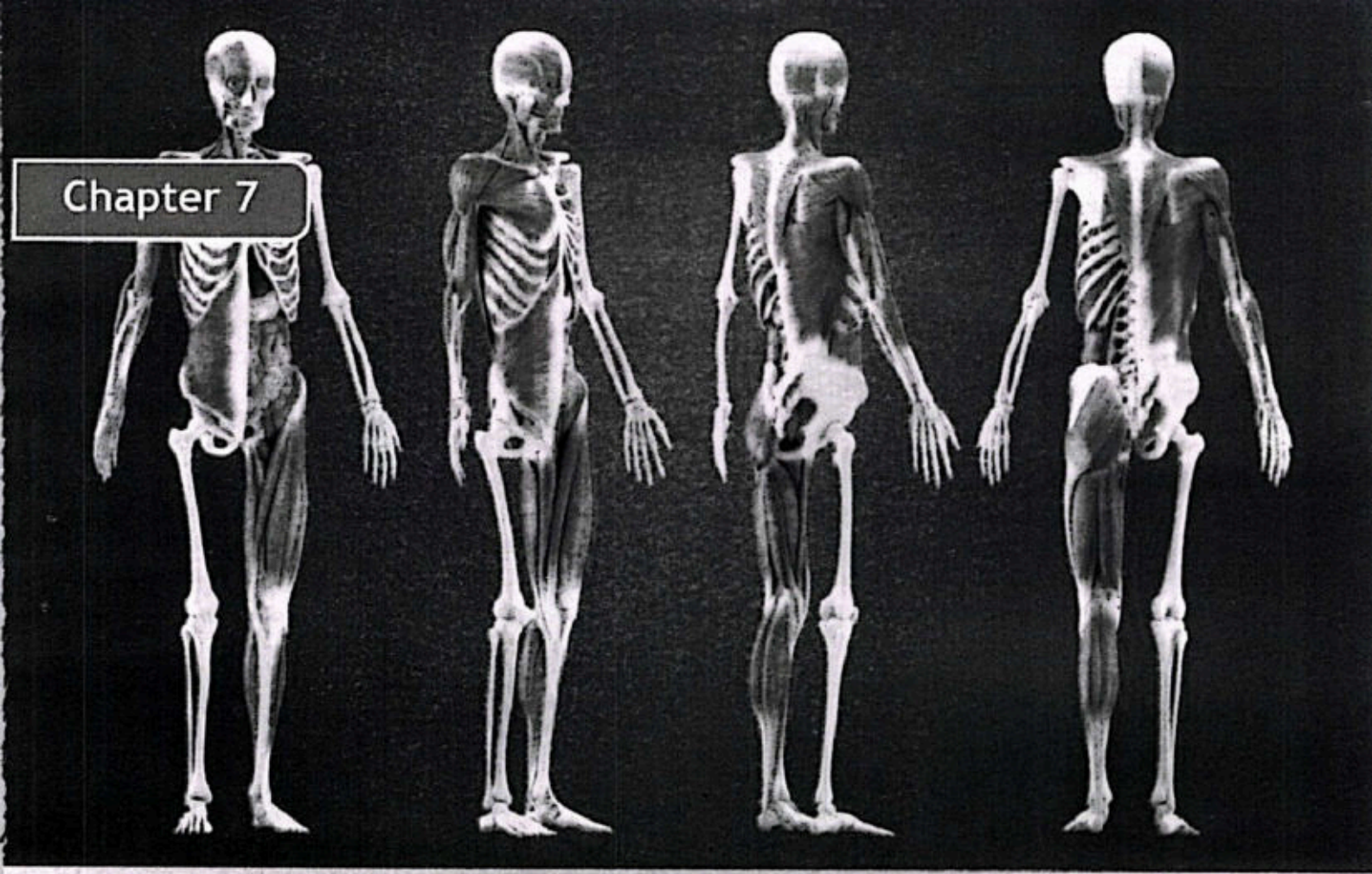


Chapter 7

SKELETAL SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-61] Describe the structure of bone and compare it with that of cartilage.
2. [B-12-R-62] Explain the functions of osteoblasts, osteoclasts and osteocytes.
3. [B-12-R-63] Identify the main divisions of the human skeleton and list the bones of the appendicular and axial skeleton of man.
4. [B-12-R-64] Describe three types of joints i.e, fibrous joints, cartilaginous joints and synovial joints and give example of each.
5. [B-12-R-65] Describe the disorders of human skeleton (disc-slip, spondylosis, sciatica, arthritis, osteoporosis) and their causes.
6. [B-12-R-66] State different types of fractures (simple, compound and complicated) and describe the repair process of simple fractures.
7. [B-12-R-67] Describe the injuries in joints (dislocation and sprain) and their first aid treatment.
8. [B-12-R-68] Compare smooth muscles, cardiac muscles and skeletal muscles.
9. [B-12-R-69] Annotate the ultrastructure of the skeletal muscle.
10. [B-12-R-70] Explain the sliding filaments model of muscle contraction.
11. [B-12-R-71] Describe the action of antagonistic muscles in the movement of knee joint.
12. [B-12-R-72] Explain muscle fatigue, cramps and tetany.
13. [B-12-R-73] Differentiate between tetanus and muscle tetany.

Support in living organisms is necessary to uphold and sustain the body against gravity and other external forces. As the living organisms have been increased in size through the process of evolution, the need for support became greater. This was particularly true once living organisms left water and colonized land. The skeleton in animals contributes to this support.

7.1 HUMAN SKELETON

Human skeletal system consists of bones and cartilage. The skeleton acts as a framework that supports soft tissues. It allows free movement through the action of muscles across joints. The study of bones and cartilage is called osteology.

7.1.1 Structure of Bone

An individual bone is composed of a variety of tissues, including bone tissue, cartilage, fibrous connective tissue, blood and nerve tissue. The terminal broad parts are called **epiphysis** and the middle part along the length of bone is called **diaphysis** or **shaft** which also contains a central cavity filled by **yellow bone marrow.** The outer connective tissue around the bone is called **periosteum** and the inner region is called **endosteum.**

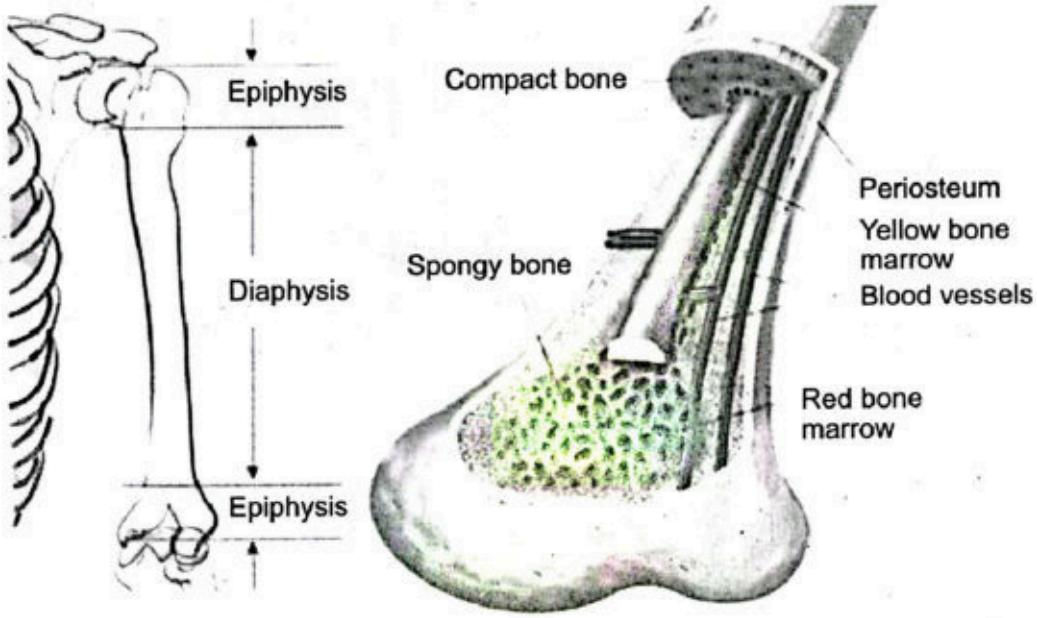


Fig. 7.1: Structure of bone

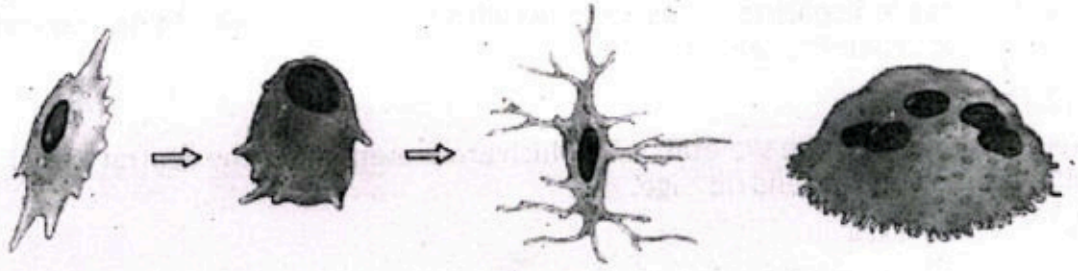
The endosteum further consists of a peripheral part, called compact bone and the inner bone mass, called **spongy bone.** Most of the spongy bone is present in epiphysis. The **red bone marrow** is also found in the spaces of spongy bone.

7.1.2 Cells associated with bone

There are three types of cells associated with bone (derived from osteogenic cells) i.e., osteoblasts are bone forming cells that synthesize and secrete unmineralized ground substance. Once the osteoblasts are surrounded by matrix, they become the osteocytes.

Osteocytes maintain healthy bone tissue by secreting enzymes and influencing bone mineral content. They also regulate the calcium release from bone tissue to blood. **Osteoclasts are bone** destroying cells. They perform bone resorption, i.e., they breakdown bone and deposit calcium

and phosphate in the blood. The work of osteoclasts is important to the growth and repair of bone.



Osteogenic cell (develops into an osteoblast) | Osteoblast (forms bone matrix) | Osteocyte (maintains bone tissue) | Osteoclast (functions in resorption, the breakdown of bone matrix)

Fig. 7.2: Types of bone cells

7.1.3 Structure of Cartilage

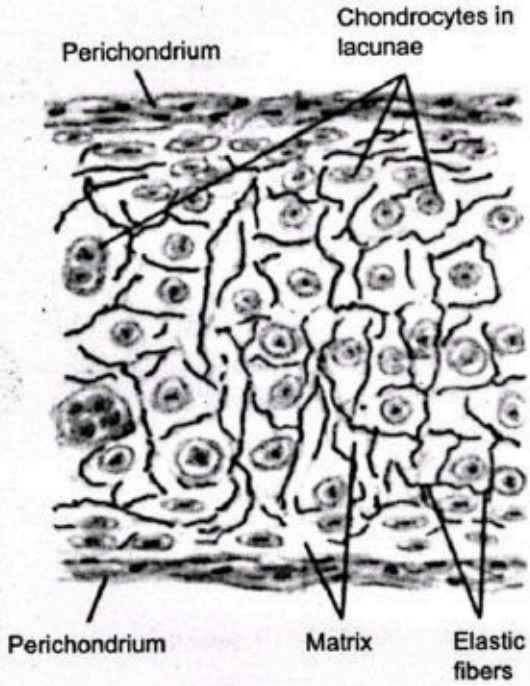


Fig. 7.3: Structure of cartilage

Cartilage is not strong as bone. It is present at particular places only. It is more flexible than the bone because the matrix is gel like and contains many collagenous and elastic fibres. The cartilage matrix is covered by a dense layer of collagen fibres, called **perichondrium**. There are many small cavities distributed in the matrix called **lacunae** which contain cartilage cells. The living cells of cartilage are called **chondrocytes**. Unlike other connective tissues, cartilage does not contain blood vessels and the chondrocytes are supplied by diffusion. Because of this, it heals very slowly. Although the human skeleton is initially made up of cartilages and fibrous membranes, most of these early supports are soon replaced by bones. A few cartilages that remain in adults are of three types. **Hyaline cartilage** is found at the ends of long bones and in the nose, at larynx and trachea. **Fibrocartilage** contains wide rows of thick collagenous fibres is found in the disks located between the vertebrae, cartilage of knee. **Elastic cartilage** is found in the ear flaps and epiglottis.

Table 7.1 Comparison between bone and cartilage

Feature	Bone	Cartilage
Collagen	Densely packed	Loosely packed
Cell types	Osteoblast, osteocytes and osteoclasts	Chondrocytes
Blood vessel	Present	Absent
Minerals	Deposit minerals such as calcium, carbonates, phosphates, etc.	No deposition of minerals
External covering	Covered by periosteum	Covered by pericondrium

7.2 DIVISIONS OF HUMAN SKELETON

Human skeletal system consists of 206 bones which are primarily divided into two division i.e., axial skeleton and appendicular skeleton.

7.2.1 Axial skeleton

Axial skeleton includes those skeletal parts which are present along the central axis of the body, like skull, vertebral column and rib cage.

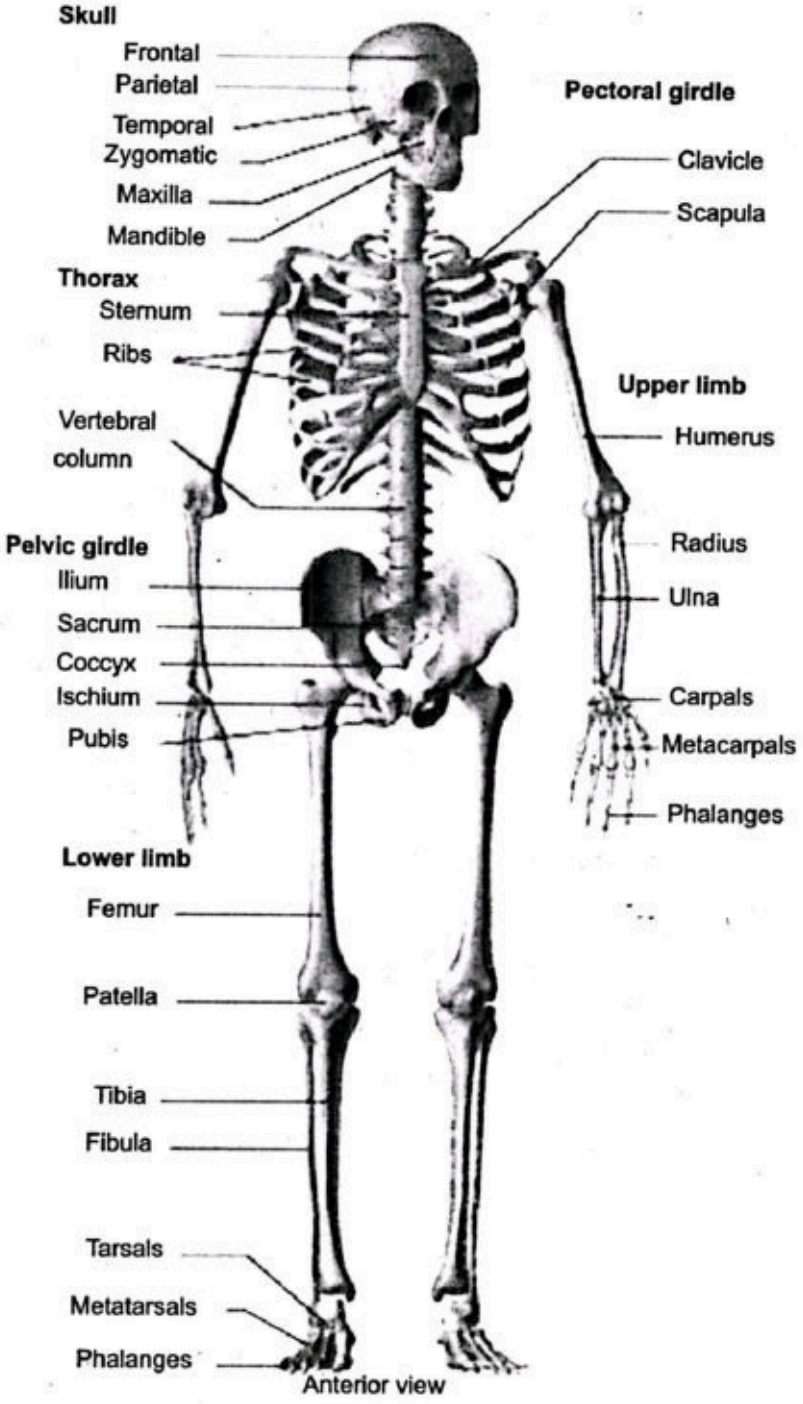


Fig. 7.4: Human skeleton

7.2.2 Head bones

Head contains 29 bones which are divided into four divisions i.e., **cranial bones, facial bones,** ear ossicles and hyoid bone. Cranial bones form cranium (brain box). Out of 8 cranial bones two are paired i.e., **parietal bones** (left and right) and **temporal bone** (left and right) while four are unpaired like **frontal bone, occipital bone, ethmoid bone, sphenoid bone**. Facial bones are fourteen in number and are attached to the cranium to form face. The six paired bones of face are: **lacrimal, zygomatic, nasal bones, inferior nasal concha, maxilla** and **palatine**. The unpaired bones of face are **mandible** and **vomer**. Three pairs of middle ear ossicles are **malleus, incus** and **stapes** (pronunciation: stay-peez). **Hyoid bone** is a small single bone which lies at the base of skull below the tongue. It does not articulate with any other bone of head.

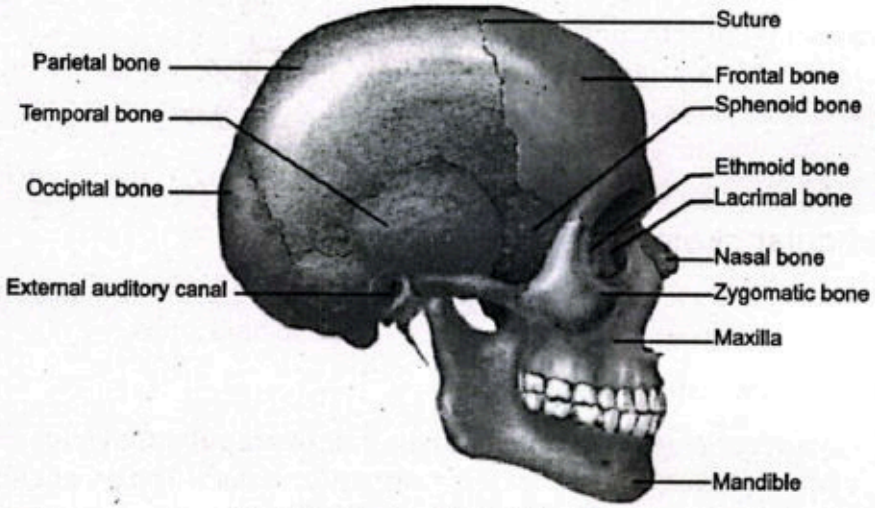


Fig. 7.5: Human Skull (side view)

7.2.3 Vertebral column

The **vertebral column** in human being consists of thirty-three vertebrae. The vertebrae may be divided into following five groups:
(a) Cervical vertebrae - 7, (b) Thoracic vertebrae - 12 (c) Lumbar vertebrae - 5 (d) Sacral vertebrae -5 (e) Coccygeal vertebrae - 4. Cervical vertebrae are the vertebrae of the neck. The **atlas** is the first cervical vertebra. **Axis** is the second cervical vertebra. **Thoracic vertebrae** are rib carrying vertebrae having large spinous processes and are found in chest region. **Lumbar vertebrae** are present in abdominal region. **Sacral vertebrae** are five fused vertebrae forming the **sacrum**. The sacrum articulates with the iliac bones of the hip bone to form the back of the pelvis. **Coccygeal vertebrae** or coccyx are four vertebrae fused in the adults. Sacral and coccygeal vertebrae are together called **pelvic vertebrae**.

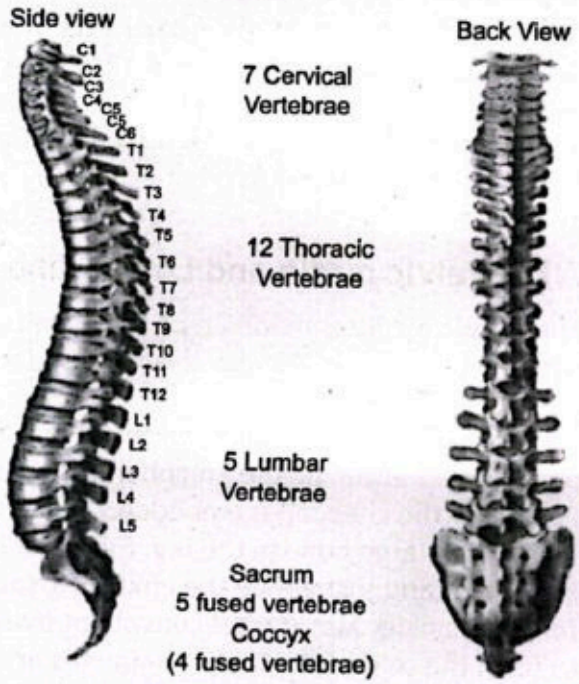


Fig. 7.6: Human vertebral column

7.2.4 Rib cage

The rib cage consists of twelve pairs of ribs. The ribs articulate posteriorly with the thoracic vertebrae. Ten ribs are connected anteriorly with sternum either directly or through the costal cartilage. The rib cage provides support for a semi-vacuum chamber called chest cavity.

The seven pairs of ribs that attach directly to the sternum are called **true ribs**. The 8th, 9th and 10th are called **false ribs**, as these three pairs of ribs are attached to the sternum by means of common costal cartilage. 11th and 12th pairs of ribs are known as **floating ribs**, because they do not attach to the sternum.

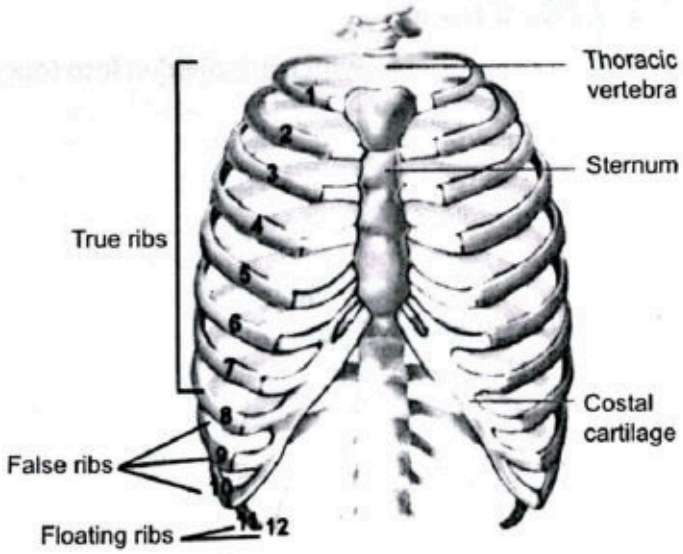


Fig. 7.7: Human rib cage

7.2.5 Appendicular skeleton

Appendicular skeleton includes those skeletal parts which are present in appendages (arms and legs). These are pectoral girdle, pelvic girdle, forelimbs and hind limbs.

7.2.6 Pectoral girdle and Upper limb

Pectoral girdle consists of a pair of **clavicles** and a pair of **scapula**. **Clavicles** are a pair of collar bones. One end of each curved bone articulates with the sternum. The other end articulates with the scapula. **Scapulas** are two shoulder blades.

Upper limb or **Forelimb** consists of humerus, ulna, radius, carpals, metacarpals and phalanges. **Humerus** is a long bone, the end of which has a spherical **head**, which fits into the **glenoid cavity**. **Radius** is a long, outer bone of the forearm (on the thumb side). **Ulna** is a long bone on the inner side of the forearm, and slightly bigger than radius. **Carpals** consist of two rows of eight short bones forming the wrist. The upper row articulates with the radius and forms the wrist joint. **Metacarpals** consist of five bones making up the palm of the hand. Each finger possesses three **phalanges** except thumb which comprises two phalanges.

7.2.7 Pelvic girdle and Lower limb

The **pelvic girdle** is made up of three units the **ileum**, **ischium** and **pubis** which form **coxa**. The two halves of the pelvic girdle are joined at the **pubic symphysis**. A cavity called **acetabulum** is also present.

Lower limb or **Hind limb** consists of femur, patella, tibia, fibula, tarsal, metatarsal and phalanges. **Femur** or the thighbone is a long bone with head, which fits into the acetabulum. **Patella** or the kneecap is embedded in a long tendon which runs over the knee joint. **Tibia** or **shin** bone is the large bone in the leg. **Fibula** or outer bone is a thin bone joins the tibia just below the knee joint and just above the ankle. **Tarsal** is made of seven bones which are tightly attached to form the ankle. **Metatarsal** consists of five bones which articulate with the tarsal and phalanges to form the sole of the foot. **Phalanges** are small bones which make up the toes. Each toe of the foot possesses three phalanges except big toe, which comprises of two phalanges.

7.3 JOINTS

A joint or articulation is a place where two bones or bone and cartilage come together. The scientific study of the structure and function of joints is called arthrology. The joints are classified as fibrous joints (immoveable), cartilaginous joints (slightly moveable) and synovial joints (freely moveable).

7.3.1 Fibrous joints

When the adjacent bones are directly connected to each other by fibrous connective tissue consisting mainly of collagen, it is called fibrous joint. In this joint the bones do not have a joint cavity between them. The gap between the bones may be narrow or wide.

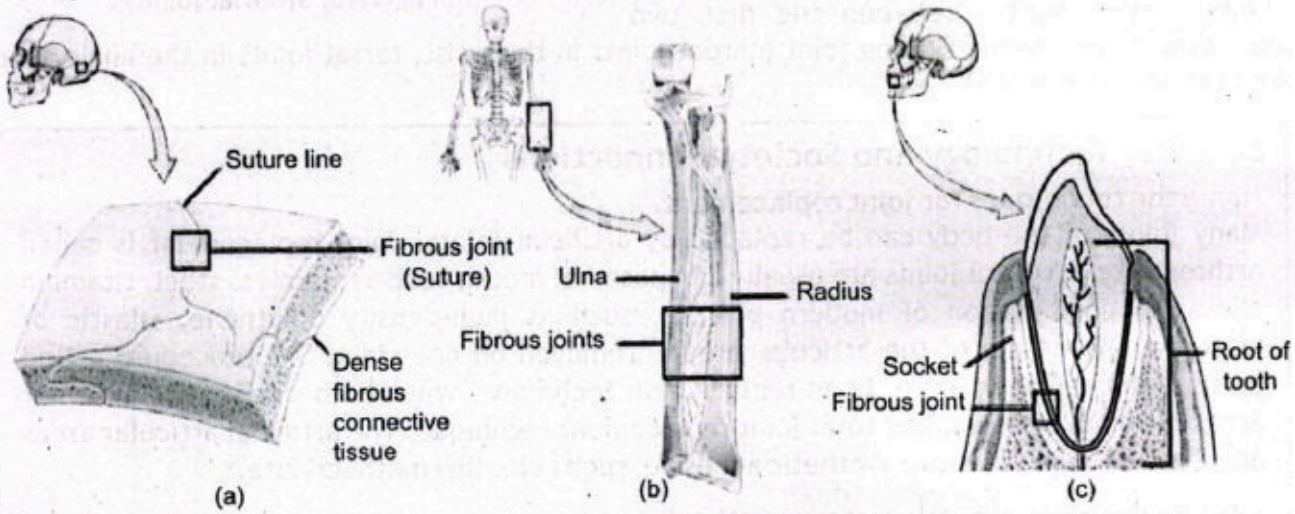


Fig. 7.8: Examples of fibrous joints

Examples: Fibrous joint is found between:

a. Most bones of the skull called suture.

b. The shaft regions of the long bones in the forearm and in the leg.

c. The root of a tooth and the socket in the maxilla or mandible (jawbones),

7.3.2 Cartilaginous joints

At a cartilaginous joint, the adjacent bones are united by cartilage, a tough but flexible type of connective tissue. These types of joints lack a joint cavity and involve bones that are joined together by either hyaline cartilage or fibrocartilage. Cartilaginous joints allow little movement. The examples of cartilaginous joint are:

a. Costal cartilages that attach ribs to the sternum.

b. Pubic symphysis and intervertebral disc.

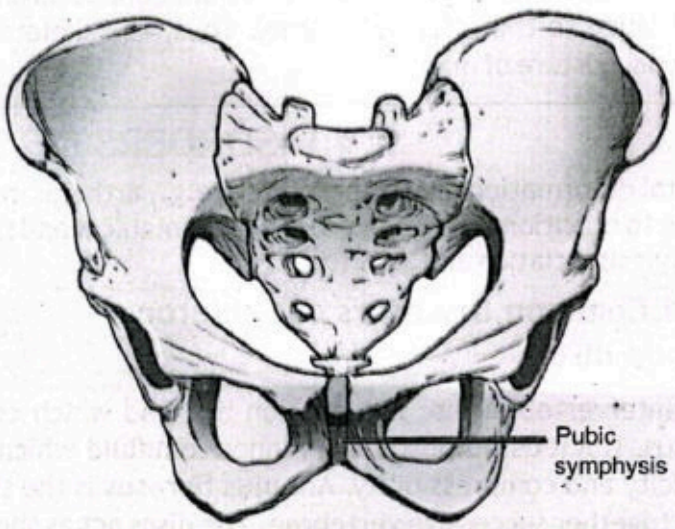


Fig. 7.9: Cartilaginous joint of pubic symphysis

7.3.3 Synovial joints

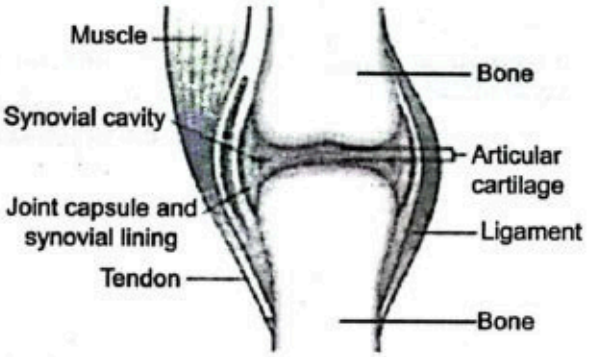


Fig. 7.10: Synovial joint

They are freely moveable joints. The ends of bones are covered with hyaline cartilage and held together by a surrounding, tube like capsule *of dense* fibrous tissue.
The joint capsule is composed of an outer layer of ligaments and an inner lining of synovial membrane, which secretes **synovial fluid.**
Examples: Hinge Joints (elbow, knee, and finger joints , Ball-and-Socket Joints: (shoulder and hip joints), Pivot Joints (between the first two vertebrae in the neck), Gliding joint (carpal joints in the wrist, tarsal joints in the ankle, and facet joints in the spine)

Science, Technology and Society Connections

Name the techniques for joint replacement.
Many joints of the body can be replaced by artificial joints. Joint replacement is called arthroplasty. Artificial joints are usually composed of metal, such as stainless steel, titanium alloys, in combination of modern plastics, such as high-density polythene, silastic or elastomer. The bone of the articular area is removed on one side. This procedure called partial joint replacement or hemi-replacement technique. When both sides of the articular area are removed it is called total joint replacement technique. The artificial articular areas are glued to the bone with a synthetic adhesive, such as methyl methacrylate.

• **Relate the bipedal posture of man with his skeleton and musculature.**
Curvatures of vertebral column help to balance the body for bipedal stance. The intervertebral discs lend flexibility to the vertebral column and absorb vertical shock. The structure of the pelvis, in its attachment to the vertebral column, permits upright posture and locomotion on two appendages (bipedal locomotion). Certain muscles are active posture muscles, whose primary function is to work in opposition to gravity. For example, the strong, complex muscles of the vertebral column are adapted to provide support and movement in resistance to the effect of gravity. Thus, the skeleton and muscular systems maintain the bipedal posture of man.

7.4 DISORDERS OF SKELETON

Skeletal deformation may be hereditary e.g., arthritis may be hormonal e.g., osteoporosis or may be due to nutritional deficiency e.g., osteomalacia and rickets. Here we will describe slipped disc *spondylosis, sciatica* and arthritis.

7.4.1 Common Disorders of Skeleton

Slipped disc

Each intervertebral disc is a cushion like pad which consists of nucleus pulposus and annulus fibrosus. **Nucleus pulposus** is an inner semifluid which acts as a rubber ball to give a disc its elasticity and compressibility. **Annulus fibrosus** is the strong outer ring of fibrocartilage, which holds together successive vertebrae. The discs act as shock absorber. Severe or sudden trauma to spines may result in herniation of one or more discs.

The herniated disc or slipped disc usually involves rupture of annulus fibrosus followed by protrusion of the spongy nucleus pulposus. If protrusion presses on spinal cord or on spinal nerves, generate severe pain or even destruction of these nervous structures. 'Slipped disc' is misleading as it is not the whole disc that slides out of the position.

7.4.2 Spondylosis

It is the immobility and fusion of vertebral joint. Cervical spondylosis results from chronic cervical degeneration, with herniation of disc and aging.

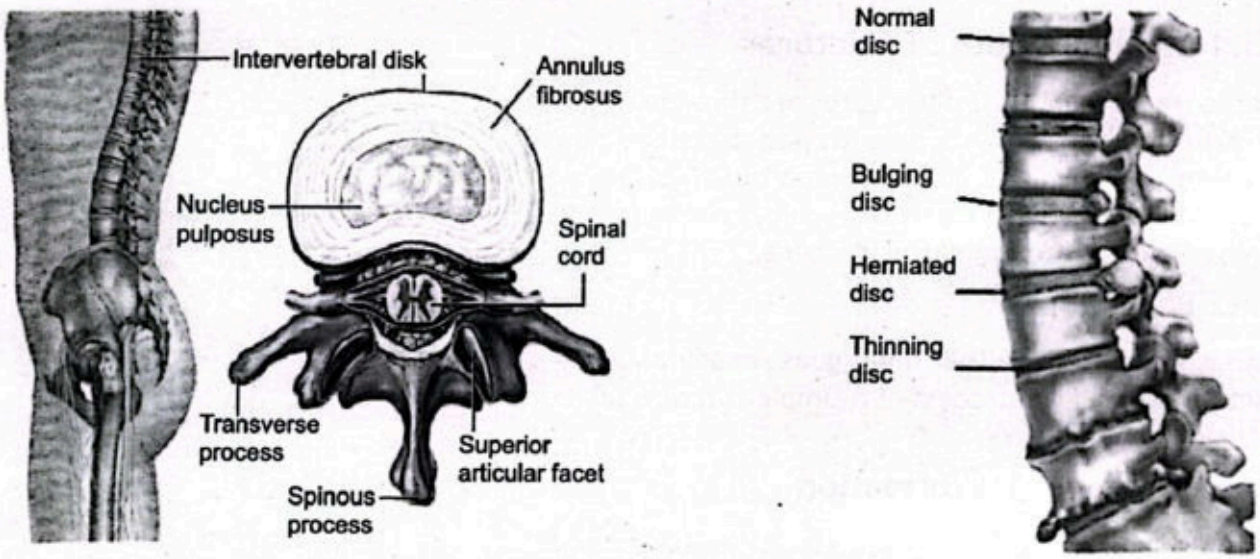


Fig. 7.11: Structure of (a) intervertebral disc (b) slipped disk

7.4.3 Sciatica

Sciatica refers to pain, weakness, numbness, or tingling in the leg. It is caused by injury to or pressure on the sciatic nerve. Common causes of sciatica include: Slipped disk, pelvic injury or fracture and tumors.

7.4.4 Arthritis

It is the inflammation of joints. The typical **symptoms** of arthritis include pain after walking which may later occur even at rest, creaking sounds in joint, difficulty in getting up from a chair and pain on walking up and down stairs. There are different types of arthritis. **Osteoarthritis** is a progressive disease in which the articular cartilages gradually soften and disintegrate. It affects knee, hip and intervertebral joints.

Rheumatoid arthritis is the result of an autoimmune disorder in which synovial membrane becomes inflamed due to faulty immune system. **Gouty arthritis** results from a metabolic disorder in which an abnormal amount of uric acid is retained in the blood and sodium urate crystals are deposited in the joints. The most common joint affected is the joint of the big toe.

7.4.5 Osteoporosis

Osteoporosis, is a common disease characterised by reduced bone mass and an increased risk of fracture. In normal individuals, bone mass increases during skeletal growth to reach a peak between the ages of 20 and 25 but falls thereafter in both sexes. Osteoporosis, occurs because in

the bone resorption exceeds bone deposition. The increased calcium is used to increase bone mass. The greater the bones mass before the onset of osteoporosis, the greater the tolerance for bone loss later in life. For this reason, it is important for adults, especially women in their twenties and thirties, to ingest adequate amounts of calcium.

7.5 BONE FRACTURES

A fracture is the medical term for a broken bone. They occur when the physical force exerted on the bone is stronger than the bone itself. So bones break when they cannot withstand a force or trauma applied to them.

7.5.1 Common types of fractures

Simple fracture or **closed fractures** are those in which the skin is intact. If the bone ends penetrate the skin and form a wound are called **compound fracture** or **open fracture**. When a fracture damages the adjacent organs it is called **complicated fracture**.

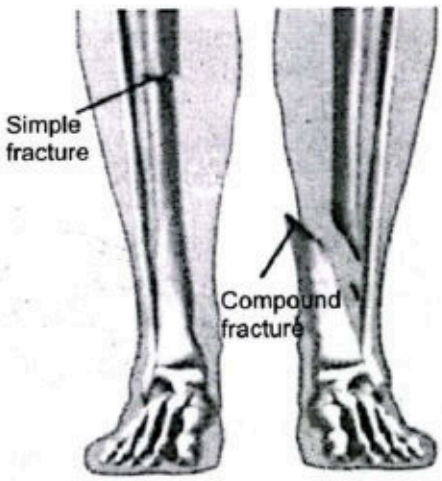


Fig. 7.12: Bone fractures

7.5.2 Bone Repair

Bone is a living tissue that undergoes repair following fracture. The repair process of a simple fracture takes place in four major steps.

Haematoma or clot formation

When a bone breaks, blood vessels in the bone, and perhaps in surrounding tissues, are torn and haemorrhage. As a result, a haematoma, a mass of clotted blood, forms at the fracture site. Soon, bone cells deprived of nutrition die, and the tissue at the site becomes swollen, painful, and inflamed.

Fibrocartilaginous callus formation

Within a few days, several events lead to the formation of fibrocartilaginous or soft callus. Capillaries grow into the haematoma and phagocytic cells invade the area and begin cleaning up the debris. A fracture ruptures the periosteum and stimulates the production and release of the numerous osteoblasts. These osteoblasts in conjunction with cartilage forming cells secrete a porous mass of bone and cartilage called callus (or cartilaginous callus) surrounding the break. The callus replaces the original blood clot and holds the ends of the bones together. This process takes 3-4 weeks.

Bony callus formation or callus ossification

Within a week, after the formation of soft callus, it is gradually converted into a hard **bony callus** of spongy bone. Bony callus formation continues until a firm union is formed about two months later. Osteoclasts breakdown the cartilage while osteoblasts replace it with bone.

Bone remodelling

It takes place when a compact bone is formed across the fracture line to connect both sides. Usually, more bone is produced at the site of a healing fracture than needed to replace the

damaged tissue. However, osteoclasts eventually remove the excess and the final result of the repair is bone shaped very much like the original. The final structure of the remodeled area resembles that of the original unbroken bony region because it responds to the same set of mechanical stressors.

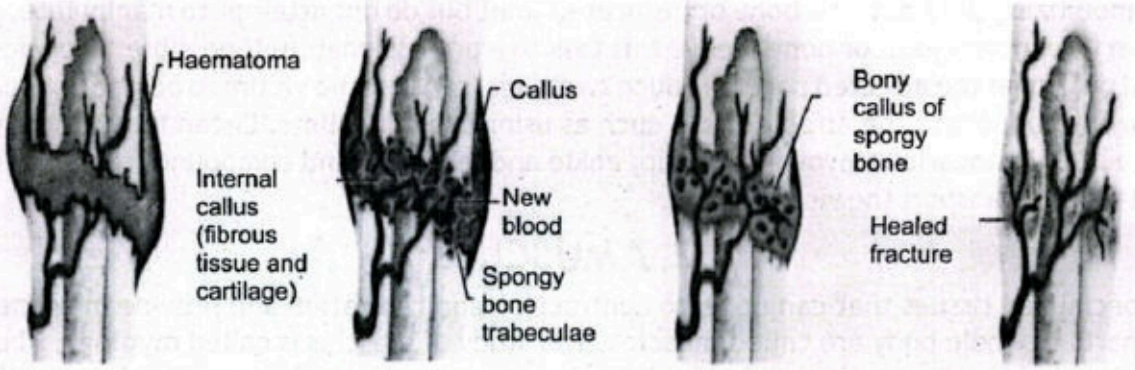


Fig. 7.13: Bone repair

Science, Technology and Society Connections

Relate improper posture to bone/joint problems

Improper posture causes increased stress on joints and their supporting structures resulting in injury, pain and early degeneration of bones and joints.

7.6 INJURIES TO JOINTS

Torsion or sudden impact to the side of a joint can be devastating. We will discuss here dislocation and sprain.

7.6.1 Dislocation of joints

A dislocated joint is a joint that slips out of place. It occurs when the ends of bones are forced from their normal positions. A severe dislocation can cause tearing of the muscles, ligaments and tendons that support the joint. Symptoms include; swelling, intense pain, and immobility of the affected joint. The most common causes are a blow, fall, or other trauma to the joint. In some cases, dislocations are caused by a disease or a defective ligament. **Rheumatoid arthritis** can also cause joint dislocation. A dislocated joint usually can only be successfully *'reduced' into its* normal position by a trained medical professional. Surgery may be needed to repair or tighten stretched ligaments.

7.6.2 Sprain

A sprain is an injury to a ligament. Commonly injured ligaments are in the ankle, knee and wrist. The ligaments can be injured by being stretched too far from their normal position. The sprain should be rested. Sprains can usually be treated conservatively with treatments such as icing and physical therapy. Dressings, bandages, or ace-wraps should be used to immobilize the sprain and provide support.

7.6.3 First Aid Treatment for Disorders of Skeleton

Prompt and proper first aid increases the chances of a complete recovery. Usually, the severity of the bone fracture and dislocation of joints depend on its cause and the affected part. If you suspect someone has dislocated a joint or fractured bone, you can help by: (a) immobilizing the fractured bone or dislocated joint but do not attempt to manipulate, pull or re-align the injured joint or bone. Leave this task to a professional (b) If possible; apply ice pack or cold pack over the affected part to reduce swelling. (c) Assist the victim to position of comfort. (d) Provide support to the affected area such as using sling or splints. Listen to what the victim tells you. (e) Dislocations involving the hip, ankle and leg joints and compound fractures require ambulance to transport the victim.

7.7 MUSCLES

The specialized tissues that can undergo contraction and relaxation and provide movements of body parts or whole body are called **muscles**. The study of muscles is called **myology**. They also function to hold body parts in postural positions, movement of body fluids and heat production.

7.7.1 Types of Muscles

There are three types of muscle tissues: smooth, cardiac and skeletal.

Smooth muscles

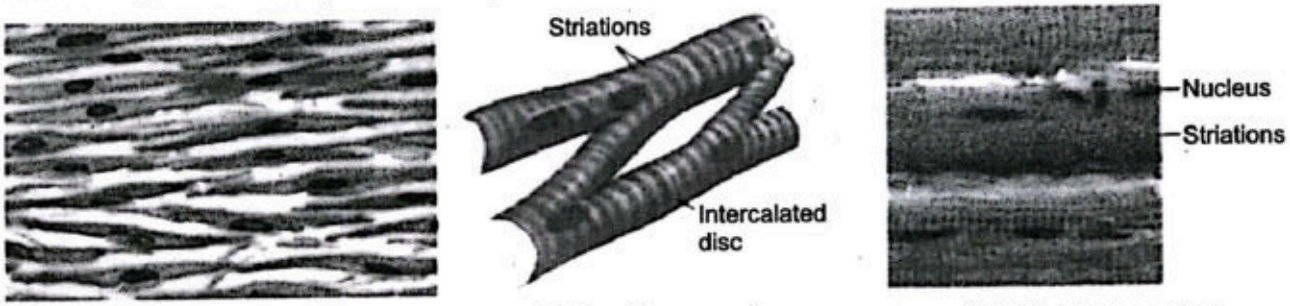
These are distributed widely throughout the body and are more variable in function than other muscle types. The smooth muscle cells are spindle shaped, with a single nucleus located in the middle of the cell. **Myofilaments** are not organised into sarcomeres. Consequently, smooth muscle does not have a striated appearance. Smooth muscle cells contain noncontractile intermediate filaments. Smooth muscles are involuntary in function. They are found in digestive, reproductive, urinary tract, blood vessels etc.

Cardiac muscles

These are found only in heart. They branch extensively. Cardiac muscles are striated like skeletal muscle, but each cell usually contains one nucleus located near the centre. Adjacent cells join together to form branching fibres by specialised cell-to-cell attachments called **intercalated discs**, which have gap like junctions that allow action potentials to pass from cell to cell.

Skeletal muscles

These muscles are attached to the bone and are responsible for movements of body parts and whole body movements (locomotion).



(a) Smooth muscles (c) Cardiac muscles (b) Skeletal muscles

Fig. 7.14: Types of muscles

Table 7.2 Comparison of three types of muscle tissues

Property	Smooth Muscles	Cardiac Muscles	Skeletal Muscles
Muscle appearance	Unstriped	Irregular striped	Regular striped
Cell shape	Spindle	Branched	Spindle or cylindrical
Number of nuclei	One per cell	One per cell	Many per cell
Speed of contraction	Slow	Intermediate	Slow to rapid
Contraction caused by	Nervous system	Spontaneous	Nervous system
Function	Controls movement of substances through hollow organs	Pumps blood	Move skeleton
Voluntary control	Usually no control	Usually no control	Have control

7.8 STRUCTURE OF SKELETAL MUSCLES

Skeletal muscles or striated muscles show alternate light and dark regions under microscope. Skeletal muscles are composed of muscle fibres or muscle cells. Bundles of muscle fibres are enclosed by collagen fibres and connective tissue. At the ends of the muscle the collagen and connective tissue forms **tendons** which attach the muscle to skeletal elements. Each skeletal muscle fibre is a single cylindrical cell, enclosed by a plasma membrane like structure called sarcolemma and has several nuclei. The sarcolemma of muscle fibre cell penetrates deep into the cell to form a hollow elongated tube, the **transverse tubule (T-tubule)**. The cytoplasm of the muscle fiber is called **sarcoplasm**. It contains **sarcoplasmic reticulum**. Within the muscle fibres are numerous thin **myofibrils** which possess characteristic cross striations.

The myofibrils are 1-2 μm in diameter that run in parallel fashion and extend the entire length of the cell. Each myofibril is composed of two types of myofilaments **thin myofilaments** and **thick myofilaments**.

7.8.1 Ultra - structure of skeletal muscles

Under a light microscope only the striated nature of the myofibrils can be observed. This is seen as a regular alternation of light and dark bands called the **I bands** and **A bands** respectively, transversed by thin, dark lines. Electron microscope studies clearly indicate that the bands are due to regular arrangement of thin and thick myofilaments. Transversing the middle of each I band is a dark line called the **Z line**. The section of myofibril between two Z lines is called a **sarcomere**, which is a contractile unit. From the Z line thin myofilaments extend in both directions, while in the centre of the sarcomere are found thick myofilaments.

In certain regions of the sarcomere, thin and thick myofilaments overlap. Transverse sections in these regions indicate that six thin myofilaments surround each thick myofilament. This arrangement of thin and thick myofilaments results in a number of other bands being recognizable in the sarcomere. The entire length of thick myofilaments constitute the **A band** because they are **anisotropic** that can polarize visible light. Thin myofilaments alone constitute **I band**, which is **isotropic** or nonpolarizing. The centre of the A band is lighter than the outer regions in a relaxed sarcomere as there are no overlap between the thin and thick myofilament in this region. It is called the **H zone** (H stands for 'hele' means bright). The H zone itself may be bisected by a dark line, the **M line**. The M line joins adjacent myosin filaments together at a point halfway along their length.

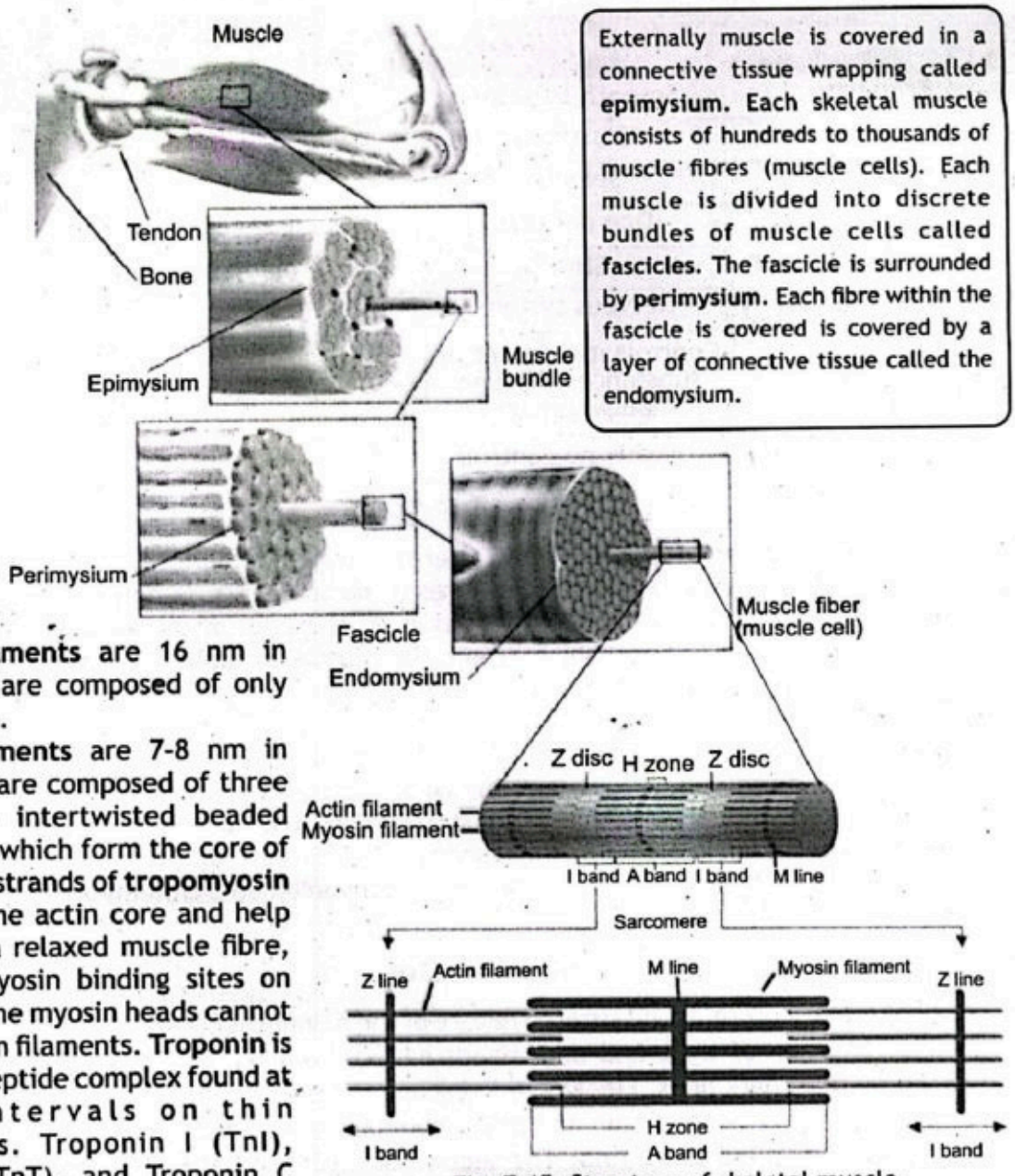


Fig. 7.15: Structure of skeletal muscle

Externally muscle is covered in a connective tissue wrapping called **epimysium.** Each skeletal muscle consists of hundreds to thousands of muscle fibres (muscle cells). Each muscle is divided into discrete bundles of muscle cells called **fascicles.** The fascicle is surrounded by **perimysium.** Each fibre within the fascicle is covered is covered by a layer of connective tissue called the endomysium.

Thick myofilaments are 16 nm in diameter and are composed of only myosin protein.

The **thin filaments** are 7-8 nm in diameter and are composed of three proteins. Two intertwisted beaded chain of **actin** which form the core of filament. Two strands of **tropomyosin** spiral about the actin core and help stiffen it. In a relaxed muscle fibre, they block myosin binding sites on actin so that the myosin heads cannot bind to the thin filaments. **Troponin** is a three-polypeptide complex found at regular intervals on thin myofilaments. Troponin I (TnI), Troponin T (TnT), and Troponin C (TnC). These proteins are crucial for regulating muscle contraction in both skeletal and cardiac muscles. TnI and TnT: are primarily found in cardiac muscle, with small amounts of TnT also present in skeletal muscle. TnC: is found in both cardiac and skeletal muscle. TnI is an inhibitory subunit that binds to actin. TnT binds to tropomysin and helps position it on actin. TnC binds calcium ions. Both troponin and tropomyosin help control the myosin-actin interactions involved in contraction.

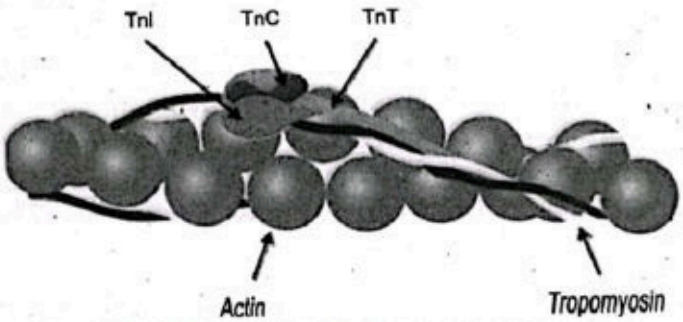


Fig. 7.16: The troponin complex

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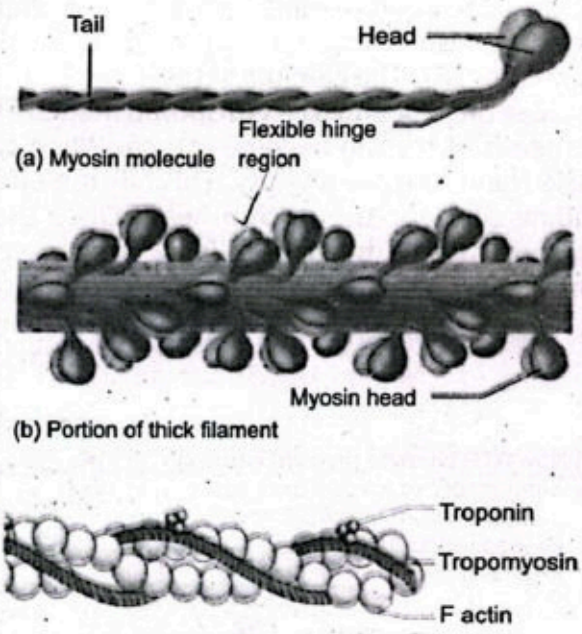
Each myosin molecule consists of six polypeptides which are arranged in such a way that each myosin molecule possesses a tail and two globular heads. Each thick filament contains about 300 myosin molecules bundled together with their tails forming the central part of the thick filament and their heads facing outward and in opposite directions at each end.

The kidney-shaped polypeptide subunits of actin, called globular actin or **G actin**, bear the active sites to which the myosin heads attach during contraction. G actin monomers are polymerized into long actin filaments called **fibrous, or F actin**. The backbone of each thin filament appears to be formed by two intertwined actin filaments that look like a twisted double strand of pearls.



7.9 MUSCLE CONTRACTION - SLIDING FILAMENT MODEL

The sliding filament theory of contraction states that during contraction the thin myofilaments slide past the thick ones so that they overlap to a greater degree. In a relaxed muscle fibre, the thick and thin myofilaments overlap only at the ends of the A band. But when muscle fibres are stimulated by the nervous system, the myosin heads are attached on to myosin binding sites on actin in the thin myofilaments, and the sliding begins. These links are called **cross bridges** which are formed and broken several times during a contraction, acting like tiny ratchets to generate tension and propel the thin myofilaments toward the centre of the sarcomere.

As this event occurs simultaneously in sarcomeres throughout the cell, the muscle cell shortens. The I bands shorten, the distance between successive Z discs is reduced, the H zone disappears, and the contiguous A bands move closer together but do not change in length.

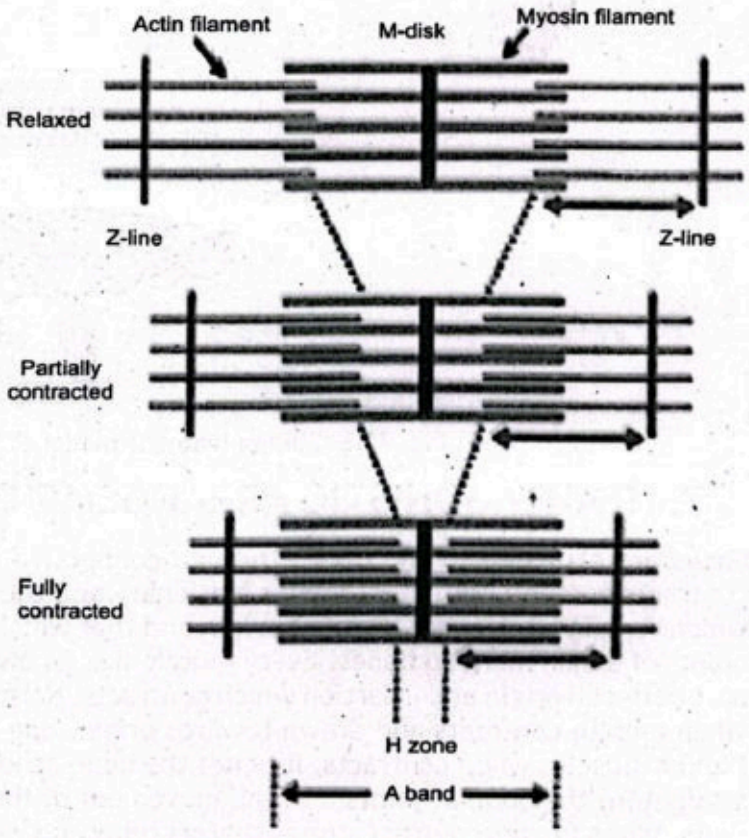


Fig. 7.17: Sliding filament model of muscle contraction

Control of cross bridges

Muscle contraction is initiated by nerve impulse arriving at the neuromuscular junction. The nerve impulse is carried through the sarcolemma to the T tubule then to the sarcoplasmic reticulum (SR). The calcium gates of the SR open releasing calcium into the cytosol. When muscle is at rest the tropomyosin is disposed in such a way that it covers the sites on the actin chain where the heads of myosin become attach. When calcium ions bind with the troponin molecules they cause them to move slightly. This has the effect of displacing the tropomyosin and exposing the binding sites for the myosin head. Once the myosin head has become attached to the actin filament, ATP is hydrolysed and the crossed bridges are broken down. The formation and breakdown of cross bridges occur again and again during the sliding of the filament.

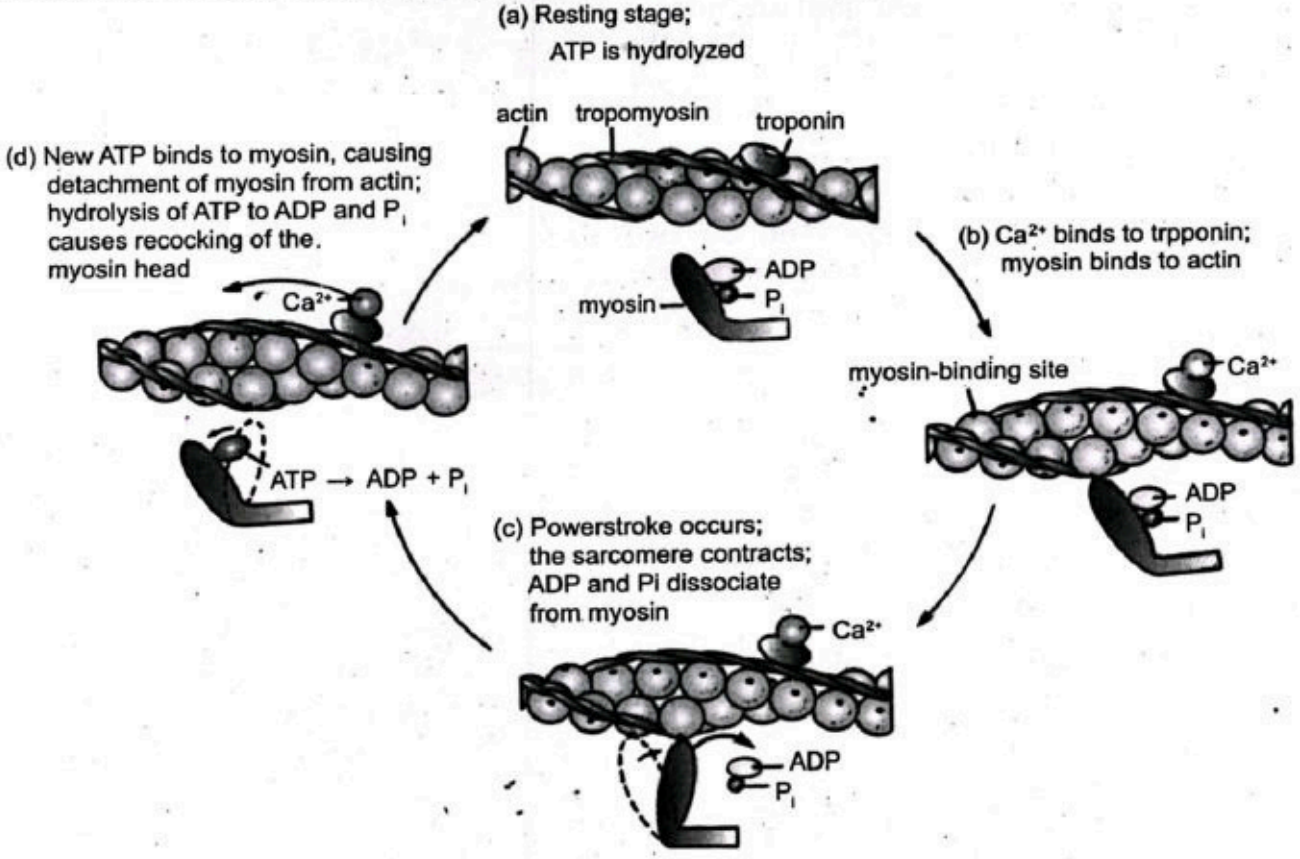


Fig. 7.18: Sliding filament model of muscle contraction

7.10 ANTAGONISTIC ARRANGEMENT OF SKELETAL MUSCLES

Bones are attached to the bones through connective tissue called **ligament**. When a muscle contracts one end normally remains stationary and the other end is drawn towards it. The end which remains stationary is called **origin** and that which moves is called **insertion**. Both are the points of attachment to bones. Every muscle has its own origin and insertion. **Belly** is the thick part between origin and insertion which contracts. Normally the bones of insertion is pulled upon when muscle contracts and drawn towards origin, one bone moving on the other at the joints. **Flexor muscle**, when contracts, it bends the bone at joint. **Extensor muscle**, when contracts it straightens the bone at joints. For the movement of the bone in two directions muscles work in pairs. When flexors contract, the extensors relax and vice versa. Such arrangement of muscles is called **antagonistic arrangement**.

Movement in knee joint

Knee or **tibio-femoral joint** is located between the femur and tibia. It is a complex hinge joint that permits limited rolling and gliding movements in addition to flexion and extensions. The flexion is carried out by the flexor muscles. These are **hamstring muscles** present at the back of the upper part of the leg (thigh). The major hamstring muscle is **biceps femoris.** It has two origins, one from pelvic girdle and other from the top of the femur. At its insertion the tendon divides into two portions to attach at the upper part of the tibia and fibula.

The extension is carried out by the extensor muscles which are present in the front of the thigh. The main extensor muscles are quadriceps femoris. They originate at the ilium and femur, come together in a tendon surrounding the patella (kneecap), and insert at the tibia. These extend the leg at the knee joint and are important for standing, walking, and almost all activities involving the legs. A fusiform muscle located in the posterior compartment of the thigh is called **semitendinosus.** One of the hamstring muscles located in the posterior (back) compartment of the thigh is called **semimembranosus.**

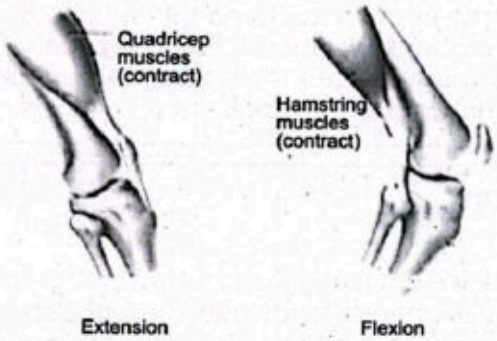


Fig. 7.19: Movement at knee joint

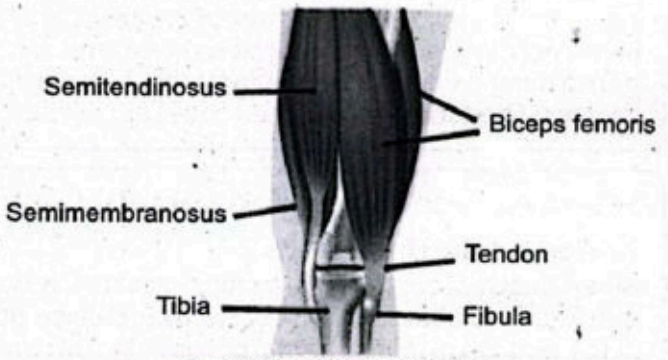


Fig. 7.20: Biceps femoris

7.11 MUSCLE DISORDERS

There are many problems related to muscle which are generally called muscle disorder. Some common muscle disorders e.g., muscle fatigue, cramp and tetany are discussed here.

Muscle fatigue

When the muscles lose the ability to contract, the physiological state of muscles is called **muscle fatigue.** The other factors which contribute to muscle fatigue are accumulation of lactic acid and ionic imbalance. The cause of extreme fatigue is lactic acid which causes muscle pH to drop and the muscle to ache.

Cramp

It is also known as **tetanic contraction** of entire muscle. It lasts for just few seconds to several hours, causing the muscle to become taut (tightly drawn) and painful. It is most common in thigh and hip muscles. It usually occurs at night or after exercise. It reflects low blood sugar level, electrolyte depletion, dehydration, irritability of spinal cord and neurons.

Tetany

In tetany the body shakes from continuous muscle contraction and convulsion occur due to calcium imbalance. It results in the excitability of neurons and results in loss of sensation. If untreated the symptoms progress to spasm of larynx, paralysis and ultimately death occurs.

Table 7.3 Difference between tetany and tetanus

Feature	Tetany	Tetanus
Cause	Electrolyte imbalance (e.g., low calcium)	Bacterial infection (Clostridium tetani)
Mechanism	Overly stimulated peripheral nerves and muscles	Toxin blocking nerve signals
Symptoms	Muscle spasms, cramps, potential larynx spasms	Muscle stiffness, spasms, especially in jaw ("lockjaw")
Treatment	Address electrolyte imbalance	Tetanus immune globulin, supportive care

Science, Technology and Society Connections

Justify why do the muscles pull but do not push.

Bones act as the levers, while joints perform as living fulcrums. Muscle, attached to bones by tendons and other connective tissue, exerts force by converting chemical energy into tension and contraction. When a muscle contracts, it shortens, in many cases pulling a bone like a lever across its hinge. Muscles move and by their motions we move. We are capable of performing a wide variety of actions, but despite this, muscle itself moves only by becoming shorter. They shorten and then they rest - in other words, a muscle can pull but it cannot push.

Science, Technology and Society Connections

Reason out the rigor mortis.

When death occurs, ATP is no longer made. It is a short-lived chemical and so it runs out fairly quickly. This causes the muscles to lock into position as cross-bridges that formed between actin and myosin filaments before death can no longer be broken. The skeletal muscles undergo a partial contraction that causes the joints to become fixed. This condition, rigor mortis (rigidity of death), happens in all body muscles. It appears about four hours after death and lasts about 34 hours. After this time, muscles proteins are destroyed by enzymes within the cells and so rigor mortis disappears.

STEAM ACTIVITY 7.1

1. Identification of the bones of the pelvic girdles, pectoral girdle, arms and legs by using the model of human skeleton
2. Comparison of the structure of skeletal, smooth and cardiac muscles with the help of prepared slides

EXERCISE

Section I: Multiple Choice Questions

Select the correct answer:

1. Ribs originate from vertebral column at:

A. lumbar region
B. cervical region
C. thoracic region
D. pelvic region

2. Skeletal muscles contain dark band, which are anisotropoic, are called
   A. A band
   B. I band
   C. Z band
   D. M line
3. The acetabulum provides the articular surface for the
   A. humerus
   B. femur
   C. pelvis
   D. fibula
4. Scapula is connected with sternum by
   A. ribs
   B. carpals
   C. clavicle
   D. atlas
5. Which statement correctly describes the smooth muscles?
   A. Unstriated involuntary with spindle shape cells
   B. Unstriated involuntary with multinucleate cells
   C. Unstriated voluntary with uninucleate cells
   D. Striated involuntary with spindle shape cell
6. Thin myofilaments consist of
   A. actin, myosin, troponin
   B. actin, tropomyosin, troponin
   C. actin, tropomyosin, fibrin
   D. actin, myoglobin, troponin
7. Which of the following changes occur when skeletal muscle contracts?
   A. The A- bands shorten
   B. The I- bands shorten
   C. The Z- lines move further apart
   D. The H- zone becomes more visible
8. A human internal organs are protected mainly by the
   A. hydrostatic skeleton
   B. axial skeleton
   C. exoskeleton
   D. appendicular skeleton
9. Arm and leg muscles are arranged in antagonistic pairs. How does this affect their functioning
   A. it provides a backup if one of the muscles is injured
   B. one muscle of the pair pushes while the other pulls
   C. it allows the muscles to produce opposing movements
   D. it doubles the strength of contraction
10. Which of the following bones in the human arm would correspond to the femur in the leg?
   A. radius
   B. ulna
   C. tibia
   D. humerus
11. The deep infolding of the muscle fibre membrane is called
   A. sarcoplasmic reticula
   B. Z lines
   C. T-tubules
   D. sarcomeres
12. Bone dissolving cells are called
   A. chondrocytes
   B. osteoblasts
   C. osteoclasts
   D. osteocytes

13. Which of the following cartilage is found at the end of long bones?
    A. calcified B. fibrous
    C. elastic D. hyaline
14. At times ligaments are overstretched or torn. It is called
    A. sprain B. dislocation
    C. fracture D. tension
15. Which ion is essential for muscle contraction?
    A. Na B. K
    C. Ca D. Cl
16. The tough layer of connective tissue surrounding each bone is called
    A. tendon B. ligament
    C. periosteum D. cartilage
17. The network of tubes that run through compact bone is called the
    A. periosteum B. joint
    C. Haversian canals D. marrow
18. Strips of tough connective tissue that hold bones together are known as
    A. tendon B. smooth muscles
    C. Striated muscles D. ligaments
19. Joints that allow circular movements are
    A. gliding joints B. ball-and-socket joints
    C. hinge joints D. pivot joints
20. Two proteins that are involved in the contraction of muscles are
    A. sarcomere and microfibril B. actin and myosin
    C. periosteum and cartilage D. ATP and acetylcholine

Section II: Short Answer Questions

1. How do compact bone and spongy bone differ in structure?
2. Name three types of cells associated with bone and write their functions.
3. Compare structure of bone with that of cartilage.
4. Name the bones of axial and appendicular skeleton.
5. Name the bones of cranium.
6. Describe the five groups of vertebrae.
7. What is the structure of the human rib cage.
8. Name the bones that form the (a) pectoral girdle (b) pelvic girdle.
9. Name the bones of upper and lower limbs.
10. What are the main types of joints found in bones?
11. What is fibrous joint?
12. What are the four steps required for bone fracture repair?
13. What skeletal structures are affected from the osteoarthritis?
14. List the major parts of skeletal muscle fibre and write the function of each part.
15. What is Z line and M line and what are their functions?
16. How the arrangement of actin filaments and myosin filaments produce I band, A band and H zone?

17. Describe the antagonistic arrangement of skeletal muscles.
18. Why are ligaments elastic and why does the tendon need to be inelastic?
19. Draw a diagram of sarcomere and label its parts.
20. Write the difference between:
    a. epiphysium and diaphysium
    b. periosteum and endosteum
    c. compact and spongy bone
    d. axial skeleton and appendicuar skeleton
    e. true ribs and false ribs
    f. false ribs and floating ribs
    g. atlas and axis
    h. rheumatid arthritis and gouty arthritis
    I. simple and compound bone fracture
    j. tropomysin and troponin
    k. tendons and ligaments
    l. callus and bony callus
    m. tetany and tetanus

Section III: Extensive Answer Questions

1. Explain the structure of bone with diagram.
2. Explain the structure of cartilage with diagram.
3. Describe the bones of appendicular and axial skeleton of man.
4. Describe the bones of cranium.
5. What are the following common types of disorders of human skeleton:
    a. Slipped disc
    b. Spondylosis
    c. Sciatica
    d. Arthritis
6. Give a detail account of bone repair.
7. Give an account of the following related to injuries to bones:
    a. Dislocation of joints
    b. Sprain
    c. First aid treatment for disorders of skeleton
8. Describe three types of muscle tissues in man.
9. Explain the ultra structure of skeletal muscle.
10. Explain the sliding filament model of muscle contraction.
11. Explain the action of antagonistic muscles in the movement of knee joint in man.
12. Give explanation of the following statement:
    a. Pregnant women should be encouraged to drink milk
    b. The sutures of the skull are fixed joint.
    c. The human femur is stronger than humerus.
13. Describe the following muscle disorders:
    a. Muscle fatigue
    b. Cramp
    c. Tetany