Chapter 12

HUMAN SKELETAL & MUSCULAR SYSTEMS

STUDENTS'LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Describe the structure of bone and compare it with that of cartilage.
- Explain the functions of osteoblasts, osteoclasts and osteocytes.
- Describe three types of joints i.e. fibrous joints, cartilaginous joints and synovial joints and give example of each.
- Describe the disorders of human skeleton (disc-slip, spondylosis, sciatica, arthritis, osteoporosis)
- and their causes.
- Describe the injuries in joints (dislocation and sprain) and their first aid treatment.
- Compare smooth muscles, cardiac muscles and skeletal muscles.
- Describe the ultrastructure of the skeletal muscle.
- Explain the sliding filaments model of muscle contraction.
- Describe the action of antagonistic muscles in the movement of knee joint.
- Explain muscle fatigue, cramps and tetany.
- Differentiate between tetanus and muscle tetany.

Support and movement are fundamental aspects of human biology, enabling us to perform a wide range of activities from basic locomotion to complex tasks. This chapter delves into the structure of bones and cartilage, which provide the necessary support framework for the body. We will explore the various types of joints, and examine the unique features of the three types of muscles—skeletal, smooth, and cardiac—that drive motions. The sliding filament model will be discussed to understand muscle contraction at a molecular level. Additionally, we will look at common disorders affecting the skeletal and muscular systems, highlighting their impact on human health and mobility.

12.1- BONES AND CARTILAGE

Bones, cartilage, and other connective tissues make an internal framework called skeleton that provides structural support, protects vital organs, and produces movement and locomotion.

Structure of Bone

Bones are made of connective tissue reinforced with calcium and specialized bone cells. The bone's surface is covered by a tough membrane called **periosteum**. The thick layer under periosteum is made of hard material and is called **compact bone**. It makes up

The broad ends of a bone are called **epiphysis**while the middle part along the length of bone is called **diaphysis** or shaft.

the majority of the bone tissue (Fig. 12.1). The basic structural units of compact bone are called **Haversian systems.** A Haversian system is made of;

i. **Lamellae:** These are concentric layers of mineralized extracellular matrix that contains **collagen fibres** and small, needle-shaped crystals of calcium phosphate. The crystals are brittle but rigid, giving bone great strength. Collagen, on the other hand, is flexible but weak. As a result, bone is both strong and flexible.
ii. **Lacunae and Osteocytes:** The lamellae are separated by small spaces called lacunae. **Osteocytes,** which are mature bone cells, are located in the lacunae. Osteocytes are connected to each other and to the Haversian canal by small channels called **canaliculi.**
iii. **Haversian canal:** The concentric layers of lamellae surround a central canal called the Haversian canal. It contains blood vessels, nerves, and lymphatic vessels.

In addition to these structures, there are small channels that run perpendicular to the Haversian canals and connect them with each other and with the periosteum. They also contain blood vessels, nerves, and lymphatic vessels. Collagen fibres anchor the periosteum to the underlying bone tissue, providing additional strength and stability to the bone.

Beneath the compact bone there is **spongy bone** (Fig. 12.1). It has a latticework structure consisting of bony spikes that make it light and strong.

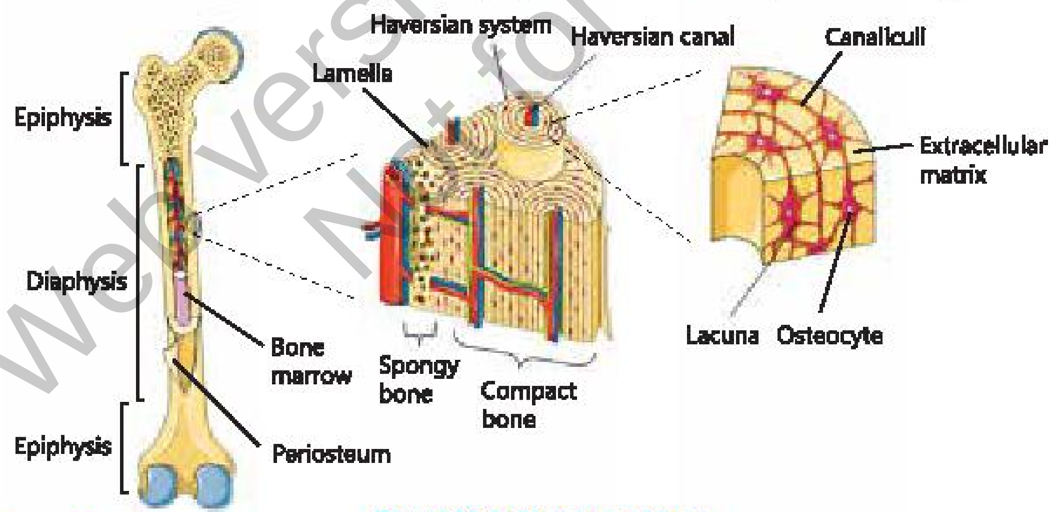


Figure 12.1: Structure of bone

Bone Marrow

Many bones also contain a soft tissue called bone marrow, which can be either red or yellow. Red bone marrow is found in spongy bone, the ends of long bones, ribs, vertebrae, the sternum, and the pelvis. It produces red blood cells, platelets, and white blood cells. Yellow bone marrow fills the shafts of long bones. It consists mostly of fat cells and serves as an energy reserve. It can also be converted to red bone marrow and produce blood cells when severe blood loss occurs.

- Despite their number and size, bones make up less than 20% of the body's mass.
- Bones are not dry, rigid structures, as they appear. They are moist, living tissues.

Types of Bone Cells

There are three types of cells i.e., osteoblasts, osteocytes, and osteoclasts involved in the development, growth and remodelling of bones.

Osteoblasts are bone forming cells that synthesize and secrete unmineralized ground substance. Once the osteoblasts are surrounded by matrix, they become the osteocytes.

Osteocytes are mature bone cells which maintain healthy bone tissue by secreting enzymes and bone mineral content. They also regulate the calcium release from bone tissue to blood. **Osteoclasts** develop from macrophages and are involved in bone resorption, i.e., they break down bone and release calcium and phosphate in blood. The work of osteoclasts is important to the growth and repair of bone.

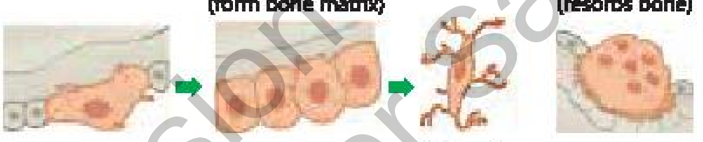


Figure 12.2: Types of bone cells

Bone Development

The process of bone formation is also called **osteogenesis**. It begins during embryonic development and continues throughout life, playing a vital role in growth, maintenance, and repair of bones. There are two primary pathways of osteogenesis.

Even after bones have fully formed, osteogenesis continues in the form of bone remodelling. This ongoing process involves the breakdown of old bone by osteoclasts and the formation of new bone by osteoblasts.

1. The formation of long bones e.g., femur and humerus, involves the transition of cartilage into bone. In this process, the center of cartilage begins to harden (calcify), and the chondrocytes (cartilage cells) in this area die, leaving behind cavities. Blood vessels penetrate these cavities and introduce osteoblasts and osteoclasts. Osteoblasts (bone-forming cells) start building bone tissue, replacing the cartilage with new bone. The step by which cartilage is replaced by bone by the deposition of minerals is called **ossification** (Fig. 12.3). Osteoclasts (bone-resorbing cells) break down

the calcified cartilage, making room for more bone tissue to form. As the bone matures, some osteoblasts become trapped within the bone tissue and transform into osteocytes (mature bone cells), which help maintain the bone structure. This process continues until all cartilage is changed to a bone except some cartilage that remains only at the articular (joint) surfaces of the bones.

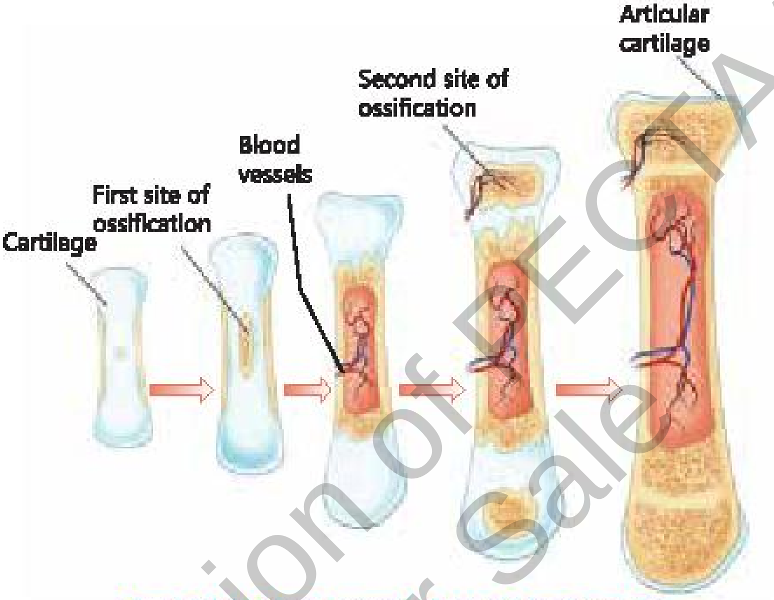


Figure 12.3: Development of bone from cartilage

2. A few bones, e.g., some bones of the skull, develop directly into hard bone without forming cartilage first. In these cases, the osteocytes are initially scattered randomly throughout the embryonic connective tissue but soon fuse into layers and become flat plates of bone.

Structure of Cartilage

As described in the previous paragraph, most of the cartilage of foetus is replaced by bone. However, some cartilage remains throughout life and provides flexibility. For example, at the areas between bones, at the end of nose, in the outer ear, and along the inside of the trachea.

A layer of connective tissue called **perichondrium** surrounds the cartilage. It contains blood vessels, lymphatic vessels, and nerves that supply the cartilage tissue. Inside perichondrium is the **cartilage matrix** which is composed of collagen, elastin, proteoglycans, and other fibres. It gives the tissue its strength, flexibility, and resistance to compression. Unlike other connective tissues, there are no blood vessels inside cartilage matrix. The cells of cartilage are supplied by diffusion. Because of this, it heals very slowly.

The cartilage cells, called **chondrocytes**, are present within small spaces called **lacunae**, which are embedded in cartilage matrix. Chondrocytes are responsible for synthesizing and maintaining the matrix of cartilage (Fig. 12.4).

Cartilage Types

Cartilage can be classified into three types. **Hyaline** cartilage is the most common type and is found in the nose, trachea, and the articulating surfaces of bones in joints. **Fibrocartilage** is found in areas of the body that experience high stress and tension, such as the intervertebral discs and the pubic symphysis. **Elastic cartilage** is found in the external ear and epiglottis.

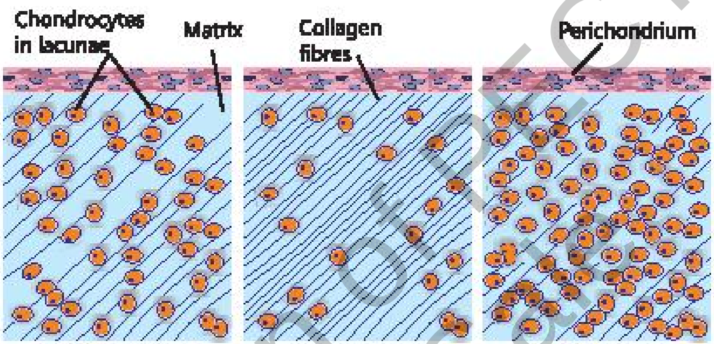


Figure 12.4: Cartilage types

Comparison between Bone and Cartilage		
Feature	**Bone**	**Cartilage**
External covering	Periosteum	Perichondrium
Cell types	Osteoblast, osteocytes and osteoclasts	Chondrocytes
Extracellular matrix	Contains calcium crystals and collagen fibres	Contains collagen and other fibres
Blood vessels	Present	Absent
Growth & repair	Have the ability to grow and repair themselves throughout life	Has limited ability to repair itself, as it has no direct blood supply

Arrangement of Bones in Skeleton

Human skeletal system consists of 206 bones. Skeleton has two main divisions i.e., axial skeleton and appendicular skeleton (Fig. 12.5).

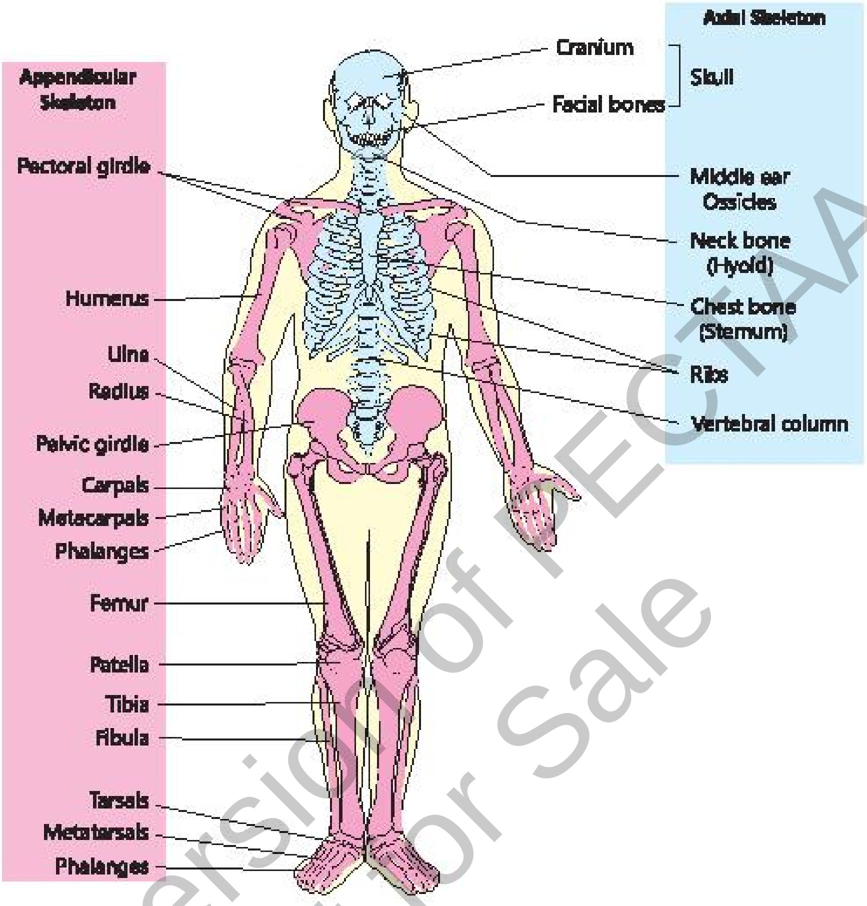


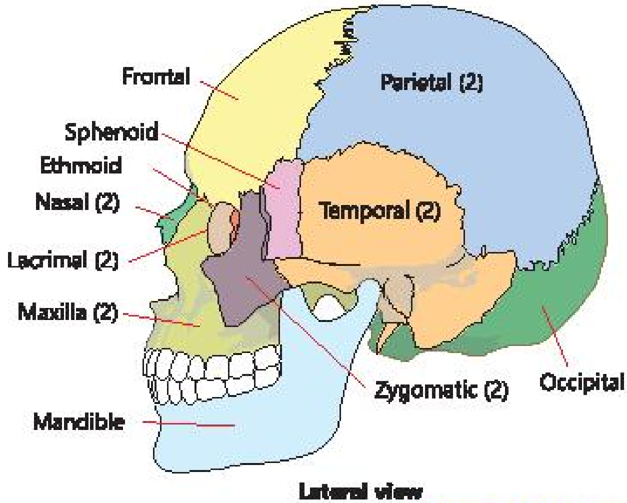
Figure 12.5: Human skeleton

Axial Skeleton

The axial skeleton forms the axis of the body. Its bones support and protect the organs of the head, neck, and chest. It consists of skull, ribs, spine, and sternum.

a- Skull: It consists of the following 22 bones.

- Eight **cranial bones** form cranium (brain box). The 2 paired bones are parietal bones and temporal bone. The 4 unpaired bones are frontal bone, occipital bone, ethmoid bone, and sphenoid bone.
- Fourteen **facial bones** are attached to the cranium. The 6 paired bones are lacrimal, zygomatic, nasal bones, inferior nasal concha, maxilla and palatine. The 2 unpaired bones are mandible (jaw bone) and vomer.



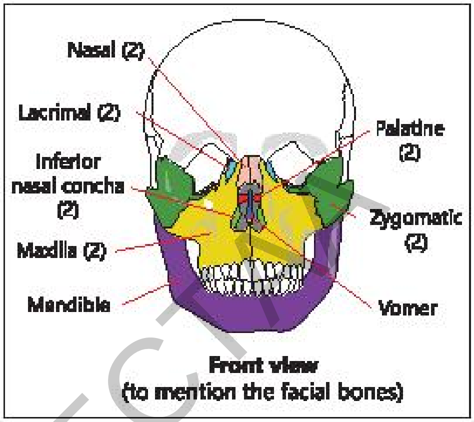


Figure 12.6: Human skull

b- Middle ear: There are 6 bones (3 pairs) in middle ears. These are called ossicles and include malleus, incus and stapes.

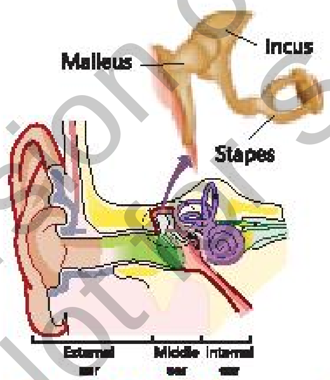


Figure 12.7: Middle ear ossicles

c- Neck bone: 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.

d- Vertebral column: It consists of 33 bones called vertebrae. The vertebrae make five groups:

(i) Seven cervical vertebrae: These are the vertebrae of the neck. The first one is called atlas and the second one is called axis.

(ii) Twelve thoracic vertebrae: These are rib-carrying vertebrae and are found in chest region.

(iii) Five lumbar vertebrae: These are present in abdominal region.

(iv) Five sacral vertebrae: These are five fused vertebrae forming the sacrum. The sacrum articulates with the iliac bones of the hip to form the back of the pelvis.

(v) Four coccygeal vertebrae or coccyx: these vertebrae are fused in the adults. Sacral and coccygeal vertebrae are together called pelvic vertebrae.

e- Rib Cage & Chest bone: The rib cage consists of 24 bones (12 pairs) called ribs and a sternum. The sternum (chest bone) is a long flat bone located in the central part of the chest. The ribs articulate posteriorly with the thoracic vertebrae. On anterior side, 7 pairs of ribs attach directly with the sternum by means of separate costal cartilages. These are called true ribs. The 8^{th}, 9^{th} and 10^{th} pairs attach to the sternum by means of a common costal cartilage and are called false ribs. The last 2 pairs of ribs (11^{th} and 12^{th}) are known as floating ribs, because they do not attach to the sternum.

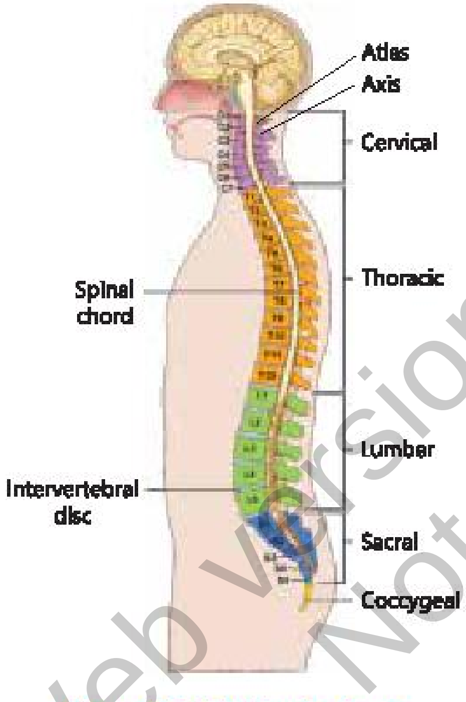


Figure 12.8: Vertebral column

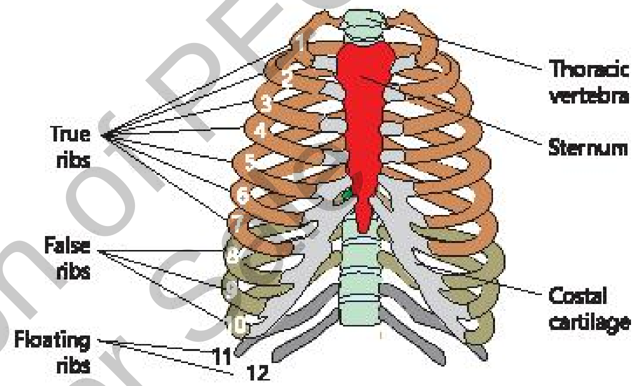


Figure 12.9: Rib cage

Appendicular skeleton

Appendicular skeleton includes the bones present in appendages (arms and legs). These are pectoral girdle, pelvic girdle, forelimbs and hindlimbs.

a- Pectoral girdle: It consists of 2 pairs i.e., a pair of clavicles (collar bones) and a pair of scapulae (shoulder bones). One end of each clavicle articulates with the sternum. The other end articulates with the scapula.

b- Forelimbs: Each forelimb (arm, wrist, hand, fingers) consists of the following 30 bones.

i. One humerus: It is a long bone, the end of which has a spherical head, which fits into the glenoid cavity.

ii. One ulna and one radius: These are long bones. Ulna is on the inner side of arm while radius is on outer side (thumb side). Ulna is slightly bigger than radius.
iii. Eight carpels: There short bones present in two rows and form the wrist. The upper row articulates with the radius and forms the wrist joint.
iv. Five metacarpals: These bones make up the palm of the hand.
v. Fourteen phalanges: Each finger has 3 phalanges while the thumb has 2 phalanges.

c- Pelvic girdle: It is made up of two hip bones. Each hip bone contains 3 bones i.e., ileum, ischium and pubis. In each hip bone, there is a bony socket, called acetabulum that is composed of the fusion of three bones. The two hip bones are joined at the front by the pubic symphysis (a cartilaginous joint that connects the pubic bones at the midline of the body).

d- Hindlimbs: Each hindlimb (leg, ankle, foot, toes) consists of 30 bones.
i. One femur: It is a long thigh bone. Its head fits into the acetabulum of pelvic girdle.
ii. One patella or kneecap: It is embedded in a long tendon which runs over the knee joint.
iii. One tibia and one fibula: Tibia or shin bone is the large bone in the leg. Fibula or outer bone is a thin bone that joins the tibia just below the knee joint and just above the ankle.
iv. Seven tarsals: These are short bones which are tightly attached to form the ankle.
v. Five metatarsals: These bones articulate with the tarsal and phalanges to form the sole of the foot.
vi. Fourteen phalanges: Each toe has 3 phalanges while the big toe comprises 2 phalanges.

Joints

A joint is a place where two bones or bone and cartilage come together. Three major kinds of joints are found in human body i.e., fibrous (immoveable) joints, cartilaginous (slightly moveable) joints and synovial (freely moveable) joints (Figure 12.10-a).

1- Fibrous Joints

In fibrous joints, the bones are directly connected to each other by fibrous connective tissue consisting mainly of collagen. These joints permit no movement of bones. Examples of fibrous joints include:

- Sutures that occur only between the immovable bones of the skull.
- Joints between the tibia and fibula bones in the lower leg.
- Joints between teeth and their sockets in the jawbone.

2- Cartilaginous Joints

In these joints, the bones are connected by a layer of cartilage. Cartilaginous joints allow little movement of the bones. There are two main types of cartilaginous joints:

- In some cartilaginous joints, the bones are connected by hyaline cartilage. For example, the joint between the first rib and sternum.
- In some cartilaginous joints, the bones are connected by fibrocartilage. For example, pubic symphysis in the pelvic girdle and intervertebral discs.

3- Synovial joints

Synovial joints are the most common type of joint in the human body, and they allow a wide range of movement. A smooth, tough, and elastic hyaline cartilage, called **articular cartilage**, covers the ends of the bones in the joint. It provides a smooth and frictionless surface for movement. A **fibrous capsule** surrounds the synovial joint and helps to hold the bones together. The fibrous capsule is composed of an outer layer of ligaments and an inner lining of synovial membrane, which secretes **synovial fluid**, which lubricates the joint. Strong bands of connective tissue that connect the bones in the joint are call **ligaments**.

There are six main types of synovial joints based on the range of motion.

1- **Ball-and-socket joints** allow motion in all directions e.g., shoulder and hip joints.

2- **Hinge joints** allow movement in only one plane, like a door hinge e.g., elbow and knee joints.

3- **Pivot joints** allow rotational movement around a single axis e.g., joint between the first and second vertebrae of the neck.

4- **Ellipsoidal joints** allow movement in two planes, but not rotation e.g., joint of wrist with radius.

5- **Saddle joints** allow movement in two planes because one bone has a concave surface and the other has a convex surface e.g., thumb joint.

6- **Gliding joints** allow gliding movements between bones e.g., joints between the vertebrae and the joints between the bones in wrist and ankle.

Joint Transplantation

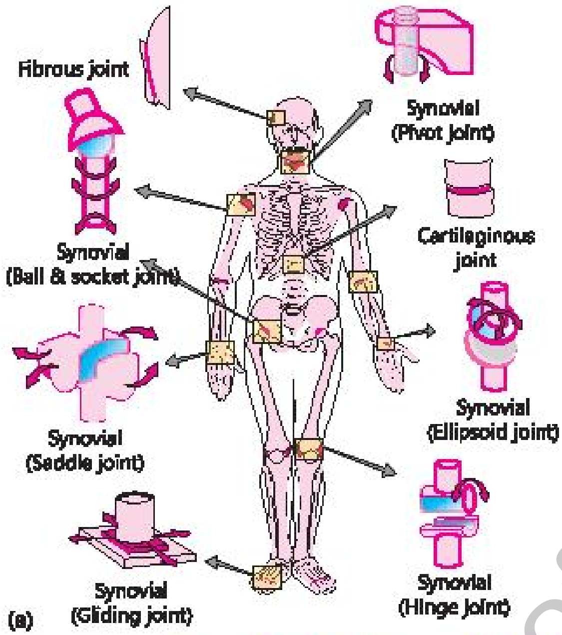
It is a surgical procedure in which a damaged joint is replaced with a healthy natural joint (from donor) or an artificial joint. The most common types of joint transplantation are:

Total joint replacement: In this procedure, the entire damaged joint is replaced with an artificial joint made of metal, plastic, or ceramic.

Partial joint replacement: In this procedure, only the damaged part of the joint is replaced with an artificial component. This is often used in the knee joint.

Allograft transplantation: In this procedure, a healthy joint from a donor is transplanted to replace the damaged joint. This technique is often used in the ankle and knee joints.

Chondrocyte implantation: In this procedure, chondrocytes from patient's own joint are implanted into the damaged joint. This technique is often used in the knee joint.



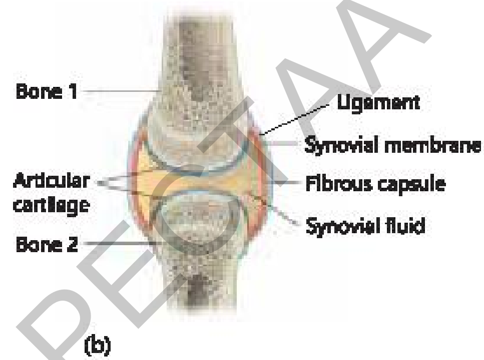


Figure 12.10: (a)- Types of joints; (b)- Structure of a synovial joint

Human Skeleton & Musculature helps in Bipedal Posture

The bipedal posture of humans is linked to skeleton and musculature in several ways.

1. The human vertebral column has a distinctive S-shaped curve, which helps to distribute weight evenly and maintain balance while standing and walking.
2. Human pelvis is shorter and broader, which helps to stabilize the torso and support the body's weight on two legs.
3. The human femur is also angled inward towards the knee joint, which helps to keep the body's centre of mass over the feet. It allows stability while standing and walking.
4. The muscles are located in the buttocks, are much larger in humans. They play a crucial role in stabilizing the torso and propelling the body forward while walking.
5. The calf muscles are also well-developed in humans, providing power for walking and running.
6. Human foot has a longitudinal arch that helps to absorb shock and distribute weight evenly across the foot.
7. The toes are shorter and less prehensile, allowing the foot to function more effectively as a lever during walking and running.

Problems due to Improper Posture

Improper posture can negatively affect bones and joints, causing:

Vertebral Misalignment: This can lead to back and neck pain, and herniated discs by putting pressure on vertebrae and nerves.

Joint Strain: Poor posture can strain neck, shoulders, hips, and knees, leading to pain, inflammation, and potentially arthritis.

Muscle Imbalances: Overused and underused muscles from poor posture can pull bones and joints out of alignment.

12.2- Disorders of Skeletal System

Skeletal system is susceptible to a wide range of disorders that can impact its structure and function. These disorders can affect any part of the skeletal system, including bones, joints, and connective tissues.

Disorders of the Skeleton

1- Disc Slip

The intervertebral discs between vertebrae act as shock absorbers and help in movement. A herniated or slipped disc occurs when the outer layer of the intervertebral disc tears or ruptures, causing the inner gel-like substance to leak out and press against nearby nerves or spinal cord. It may be due to a trauma, degenerative changes due to aging, or repetitive strain on vertebral column. Symptoms of slipped disc include pain, numbness, and tingling in the affected area, weakness or loss of muscle function, and in severe cases, bowel or bladder dysfunction.

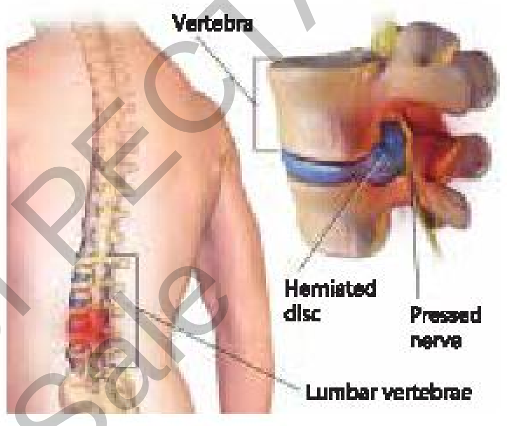


Figure 12.11: Disc slip (herniation)

2- Spondylosis

Spondylosis means degeneration of vertebrae, intervertebral discs, ligaments or cartilage of vertebral column. It may result in narrowing and fusion of intervertebral disc and development of bone outgrowths. It puts pressure on the nerves or spinal cord. Spondylosis is most common in the lower back (lumbar vertebrae) and neck (cervical vertebrae). The most common cause is the natural degeneration of intervertebral discs. It occurs with aging, genetic factors, trauma, and prolonged periods of poor posture and obesity. Symptoms include back or neck pain, stiffness, and reduced range of motion.

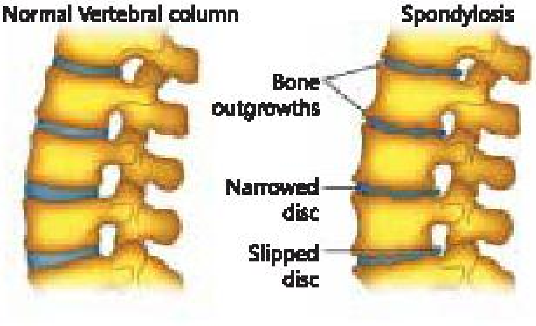


Figure 12.12: Spondylosis

3- Sciatica

Sciatica means compression or irritation of the sciatic nerve. The sciatic nerve starts from lower back and goes down through the buttocks into each leg. Sciatica is often caused by a herniated disc or bulging disc, which can put pressure on the sciatic nerve. Other causes of sciatica include trauma, infection, inflammation, and spondylosis.

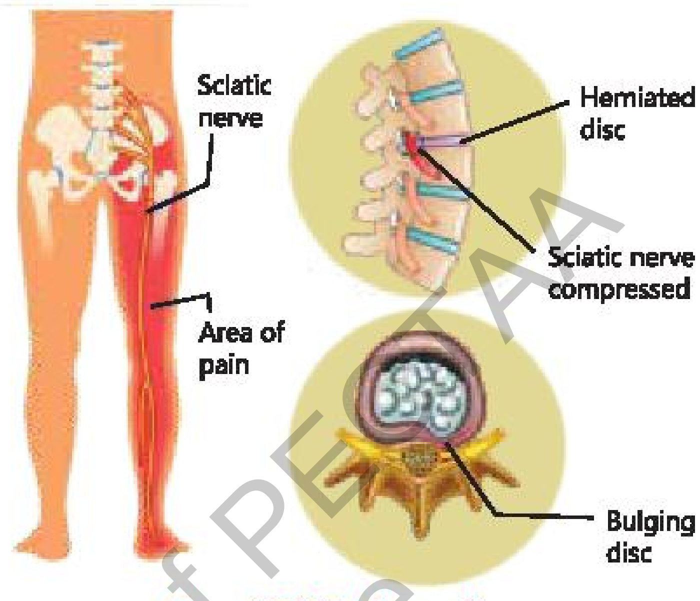


Figure 12.13: Sciatica and its causes

Symptoms include pain or discomfort in the lower back, buttocks, legs, or feet, tingling or numbness in the legs or feet, weakness or difficulty moving the legs or feet.

4- Arthritis

Arthritis includes different inflammatory conditions that affect the joints. Symptoms of all types include joint pain and stiffness. Other symptoms may include redness, warmth, swelling in affected joints. The following are important types of arthritis.

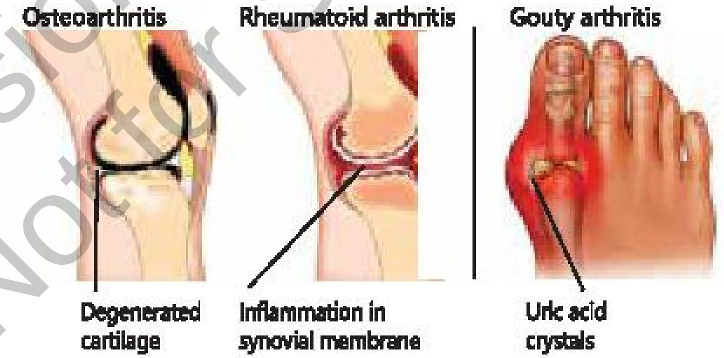


Figure 12.14: Types of arthritis

Osteoarthritis is the most common type. It occurs when the articular cartilage at the ends of bones in joints gradually softens and disintegrates. It affects knee, hip and intervertebral joints.

Rheumatoid arthritis is the result of an autoimmune disorder in which synovial membrane becomes inflamed. Most commonly, the wrist and hands are involved.

Gouty arthritis (or gout) occurs when there is a build-up of uric acid in the blood, which can form crystals in the joints and cause inflammation. The most common joint affected is the joint of the big toe. Other joints (knees, wrists and fingers) may also be affected.

5- Osteoporosis

Osteoporosis is a condition characterized by weakened bones that are more prone to fractures and breaks. It occurs when bone density decreases, making the bones fragile and porous. Its causes include:

- As people age, bone mass naturally decreases. But it can be more pronounced in some individuals.
- In women, a drop in oestrogen levels after menopause accelerates bone loss.
- Lack of calcium and vitamin D in the diet can impair bone health. Calcium is crucial for bone strength, while vitamin D helps the body absorb calcium.
- Lack of weight-bearing exercise can lead to weakened bones.

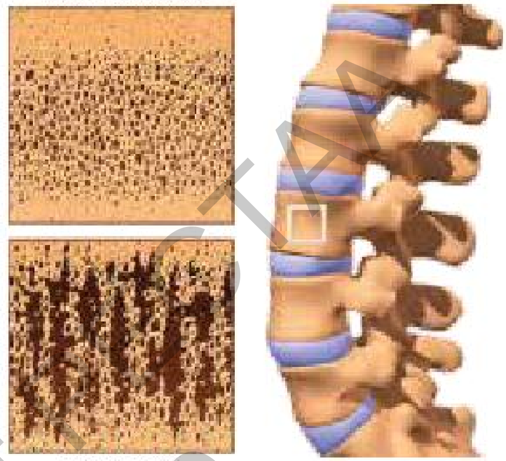


Figure 12.15: Normal bone and osteoporosis

- Certain treatments such as long-term use of corticosteroids, can contribute to bone loss.
- Smoking and alcohol consumption can also increase the risk of osteoporosis.

Injuries to Joints

Joints can be subject to a variety of injuries, which can result in pain, swelling, and reduced motion. Here are some common injuries to joints:

1- Dislocations

A dislocation is when the bones in a joint are forced out of their normal positions. This can happen as a result of a sudden impact or trauma. A severe dislocation can cause tearing of the muscles, ligaments and tendons. Symptoms include swelling, intense pain, and immobility of the affected joint. Rheumatoid arthritis can also cause joint dislocation. A dislocated joint can only be successfully corrected by a physiotherapist. Surgery may be needed to repair or tighten the stretched ligaments.

Figure 12.16: Dislocation in elbow joint

2- Sprain

A sprain is an injury to the ligaments that connect bones in a joint. Commonly injured ligaments are in the ankle, knee and wrist. This can happen when the joint is forced beyond its normal range of motion, causing the ligaments to stretch or tear. Sprains are usually treated with physical therapy. Dressings is done to immobilize the sprain and provide support.

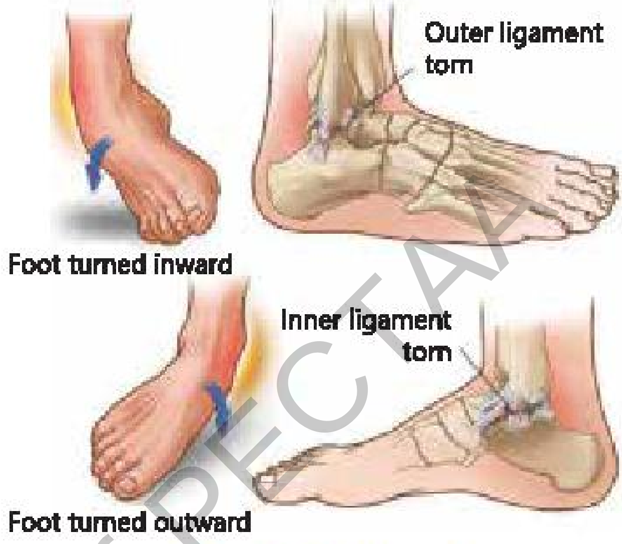


Figure 12.17: Ankle sprain

First aid Treatment for Dislocation and Sprain

First aid treatment for dislocation and sprain includes the following steps (Fig. 12.18):

1. **Immobilize the affected area:** Keep the affected area immobile and do not attempt to re-align the dislocated joint. Use a sling or splint to support the limb.

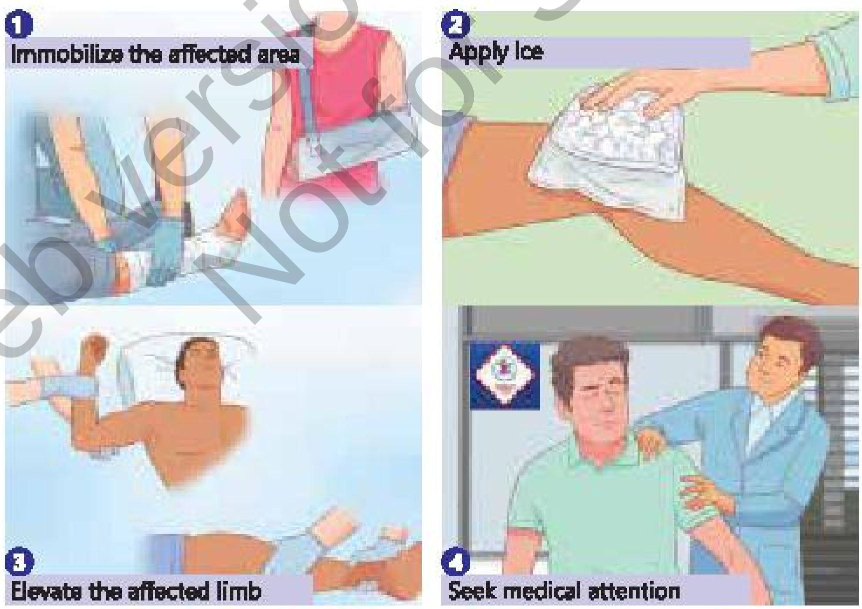


Figure 12.18: First aid treatment for dislocation or sprain

2. **Apply Ice:** Apply an ice pack or cold compress to the affected area to reduce swelling and pain.

3. **Elevate the affected limb:** In the case of dislocation, if possible, elevate the affected limb above to help reduce swelling.
4. **Seek medical attention:** Dislocations and sprain require medical attention, so call for emergency medical services 1122 or take the person to the hospital for further evaluation and treatment.

12.3- MUSCLES

Muscle is defined as the tissue that can contract in a coordinated way to produce movements of body parts or whole body. The individual cells of muscle are called **muscle fibres** or **myofibres**.

Muscles' ability to contract and relax not only enables the body to move, but also provides the force that pushes substances, such as blood and food, through the body.

Types of Muscles

Human body has three types of muscle tissues: skeletal, smooth, and cardiac (Fig. 12.19).

Although our focus in this chapter is on humans, it is important to realize that essentially all animals employ muscles. For example, when a mosquito flies, its wings are moved rapidly through the air by quickly contracting flight muscles. When an earthworm burrows through the soil, its movement is driven by strong muscles pushing its body past the surrounding soil.

1- Skeletal Muscles

Skeletal muscles are responsible for moving parts of the body, such as the limbs, trunk, and face. The muscle fibres of skeletal muscles are elongated cells with striations. Because their contractions are usually consciously controlled, skeletal muscles are called as voluntary muscles.

2- Smooth Muscles

Smooth muscles are present in the walls of the stomach, intestines, blood vessels, and other internal organs. Smooth muscle fibres are spindle-shaped, have a single nucleus and lack striations. Smooth muscle fibres are surrounded by connective tissue. Because most of their movements cannot be consciously controlled, smooth muscle is referred to as involuntary muscle.

3- Cardiac Muscles

These are found only in the walls of the heart. Their fibres branch extensively. The muscle fibres of cardiac muscles are striated like skeletal muscle, but each cell usually contains one nucleus located near the centre.

Comparison of three types of muscle tissues

Property	Skeletal Muscle	Smooth Muscles	Cardiac Muscles
Appearance	Regular striped	Un-striped	Irregular striped
Cell shape	Spindle or cylindrical	Spindle	Branched
Number of nuclei	Many per cell	One per cell	One per cell
Voluntary control	Have voluntary control	Usually, no voluntary control	No voluntary control
Function	To move skeleton	To move substances through hollow organs	To pump blood

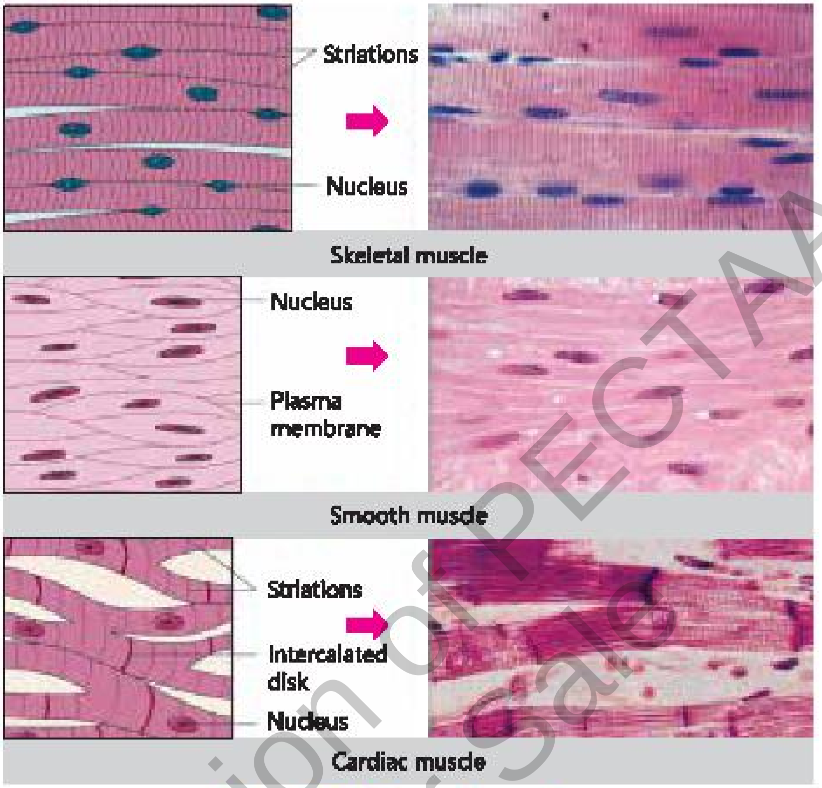


Figure 12.19: Types of muscles

Structure of Skeletal Muscles

The cells of skeletal muscles i.e., muscle fibres (myofibres) are in the form of bundles which are enclosed by collagen fibres and connective tissue. At the ends of a skeletal muscle, the collagen and connective tissue forms **tendons** which attach the muscle to bones.

Ultrastructure of Skeletal Muscles

Each skeletal muscle cell i.e., muscle fibre is a cylindrical multinucleated cell, enclosed by a plasma membrane called **sarcolemma** (Fig. 12.20). Its cytoplasm is called **sarcoplasm** and it contains **sarcoplasmic reticulum (SR).** The sarcolemma penetrates deep into the cell to form hollow elongated tubes, the **transverse tubule (T-tubules).** The T-tubules reach the ends of SR.

Each muscle fibre contains a bundle of 4 to 20 elongated threadlike structures called **myofibrils**. Myofibrils are made up of two types of filaments: thick filaments composed of **myosin** and thin filaments composed of **actin**. The thick filaments create dark bands called **A-bands**, while the thin filaments create light bands called **I-bands**. These alternating dark and light bands give skeletal muscle its striped (striated) appearance.

We can summarize the structural organization of a skeletal muscle as;

- A skeletal muscle is made of groups of cells called muscle fibres.
  - Each muscle fibre contains bundles of myofibrils in its cytoplasm.
    - Each myofibril is made of 2 types of myofilaments (myosin and actin).

The thin actin filaments are attached to protein discs called **Z-lines**. The section between two Z-lines is a **sarcomere**, the smallest unit of muscle contraction. Within a sarcomere, the thin filaments extend from the Z-line toward the center, where they overlap with thick filaments. This overlap creates the **A-band**, with a lighter central region called the **H-band**, where no overlap occurs (Fig. 12.20).

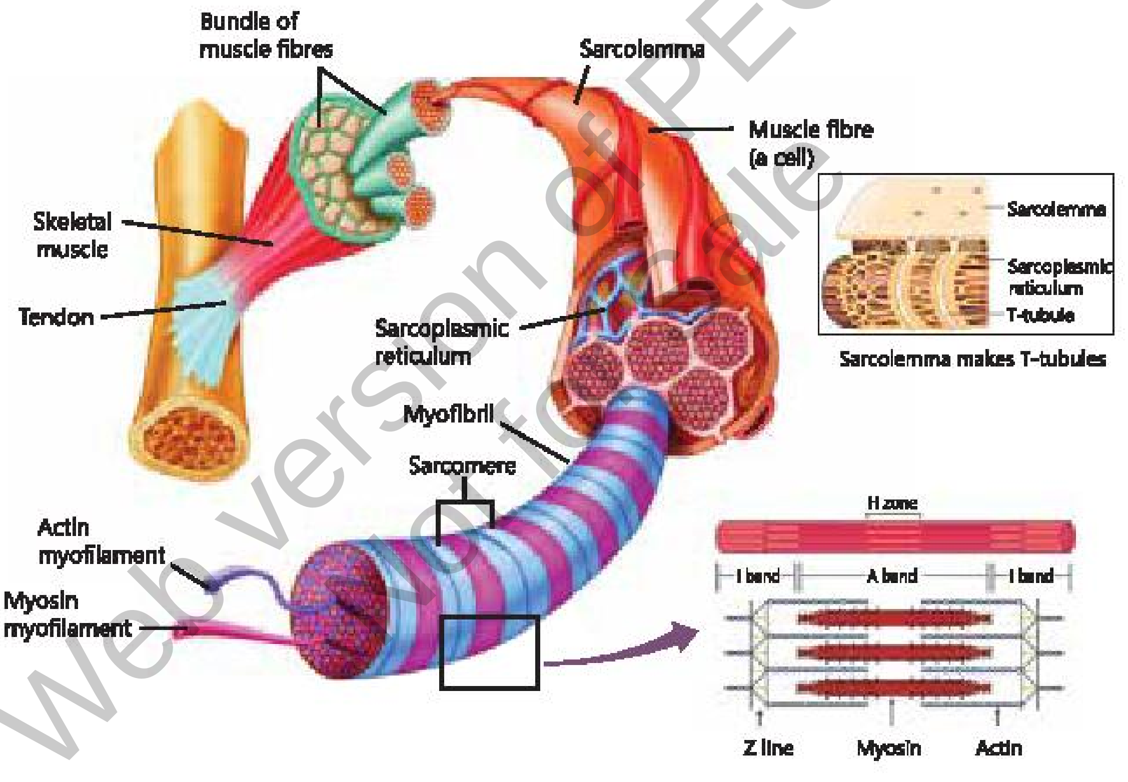


Figure 12.20: Ultrastructure of skeletal muscle

During muscle contraction, the thin filaments slide deeper into the A-band, causing the H-band and I-band to narrow. The A-bands are pulled closer together, shortening the muscle. The center of the H-band may have a dark line called the **M line** which helps stabilize the thick filaments.

Biochemistry of Myofilaments

Thick myofilaments, about 16 nm in diameter, are made up of many myosin proteins. Each myosin protein consists of two intertwined polypeptide chains, ending in a globular "head." These myosin heads extend from the thick filaments and connect to actin during muscle contraction (Fig. 12.21).

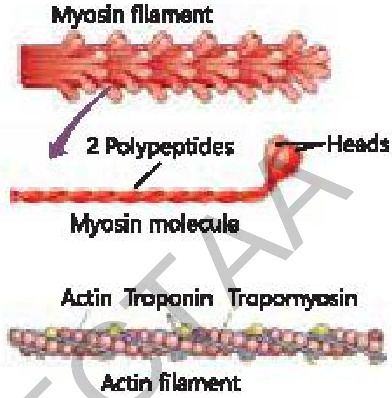


Figure 12.21: Structure of myofilaments

Thin myofilaments, 7-8 nm in diameter, are made of three proteins: (i) Core is made of two twisted strands of actin. (ii) Two strands of **tropomyosin** wrap about actin core and stiffen it. In a relaxed muscle fibre, they block myosin binding sites on actin. (iii) **Troponin** protein is present at regular intervals on thin myofilaments. It is made of three polypeptides. One polypeptide is inhibitory and binds to actin; second polypeptide binds to tropomyosin to keep it in place. The third polypeptide binds to calcium ions.

Mechanism of Muscle Contraction - Sliding Filament Model

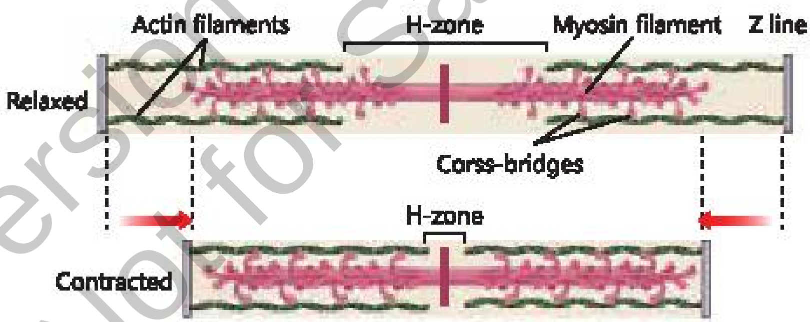


Figure 12.22: Sliding filament model of muscle contraction

The sliding filament model explains how a muscle contracts. According to this model, a muscle contracts when its thin myofilaments slide past the thick ones so that they overlap to a greater degree. It occurs in the following steps (Fig. 12.23);

1- Sarcomeres at relaxed state

In a relaxed muscle, sarcomeres are at their normal length. The myosin heads are not bound to actin because the binding sites on actin are blocked by tropomyosin of thin filaments. Troponin, another protein, is attached to tropomyosin. Myosin heads have hydrolysed ATP into ADP and Pi.

When a nerve impulse reaches sarcolemma, a neurotransmitter (acetylcholine) is released by motor neuron at the synapse. It

2- Arrival of Nerve Impulse

When a nerve impulse reaches the muscle fibre, it travels along the sarcolemma to the T-tubules and then to the sarcoplasmic reticulum (SR). The SR releases calcium ions into the cytosol. These calcium ions bind to troponin, causing it to shift tropomyosin away from the myosin-binding sites on actin.

> stimulates the sarcolemma to produce its own electrochemical impulses which are carried into the muscle fibre to the T tubules.

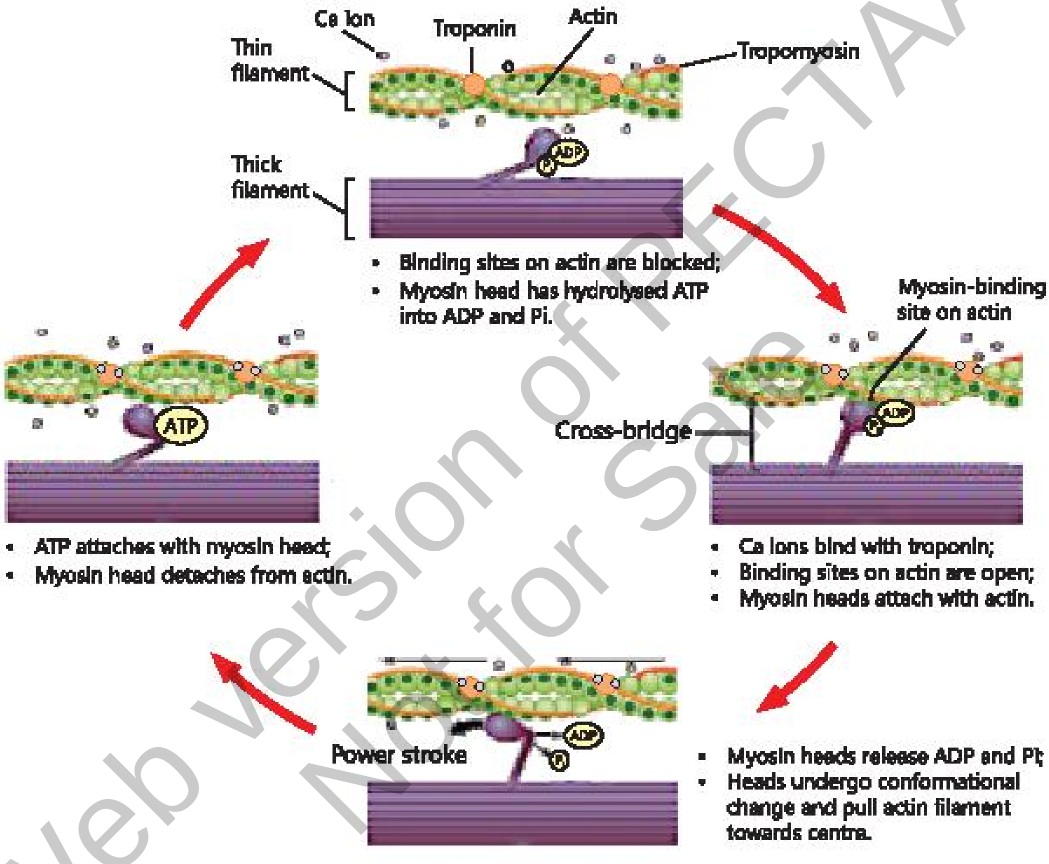


Fig. 12.23: Steps of a power-stroke (cross bridge cycle)

3- Cross-bridges and Power-stroke

When binding sites on actin are exposed, the myosin heads bind to them and form **crossbridges**. Once the cross-bridges are formed, the myosin heads release the ADP and Pi, and undergo conformational change. They bend towards the centre of sarcomere, pulling actin filaments with them. This pulling action is called a **power stroke**. It shortens the sarcomere, bringing Z-lines closer together and H-zone disappears. It occurs simultaneously in all sarcomeres, causing the muscle to contract. The adjacent A-bands of sarcomeres come closer to each other but do not shorten.

4- Separation of Myosin Heads from Actin

After pulling, the myosin head receives a new molecule of ATP. This allows the head to detach from actin. Splitting of this ATP into ADP and Pi puts the head into its original conformation, allowing the cross-bridge cycle to begin again.

> After death, the cells can no longer produce ATP and therefore the cross-bridges cannot be broken. It causes the muscle stiffness of death, or **rigor mortis**. A living cell, however, always has enough ATP to allow the myosin heads to detach from actin.

Arrangement of Skeletal Musclesat Moveable Joints

Skeletal muscles are attached to bones by tough connective tissues called **tendons**. Typically, a muscle has two attachment points on different bones. The end attached to the stationary bone during contraction is called the **origin**, while the end attached to the bone that moves is the **insertion**. The middle part of the muscle is known as the **belly** (Fig. 12.24).

For the movement of bones at a joint in two directions muscles work in pairs. They produce opposing actions when they contract. Such arrangement of muscles is called antagonistic arrangement. In such arrangement, when one muscle, called **flexor**, contracts it bends the bone at joint. When the opposing muscle, called **extensor**, contracts it straightens the bone at joints.

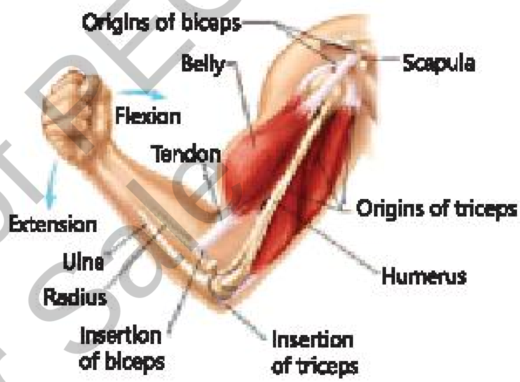


Figure 12.24: Arrangement of skeletal muscles at elbow joint

During such antagonistic action, when a muscle e.g., flexors contracts, the other muscle i.e., extensor is relaxed and vice versa.

Movement at KneeJoint

The knee joint is located between the femur (thigh bone) and the tibia and fibula (lower leg bones). Flexion, or bending, of the lower leg is done by the **hamstrings**. It is a group of three muscles at the back of the thigh. The hamstrings originate at the pelvic girdle and the top of the femur, with insertions at the upper parts of the fibula and tibia.

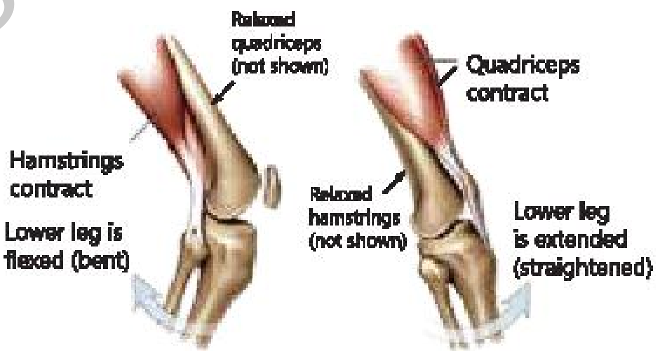


Figure 12.25: Movement at knee joint

Extension, or straightening, of the lower leg is done by the **quadriceps**. It is a group of four muscles at the front of the thigh. The quadriceps originate at the ilium (part of the pelvic girdle) and femur, with insertions at the patella (kneecap) and tibia. When the hamstrings contract, the lower leg bends and the quadriceps relax. When the quadriceps contract, the lower leg straightens and the hamstrings relax.

Muscle Disorders

The following are some common muscle disorders.

1- Muscle Fatigue

Muscle fatigue means a decline in muscle performance that occurs after prolonged or intense physical activity or due to some disease. Its symptoms include pain, decreased muscle strength, and reduced endurance. The following factors contribute to muscle fatigue:

- During exercise, the muscles use ATPs to contract. When the supply of ATPs is depleted, the muscle is no longer able to contract.
- As muscles work, they produce metabolic wastes e.g., lactate, hydrogen ions, and reactive oxygen. These wastes contribute to muscle fatigue.
- When muscle fibres are repeatedly activated, they are not able to effectively handle calcium ions, which can impair muscle function.
- Prolonged or intense exercise can cause small amounts of damage to muscle fibres, leading to inflammation and reduced muscle function.

Muscle fatigue typically improves with rest. If it is severe, it requires medical attention.

2- Muscle Cramps

Muscle cramps are sudden, involuntary, and often painful contractions of a muscle or group of muscles. They usually last from a few seconds to several minutes and most commonly occur in the legs and feet. Common causes include dehydration, an imbalance of salts, overuse or injury of the muscle, certain medications (like diuretics), and medical conditions such as diabetes, liver disease, and nerve damage.

To relieve muscle cramps, gently stretch and massage the affected muscle. Applying heat or cold to the area and using pain-relieving medications can also help.

3- Tetany

Tetany is a condition characterized by involuntary muscle contractions or spasms due to increased muscle tone and hyperexcitability of the nerves. These contractions can occur in various parts of the body such as hands, feet, face, or larynx. The most common cause of tetany is hypocalcaemia (low level of calcium in blood) which may be due to vitamin D deficiency, renal failure, or thyroid disorders. Tetany may also be due to other salts imbalances, such as low level of magnesium in blood. Treatment for tetany depends on the underlying cause. If tetany is caused by salts imbalances, treatment may involve calcium or magnesium supplements or intravenous fluids to restore electrolyte balance.

Difference between Tetany and Tetanus

Tetany and tetanus are different conditions often confused due to their similar names:

1. Tetany involves increased muscle tone and overactive nerves, causing involuntary muscle contractions or spasms. Tetanus is a severe bacterial infection caused by *Clostridium tetani*, which produces a toxin affecting the nervous system, leading to muscle stiffness and spasms.
2. Tetany can affect various body parts like the hands, feet, face, or larynx. Tetanus mainly affects the jaw and neck muscles.
3. Tetany can result from issues like electrolyte imbalances or nerve problems. Tetanus is caused by a specific bacterial infection.
4. Tetanus is more serious and potentially life-threatening compared to tetany.

Muscles pull but do not push.

Muscles can only pull, not push. This is because muscle fibres are designed to contract and shorten, pulling on tendons and thus moving bones. When a muscle contracts, it pulls on the bone via the tendon, and when it relaxes, the bone moves back to its original position.

Muscles cannot push because they only generate force by pulling. If a muscle were to push, it would need to be attached to bones at both ends and make both ends move closer together, which is not possible in the body. Muscles are usually attached to bone at only one end.

Skeleton is a system of rods and levers

The skeleton works like a system of rods and levers. Bones act as the rods, giving structure and support to the body and protecting internal organs.

In this system, joints serve as fulcrums (pivot points) for the levers, allowing movement. Muscles generate the effort or force, while the weight or resistance being moved is the load.

For example, when lifting a weight, the bicep muscle in the upper arm acts as a lever. The elbow joint is the fulcrum, the bicep provides the effort, and the weight is the load.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. **Which structures are part of the appendicular skeleton?**
   (a) Ethmoid bone (b) Floating ribs (c) Lumber vertebrae (d) Humerus bone
2. **The term muscle fibre or myofibre refers to;**
   (a) A cellular organelle (b) A cell
   (c) A tissue (d) An organ
3. **Which of these extends the entire length of a muscle fibre?**
   (a) Sarcomere (b) Myofibril (c) Myosin filament (d) Actin filament
4. **Actin filaments are made of proteins;**
   (a) Myosin and troponin (b) Actin and troponin
   (c) Actin and myosin (d) Actin, tropomyosin and troponin
5. **In a muscle, the Z-line are the proteins for the attachment of the ends of;**
   (a) Actin filaments (b) Myosin filaments

(c) Both actin and myosin filaments (d) Sarcomeres

6. Sarcomere is a part between;
(a) Two H-lines (b) Two A-bands (c) Two Z-lines (d) Two I-bands

7. Which part of muscle fibre releases calcium ions which trigger contraction?
(a) Sarcolemma (b) Sarcoplasm
(c) T-tubules (d) Sarcoplasmic reticulum

8. Which statement is correct to describe sliding filament model of muscle contraction?
(a) Myosin filaments pull on the sarcomere so that actin filaments are shortened.
(b) Myosin filaments pull on actin filaments so that sarcomere is shortened.
(c) Actin filaments pull on myosin filaments so that sarcomere is shortened.
(d) Actin filaments pull on sarcomere so that myosin filaments are shortened.

9. When a muscle fibre shortens, which of the following also shortens?
(a) Actin filament (b) Myosin filament (c) Sarcomere (d) Z-line

10. Which statement correctly describes an event of muscle contraction?
(a) Myosin heads bind to troponin.
(b) ATP binds to the actin binding site.
(c) ATP is used to detach the myosin head from actin.
(d) Troponin blocks the binding sites.

11. Tendons connect bone and;
(a) Bone (b) Ligaments (c) Muscle (d) Cartilage

12. What is true about antagonistic pair of muscles?
(a) It provides a backup if one of the muscles is injured
(b) One muscle pushes while other pulls
(c) It allows muscles to produce opposing movements
(d) It doubles the strength of contraction

SHORT QUESTIONS

1. Name three types of cells associated with bone and write their functions.
2. Name the bones of cranium.
3. Enlist the bones in the five groups of vertebrae.
4. What bones make the rib cage.
5. Name the bones of pectoral girdle and pelvic girdle.
6. Name the bones of forelimbs and hindlimbs.
7. What is fibrous joint? Give examples.
8. Name the steps involved in bone repair.
9. What skeletal structures are affected from the osteoarthritis?
10. List the major parts of skeletal muscle fibre.
11. What do you mean by I-band, A-band and H-zone?
12. Describe the antagonistic arrangement of skeletal muscles.

13. Ligaments are elastic while tendons are hard. Justify.
14. Draw a diagram of sarcomere and label its parts.
15. Differentiate between:
    - Compact and spongy bone
    - Axial skeleton and appendicular skeleton
    - True ribs, false ribs and floating ribs
    - Rheumatoid arthritis and osteoarthritis
    - Fibrous and cartilaginous joints
    - Cartilaginous and synovial joint
    - Osteoblasts and osteocytes
    - Tropomyosin and troponin
    - Ligament and tendon
    - Tetany and tetanus

LONG QUESTIONS

1. Explain the structure of bone.
2. Describe the structure of three types of cartilage.
3. Write the cause and symptoms of joint dislocation, spondylosis, and sciatica.
4. Describe the types of arthritis, with their causes, symptoms and treatments.
5. Describe the three types of muscles.
6. Explain the ultrastructure of skeletal muscle.
7. Write a detailed note on the sliding filament model of muscle contraction.
8. Explain the action of antagonistic muscles in the movement of knee joint.
9. Draw a diagram of sarcomere and label its parts.
10. Describe causes and symptoms of muscle fatigue, cramps and tetany.
11. Justify how the main functions of the skeleton are to act as a system of rods and levers.
12. Justify why do the muscles pull but do not push.

INQUISITIVE QUESTIONS

1. Why is calcium essential for both the structural integrity of bones and the process of muscle contraction?
2. Why is the human skeleton designed with both rigid bones and flexible joints instead of being made of a single solid structure?
3. Why do muscles always work in pairs (antagonistic muscles) rather than alone?
4. Why does prolonged inactivity or space travel lead to muscle atrophy and bone weakening??