas the 'A' bands retain the length.
- The myosin, releasing the ADP, and Pi goes back to its relaxed state. A new ATP binds and the cross-bridge is broken. The ATP is again hydrolyzed by the myosin head and the cycle of cross-bridge formation and breakage is repeated causing further sliding. The process continues till the Ca++ 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 occurs. The reaction time of the fibers can vary in different muscles.

Types of striated muscle

Repeated contraction of the muscles can lead to the accumulation of lactic acid due to anaerobic breakdown of glycogen in them, causing fatigue.

There may be two types of muscles- Red muscle and white muscle.

(i) **Red muscle-** Muscle contains a red-colored oxygen storing pigment called myoglobin. Myoglobin content is high in some of the muscles which give a reddish appearance. Such muscles are called the Red fibers. These muscles also contain plenty of mitochondria which can utilize a large amount of oxygen stored in them for ATP production. These muscles, therefore, can also be called aerobic muscles.

(ii) **White muscle-** Some of the muscles possess a very less quantity of myoglobin and therefore, appear pale or whitish. These are the White fibers. The number of mitochondria is also few in them, but the amount of sarcoplasmic reticulum is high. They depend on an anaerobic process for energy. So also it is said as anaerobic respiration.

Cori's cycle

Cori's cycle- It is a metabolic pathway involved in the conversion of lactic acid in glycogen. It occurs in the liver. All the lactic acid is synthesized in white muscle fiber is transported to the liver. In the liver, most lactic acid is converted into glycogen and a small amount of lactic acid is oxidized to produce ATP, which ATP is used in the conversion of lactic acid in glycogen. Later the lactogen is transported to the liver and stored there.

Skeletal system

A system that forms the skeleton of our body is known as the skeletal system. In animals, there may be two types of the skeletal system-

(i) Exoskeleton- The skeleton formed at the outer side of the body. In different animals there may be different types of exoskeleton e.g. as in lower forms like in marine Protozoans the body may be covered with a shell made of $CaCO_3$ or silica, in Mollusca the body is covered with a shell made of $CaCO_3$, in birds body is covered with feather. In human beings, the main exoskeleton is hair, nail, etc. The main function of the exoskeleton is to protect organisms from the external environment.

(ii) Endoskeleton- The skeleton which forms the framework of the body. It provides internal support to the body. In most vertebrates including human beings, the endoskeleton consists of bone and cartilage. This system has a significant role in the movement shown by the body. Bone and cartilage are specialized connective tissues. The cartilage has a very hard matrix due to calcium salts in it and the latter has a slightly pliable matrix due to chondroitin salts. In human beings, it consists of 206 bones and few cartilages. In the human body, the endoskeleton is grouped into two principal divisions – the axial and the appendicular skeleton.

Axial skeleton

In human beings, it consists of 80 bones distributed along the main axis of the body. The skull, vertebral column, sternum and ribs constitute axial skeleton.

(1) Skull- It consists of two sets of bones – cranial and facial bones. Cranial bones are 8 in number. These bones are-

- Frontal bone (1)

- Parietal (2)
- Temporal (2)
- Occipital (1)
- Sphenoid (1)
- Ethmoid (1)

Cranial bones form the hard protective outer covering, cranium for the brain.

The facial region is made up of 14 skeletal elements that form the front part of the skull. These bones are

- Interconchal (2)
- Lacrimal (2)
- Nasal (2)
- Vomer (1)
- Zygomatic (2)
- Palatine (2)
- Maxillary (2)
- Mandibular (1)

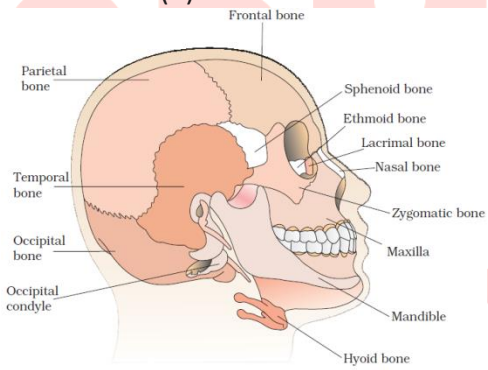

Figure Diagrammatic view of human skull

Despite these bones, there is a "U" shaped bone known as Hyoid bone. It supports the tongue and provides surface for attachment of muscles of tongue and floor of the buccal cavity.

Each middle ears also contains 3 bones the Malleus, Incus and Steps. These bones are said as ear ossicles. Thus in two ears total 6 bones are found.

(2) Vertebral column- In the adult human body vertebral column is formed by 26 serially arranged units called vertebrae. It 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. The first vertebra is the atlas and it articulates with the occipital condyles of the skull. The second vertebra is ring-like and known as the axis. The vertebral column is differentiated into

- cervical (7)
- Thoracic (12)
- Lumbar (5)
- Sacral (1-fused)
- Coccygeal (1-fused)

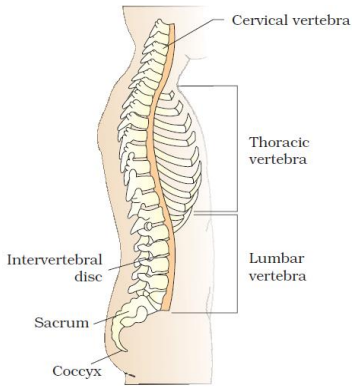

Figure Vertebral column (right lateral view)

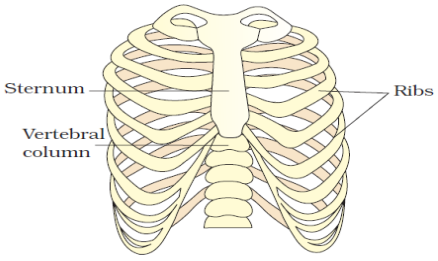

Figure Ribs and rib cage

The number of cervical vertebrae is 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.

In human beings and in most of the mammals the typical vertebra is acoelos type.

(3) Sternum- It is a flat bone on the ventral midline of the thorax, forming the ventral surface of the thoracic cage.

(4) Ribs

- There are 12 pairs of **ribs.** It forms the lateral side of the thoracic cage. 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.
- The 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 8th, 9th, 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 or false ribs.
- The last 2 pairs i.e. 11^{th} and 12th 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.

Thus total 8 bones in the cranium, 14 bones in the facial region of the skull, 1 hyoid bone, 6 bones in-ear ossicle, 26 bones in vertebra, 1 bone-in sternum, 12 pairs or 24 bones in ribs are found. In this way, all these 80 bones form an axial skeleton.

Appendicular skeleton

In a human being, the limbs and associated structures form the appendicular structures. There is a total of 126 bones in the appendicular skeleton. This skeletal system consists of a Pectoral girdle, Pelvis girdle, Forelimb or arm, and Hind limb or legs.

The pectoral girdle consists of 4 bones, the pelvic girdle consists of 2 bones and each of the limbs consists of 30 bones. In this way, a total of 126 bones are present in it.

1. Forelimb- The bones of hand or forelimb are the humerus, radius and ulna, carpals or wrist bones (8 in number), metacarpals or palm bones (5 in number) and phalanges or digits (14 in number)

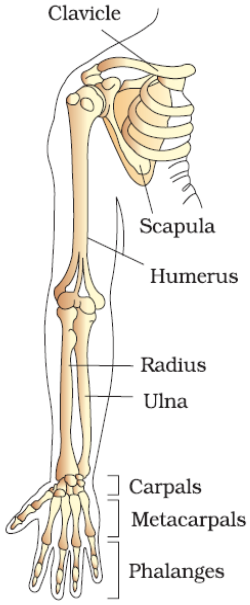

Figure Right pectoral girdle and upper arm. (frontal view)

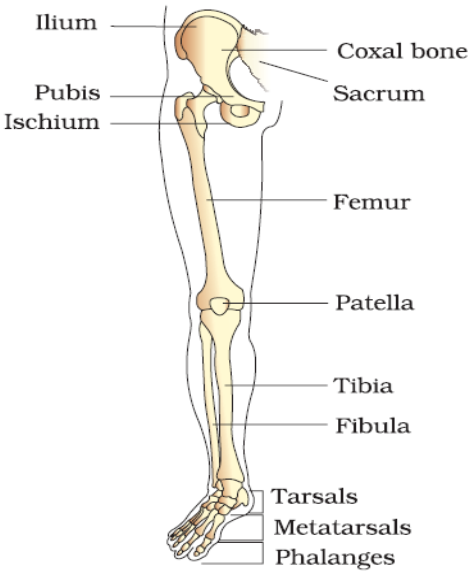

Figure Right pelvic girdle and lower limb bones (frontal view)

2. Hind limb- The bones of the leg are the Femur or thigh bone (longest bone), tibia and fibula, tarsals or ankle bones (7 in number), metatarsals (5 in number), and phalanges or digits (14 in number) A cup-shaped bone called patella cover the knee ventrally (knee cap).
3. Pectoral girdle- Its bones help in the articulation of the upper limbs with the axial skeleton. Each of pectoral girdle is formed of two halves. Each half of the pectoral girdle consists of a clavicle and a scapula. The 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 the 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.
4. 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.

Joints

. Joints are essential for all types of movements involving the bony parts of the body. 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 depending on different factors. Joints have been classified into three major structural forms, namely, fibrous, cartilaginous and synovial.

1. **Fibrous joints- This type of jodoest** do not allow any movement. This type of joint is usually found in between flat bones like as between flat skull bones. The skull bones fuse end-to-end with the help of dense fibrous connective tissues in the form of sutures, to form the cranium.
2. **Cartilaginous joints- In this type of joint** bones are joined together with the help of cartilages. Like the joint between the adjacent vertebrae in the vertebral column. It permits limited movements. This type of bones is also found in pubic symphysis. In females this joint is more prominent and it protects the fracture of pelvic bone at time of parturition.
3. **Synovial joints- This type of joints** are characterized by the presence of a fluid-filled synovial cavity between the articulating surfaces of the two bones. Such an arrangement allows considerable movement. These joints help in locomotion and many other movements. It may be of several types like-

- Ball and socket joint-e.g. between the humerus and pectoral girdle.
- Hinge joint- e.g. knee joint.
- Pivot joint- between atlas and axis.
- Gliding joint- e.g. between the carpals.
- Saddle joint- e.g. between carpal and metacarpal of thumb.

Disorders of the muscular and skeletal system

1. Myasthenia gravis: Autoimmune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.
2. Muscular dystrophy: Progressive degeneration of skeletal muscle mostly due to a genetic disorder.
3. Tetany: Rapid spasms (wild contractions) in muscle due to low Ca++ in body fluid.
4. Arthritis: Inflammation of joints.
5. Osteoporosis: Age-related disorder characterized by decreased bone mass and increased chances of fractures. A decreased level of estrogen is a common cause.
6. Gout: Inflammation of joints due to accumulation

IMPORTANT TERMS

Sl No.	Terms	Explanation
1	**Amoeboid movement**	Movement of an organism or a cell by the formation of pseudopodia.
2	**Actin**	A contractile protein which is one of the parts of a thin filament of muscle filament.
3	**Appendicular skeleton**	The girdles and limbs together constitute the appendicular endoskeleton. In the human being, it consists of 126 bones
4	**Axial skeleton**	The part of the endoskeleton which forms the axis of the endoskeletal system. In human beings, it consists of 80 bones.
5	**Bone**	A toughest specialized connective tissue which forms the endoskeleton
6	**Cartilage**	The pliable specialized connective tissue that forms the part of the endoskeleton.
7	**Cranium**	The part of the skull which houses the brain. In human beings, it consists of 8 bones.
8	**Chondrin protein**	The characteristic protein of cartilage
9	**Chondrology**	Study of cartilage
10	**Cartilaginous joints**	The joint between bones which articulate through cartilage. It gives restricted movement. Like the joints between the vertebra.
11	**Cori's Cycle**	The biochemical cycle occurs in the liver. It is involved in the conversion of lactic acid in glycogen.
12	**Cardiac muscle**	The muscle is found in the heart.
13	**Ciliary movement**	The movement occurs with the help of cilia.
14	**Exoskeleton**	The skeleton is found outside of the body. In human beings hair, nail, etc are representing the exoskeleton.
15	**I band and A band**	The light region in striated muscle fiber is the I band and the dark region in striated muscle fiber is the A band.
16	**Myofibril**	The muscle fiber consists of thin and thick filament which is known as myofibril.
17	**Thin filament**	It consists of Actin, Tropomyosin, and Troponin.
18	**Thick filament**	It consists of Myosin protein.

19	**Neuro-muscular end plate**	The junction between motor neurofibre and muscle fiber.