Chapter 16

Support and Movements

16.1 CONCEPT AND NEED

Animals and plants show a variety of physical and biochemical activities. The main difference between animals and plants is in their locomotion. Animals show movement while plants do not show movement.

Need and advantage of movement

Movement is required to get food, shelter and to escape from the danger.

Need of support

Both plants and animals need support against gravity for support following things are needed.

(i) Support to ***baby plant*** is provided by ***collenchyma*** cells and to ***adult*** plants by ***sclerenchyma*** cells.

(ii) Support to ***animals*** is provided by muscles, cartilage and bones. They are also involved in movement.

16.2 SUPPORT IN PLANTS

Main support to the plant is provided by stem, which also acts as supply line between roots and aerial parts of plant.

Mechanisms Involved To Support Plant

Several mechanisms are involved in providing support to plant. Some are described below.

i) Turgor Pressure

The living cells of epidermis, cortex and pith take in water by osmosis. This water produces an internal hydrostatic pressure, called turgor pressure. This turgor pressure keeps cells turgid and thus stem remains rigid and resistant to bending. If there is loss of turgidity, herbaceous stem wilts.

Generation of Turgor Pressure

Turgor pressure is generated by high osmotic pressure of vacuole. In this case, membrane of vacuole, ***tonoplast*** is very important. Different steps involved in generation of turgor pressure are described below.

i) There is active transport of ions into the vacuole despite their high concentration than that of extracellular fluid.

ii) These ions cause increase in concentration inside the vacuole.

iii) Higher ionic concentration causes entry of water into the vacuole.

iv) Increased water increases turgor pressure.

Increased turgor pressure provides turgidity and mechanical support to the soft tissues of plant.

ii) Stiffness by Lignified Cells

Collenchyma cells of cortex and sclerenchyma of xylem tissue are with heavily lignified cells. They also give support to the plants.

iii) Ring Arrangement of Vascular Bundle

Most of the terrestrial plants are tracheophytes (vascular plants).

- They have vascular bundle containing xylem, which is tough and inextensible to perform the same function as steel rods in reinforced concrete.
- These vascular bundles form rings within the stem.

This arrangement provides very effective resistance to wind stress and increase weight-bearing ability.

iv) Strengthening by Bundle Cap

In the stem of some plants e.g. **sunflower**, the vascular bundles are strengthened by additional sclerenchyma fibers, which form bundle cap. It is also important for support.

CELLS INVOLVED IN PROVIDIG SUPPORT TO PLANTS

Cells, which provide support to the plants, are following.

A) Sclerenchyma Cells

Different features of such cells are following

- These cells have thick secondary cell walls, usually impregnated with lignin (an organic substance that makes walls tough and hard).
- Mostly are non-living.
- Their primary function is to provide support to the plant parts.

Types of Sclerencyma Cells

Sclerenchyma cells are divided into three types.

i) Fibers (Tracheids)

They are long and cylindrical and they may exist as a solid bundles in the xylem or as bundle caps.

ii) Sclereides

They are shorter than fibers and are found in seed coats and nut shells and provide protection.

iii) Vessels (Tracheae)

They are long, tubular structures joined end to end to form long water conducting pipes in xylem.

B) Collenchyma Cells

They show following features.

- They have protoplasts.
- They usually lack secondary walls.
- They have angular thickening in their primary walls.
- They are usually grouped in strands or cylinders.
- They are elastic and elongate with the growth of stem and leaves.
- Collenchyma cells provide support to young herbaceous parts of the plant.
- Young stems, for instance, often have a cylinder of collenchyma just below their surface.

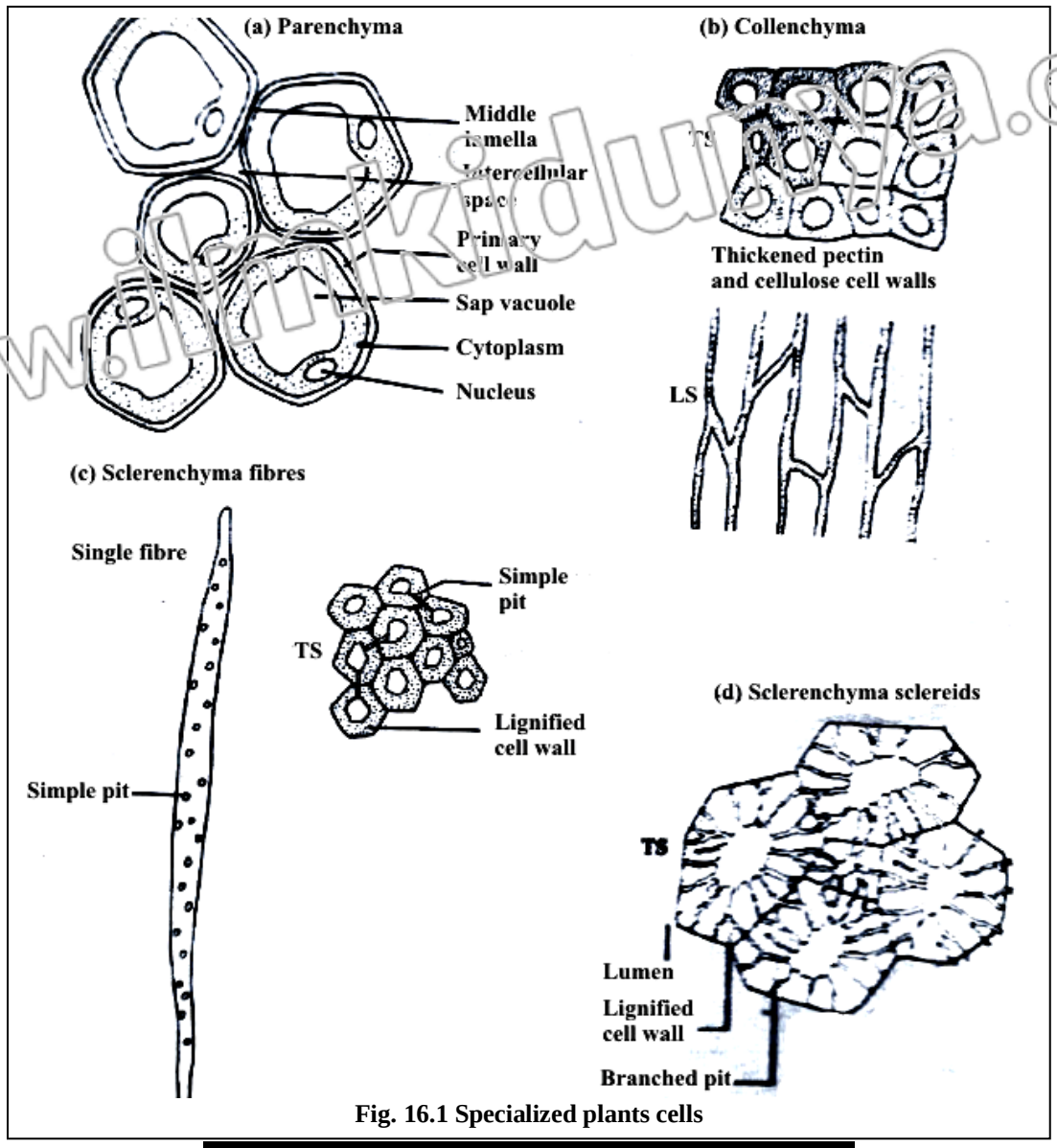

Fig. 16.1 Specialized plants cells

QUESTIONS RELATED TO ABOVE ARTICLE

What do you know about collenchyma cells?

Explain different mechanisms involved to provide support in plants

Write a note on sclerenchyma cells and collenchyma's cells. (LHR 2021)

Write down a note on sclerenchyma cells and detail. (GRW 2021)

Differentiate between sclerenchyma cells and collenchyma cells and sketch diagrams. (RWP 2021, LHR 2022)

16.2.1 Significance of Secondary Growth in Support

Secondary Growth

An increase in plant girth due to the activity of vascular cambium and cork cambium is called secondary growth.

Types of Cambium

Secondary growth in plants occurs due to cell division in

(i) Vascular cambium

(ii) Cork cambium

Role of Vascular Cambium in Secondary Growth

Vascular cambium first time appears as a cylinder of actively dividing cells between primary xylem and phloem. Vascular cambium give rise two new tissues

- One is the ***secondary xylem***, which lies next to inner surface of the vascular cambium. Main increase in thickness is due to this xylem
- Other is ***secondary phloem***, which lies next to the outer surface of the vascular cambium. This process continues and vascular cambium produces secondary xylem, layer upon layer. Due to this, a woody stem gets thicker and thicker.

Overall Functions of Cambium

i) It is involved in ***secondary growth***.

ii) It is involved in formation of ***callus***.

Callus

A Callus is a soft parenchymatous tissue which is rapidly formed on or below the damaged surface of stem and roots.

Significance of Callus

(i) Formation of wood tissue on or over the wound.

(ii) Callus unites the branches during budding and grafting.

Special Structures Produced Due to Secondary Growth

i) Annual Ring

Layers of xylem are visible as rings. Since one ring is formed in one year, it is termed as annual ring. A count of these rings at the base of trunk indicates the age of trees at the time it was cut.

ii) Sapwood

With age, conduction of water and solutes becomes limited to the outer or younger portion. The outer region of secondary xylem of tree trunks which is the active portion is called sapwood.

iii) Heartwood

Inner, inactive, non-conducting wood is called heartwood.

Significance of Secondary Growth

- In most species, the heartwood accumulates a variety of chemicals such as **resins, oils, gums** and **tannins.** These provide a resistant to decay and insect attack e.g. **red cedar** and **conifers**.
- ***Wood*** is also formed due to cambial activity. Wood of different species varies in its suitability for specific uses, density, hardness, flexibility, shock resistance, compression strength and texture.
- ***Cork*** is also result of cambial activity. It is formed from bark of trees such as ***Quercus suber***.

QUESTIONS RELATED TO ABOVE ARTICLE

Define secondary growth. What is its significance in plants?

Describe significance of secondary growth.

Explain the type of growth in plants due to which diameter of stem increase.

(GRW 2022, RWP 2022)

Define secondary growth. Explain its significance. **(Exercise Question viii)**

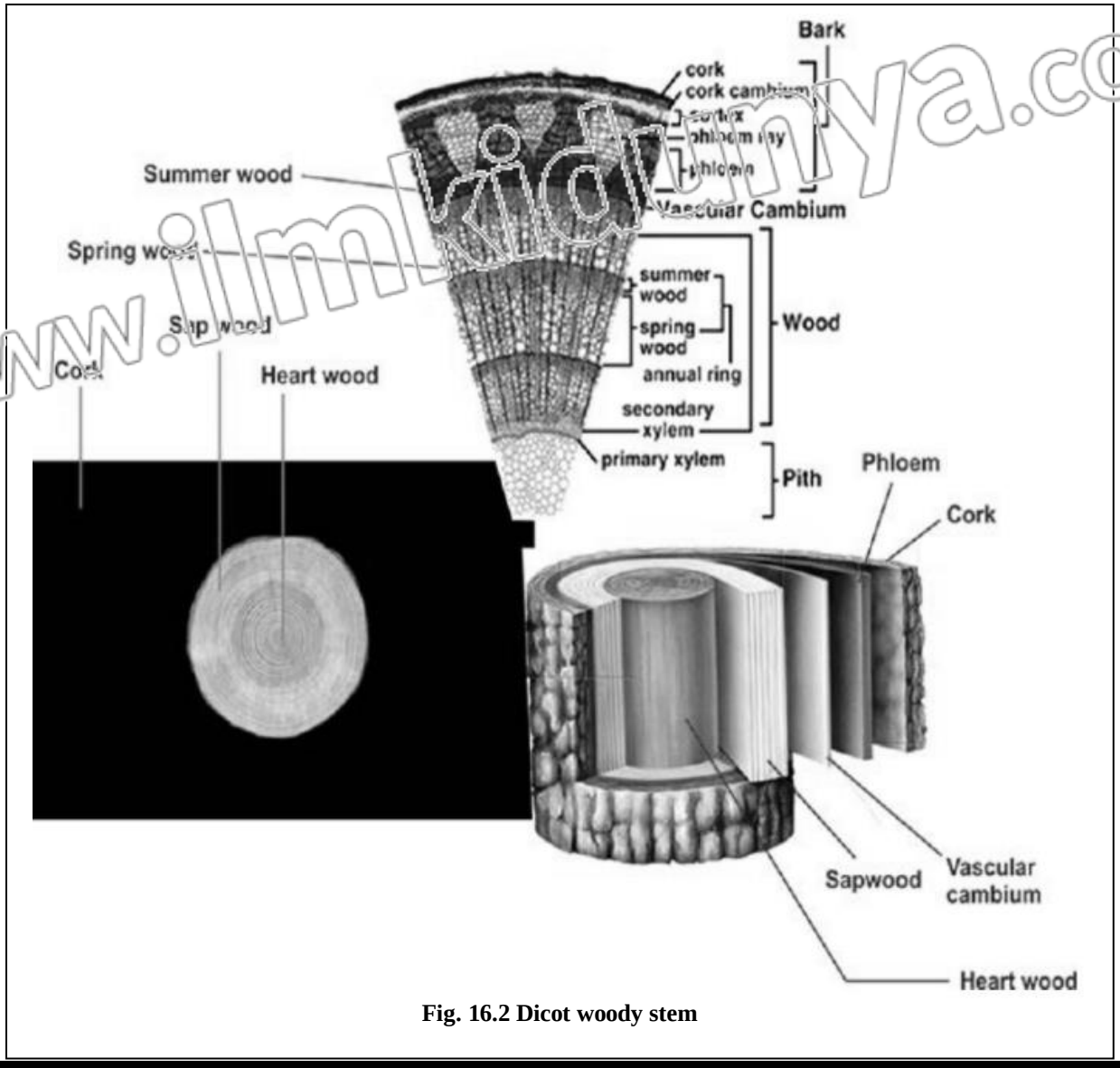

Fig. 16.2 Dicot woody stem

16.3 MOVEMENTS IN PLANTS

Organisms respond to external as well as internal stimuli, but there is difference in response in animals and plants.

Major differences are:

- Animals change their location while plants are fixed.
- Animals show movement in response to external stimulus, while plants show movement related to their growth pattern.

TYPES OF PLANT MOVEMENTS

There are two types of plant movements.

1) Autonomic movements
2) Paratonic movements.

1) AUTONOMIC MOVEMENTS

Definition

Movements performed by plant, which are spontaneous movements due to internal causes are called autonomic movements.

Types

These are further divided into three types.

A) Tactic movements
B) Turgor movements
C) Growth movements

A) Tactic Movements

Definition

Movements of an entire cell or an organism i.e. locomotion due to internal stimulus are called tactic movements.

Types

These are further divided on two basis.

a) According to direction of movement
b) According to nature of stimulus.

a) According To Direction of Movement

On this base, they are again divided into two types.

i) Positive Tactic Movement

If tactic movement is towards the stimulus, it is called positive tactic movement.

ii) Negative Tactic Movement

If tactic movement is away from the stimulus, it is called negative tactic movement.

b) According To Nature of Stimulus

On this base it is again divided into two types.

i) Phototactic movement

It is a movement in response to stimulus of ***light***.

It may be towards the source of light (positive) or away from the source of light (negative).

Example

Passive movement of chloroplast is due to cyclosis is the best example of positive tactic movement.

This movement helps the chloroplast to absorb maximum light for CO_2 fixation. The light intensity and direction both affect the intra cellular distribution of chloroplasts.

ii) Chemotactic Movement

The movement in response to stimulus of ***chemicals*** is called chemotactic movement.

Example

The movements shown by sperms of liverworts, mosses and ferns towards archegonia in response to stimulus of nucleic acid released by the ovum.

B) Turgor Movements

Definition

Movements due to differential changes in turgor and size of cells as a result of gain or loss of water are called turgor movements.

Types or Turgor Movements

These are further divided into two types.

a) Sleep Movements

Bean plants and some other plants of legume family lower their leaves in the evening and raise them in morning. These are known as sleep movements.

These sleeping movements are due to daily changes in turgor pressure in ***pulvinus*** (place of attachment of leaf with the shoot).

Pulvinus

Pulvinus is swollen portion of the petiole composed of parenchyma cells with relatively large intercellular spaces and central strand of vascular tissue.

Mechanism

- When turgor pressure on the lower side of pulvinus increases, the leaves rise and become horizontal.
- When turgor pressure decreases on the lower side of pulvinous, the leaves lower and go sleeping position.

b) Rapid Movement of Leaflets

It is also a turgor movement shown rapidly after ***touch***.

Example

Rapid movements of leaflets shown by 'touch me not'.

Mechanism

When the compound leaf of sensitive plant Mimosa is touched, the leaflets fold together.

- Touch acts as stimulus.
- Touch stimulates K^+ ions, which move out of cells of pelvinous.
- K^+ ion movement causes water to leave the cells by exosmosis.
- This response takes about 1-2 seconds resulting in loss of turgor pressure and drooping of leaflets.

It takes about ten minutes to regain the turgor and restore the internal turgidity of leaf.

C) Growth Movements

Definition

Movements shown due to unequal growth on two sides of plant organs like stem, root, tendrils, buds etc. are called growth movements.

Types

There are further three types of growth movements.

a) Epinasty

Such type of movement in which upper surface of leaf in bud condition shows more growth as compared with lower surface is called epinasty.

Example

This movement is shown by leaves, buds, petals etc. It leads to opening of these structures.

b) Hyponasty

If growth in the lower surface of the leaf in bud condition is more than the upper surface, then bud remains close. It is called hyponasty.

c) Nutation

The growing tip of young stem moves in a zig-zag fashion due to alternate changes in growth on opposite side of the apex. The mode of growth is called nutation.

2) PARATONIC MOVEMENTS

Definition

Movement of plant parts induced by external stimuli are called paratonic movements.

Types

These are of following types.

A) Tropic movements

B) Nastic movements

A) Tropic Movements

Definition

The word tropic is derived from Greek word 'tropos' meaning 'turn'.

It is the movement in curvature of whole organ towards or away from the stimulus is called tropic movement (tropism) such as light, gravity and touch.

These are in actual case growth responses to external stimuli.

These stimuli may be light, gravity, touch etc.

Types

Following are common tropic movements.

a) Phototropism

Movement of plant part in response to stimulus of ***light*** and is caused by the differential growth of part of a plant like stem or root.

Example

Movement of stem towards light or of root away from light.

b) Thigmotropism

Movement in response to stimulus of ***touch*** is called thigmotropism.

Example

Movement shown by climbing vines.

When they come in contact with some solid object, the growth on opposite side of contact increases and the tendril coils around the support.

c) Chemotropism

Movement in response to some ***chemicals*** is chemotropic movement.

Example

The hyphae of fungi are chemotropic.

d) Hydrotropism

Movement of plant parts in response to stimulus of ***water*** is called hydrotropism.

Example

Growth of root towards water is positive hydrotropism and of shoots away from water is negative hydrotropism.

e) Geotropism

Movement shown in response to ***gravity*** is called geotropism.

Example

Roots show positive geotropism, while shoot shows negative geotropism.

B) Nastic Movements

Definition

Non-directional movements of plant parts in response to external stimuli are called nastic movements (***nasties***).

Types of Nastic Movements

These are of two types.

a) Nyctinasty

These are nastic movements in response to external stimuli leading to differential growth.

These are due to turgor and growth changes.

Types

These are further divided into two types.

i) Photonasty

Nastic movement shown by plant parts in response to stimulus of ***photoperiod*** is called photonasty.

Example

Opening and closing of flowers due to light intensity.

ii) Thermonasty

Nastic movement shown in response to ***temperature*** is called thermonasty.

Example

Closing of flowers of tulip at night.

In them, at night, rapid growth on the lower side causes upward and inward bending of the petals.

b) Haptonasty

Nastic movements shown in response to ***contact***.

Example

Action of Venus fly trap.

QUESTIONS RELATED TO ABOVE ARTICLE

Give an account of autonomic movements in plants.

Define paratonic movements in plants. Describe nastic movements in detail. (MTN 2019)

Explain the phenomenon of turgor movements in plants. (SWL 2019)

Describe paratonic movements in plants. (FSD 2019)

What are turgor movements? Write significance of predation. (FSD 2021)

Relate the concept of turgor movement in plant with turgor pressure changes by given example? (DGK 2022)

16.3.1 Role of Plant Growth Substances in Plant Movement

Plant movements are mainly controlled by different hormones. Important hormones, which play role in this context, are auxins (indole acetic acid IAA), abscisic acid and gibberellins.

i) Phototropism

Phototropism is mainly controlled by **auxins**. It is believed that unequal distribution of auxins in the cleoptiles stumps produces unequal cell enlargement causing a bend in the organ towards source of light.

ii) Gravitropism

Auxins are also responsible for positive gravitropism of roots and negative gravitropism of stems.

Auxins inhibit growth of root cells and stimulate growth of stem cells.

- They inhibit growth of root cells at lower surface, the cells of upper surface elongate and thus the root curves downward.
- They stimulate growth of stem cells at lower surface. These cells elongate and stem curves upward.

iii) Nastic Movements

Nastic movements are due to some balance or ratio between growth inhibitors **(abscisic acid)** and growth stimulators (gibberellins).

iv) Growth Movements

It has been observed that epinasty is due to auxins and hyponasty due to **gibberellins.**

QUESTIONS RELATED TO ABOVE ARTICLE

Explain the role of plant growth substance in plant movement.

16.4 SUPPORT AND MOVEMENT IN ANIMALS

Skeleton

It is tough and rigid framework of the body of animals, which provides protection, shape and support to the body organs.

Composition

It is composed of inorganic or organic substances or both.

Production

- In ***protozoa***, it is secreted by a single cell.
- In ***multicellular animals***, it is composed by specialized cells.

Types of Skeleton

Following are important types of skeleton

1) Hydrostatic skeleton
2) Exoskeleton
3) Endoskeleton

16.4.1 Hydrostatic Skeleton

In animals that lack a hard skeleton, a fluid filled gastrovascular cavity or coelom can act as hydrostatic skeleton.

Major Functions

It mainly provides support and resistance to the contraction of muscles so that motility results.

Examples

It is found in cnidarians (sea anemone), annelids (earthworm) and other soft-bodied invertebrates.

Mechanism in Sea Anemone

The sea anemone has hydrostatic skeleton.

i) Its cavity is filled with sea water to extend its body and tentacles.
ii) It closes its mouth and constricts its muscle fibers that are arranged in circles around the body.
iii) Contraction of circular muscles puts pressure on liquid of body cavity and that pressure forces the body to maintain upright stature.

Mechanism in Earthworm

In earthworm, the hydrostatic skeleton consists of fluid filled compartments separated by septa.

- Contraction of circular muscles causes compartments to elongate.
- Contraction of longitudinal muscles causes compartments to shorten.

Alternating waves of elongation and contraction move the earthworm through the soil, aided by paired setae in each segment.

QUESTIONS RELATED TO ABOVE ARTICLE

Write a detailed note on hydrostatic skeleton.

Define hydrostatic skeleton, How it helps in support and movement? Explain with examples.

How is support provided to those animals, which lack a hard skeleton? Explain your example with two examples. (FSD 2022)

Explain in detail the significance of hydrostatic skeleton in animals having no hard part such as bones. (SGD 2022)

16.4.2 Exoskeleton

Definition

Such type of skeleton, which lies outside the body and provides attachment to muscles internally, is called exoskeleton.

Composition

- It is inert and non-living.
- It is secreted by ectoderm in animal cells.
- It is composed of two layers

i) The ***epicuticle*** is the outer most layer. It is made up of waxy lipoprotein. Thus it is impermeable to water and serves as a barrier to microorganisms and insects.

ii) Bulk of exoskeleton below the epicuticle is called the ***procuticle***. It is composed of chitin, tough and leathery polysaccharide and several kinds of proteins. It is further hardened by sclerotization and sometimes by impregnation with calcium carbonate.

Example

Exoskeleton of Mollusca

Shell of Mollusca is simplest example of exoskeleton.

- It generally consists of one or two pieces.
- Some marine bivalvia and snail have shell composed of crystals of calcium carbonate.
- Shell of land snail generally lack the hard minerals and are much lighter.
- Molluscan shell can grow as the animal grows and growth rings are apparent on the shell. The soft body parts of the molluscan body have a hydrostatic skeleton as well.

Exoskeleton of Arthropods

The most complex exoskeleton is found among the Arthropods.

Adaptations Exhibited By Arthropods

Arthropods have made variety of adaptations to live and grow within their exoskeleton. Some are given below.

i) The invagination of exoskeleton forms firm ridges and bars for ***muscle attachment***.

ii) There is formation of ***joints*** in the exoskeleton. At the level of joint, exoskeleton becomes thin, soft and flexible and thus allows easy movement.

iii) Exoskeleton has developed ***sensory receptors*** called sensilla that are in the form of bristles, and lenses.

iv) Their exoskeleton permits ***gaseous exchange***

Advantage of Exoskeleton

The exoskeleton in arthropods

- Protects the animal against their enemies and rough environment.
- Protects from drying.

Disadvantage of Exoskeleton

Single disadvantage of exoskeleton in arthropods is that it restricts growth and movement and animal cannot grow larger and cannot move faster. They over come this problem by ecdysis.

Ecdysis (Moulting)

Arthropods need to shed off their exoskeleton periodically and replace it with one of the larger size. This process is known as ***ecdysis*** or ***moulting***.

Stages of Ecdysis

Ecdysis is divided into ***four stages***.

i) Enzymes secreted from hypodermal glands begin digesting the old endocuticle. This digestion separates hypodermis and the exoskeleton.

ii) Digestion of endocuticle is followed by secretion of new procuticle and epicuticle.

iii) Old exoskeleton is split and pores are formed.

iv) Finally new exoskeleton is hardened by deposition of calcium carbonate.

During the hardening process, the arthropod is vulnerable to predators and remain hidden. All these changes are controlled by the ***nervous system*** and hormone ***ecdysone***.

QUESTIONS RELATED TO ABOVE ARTICLE

Discuss the composition of exoskeleton. Compare the exoskeleton of arthropods with mollusks.

Why arthropod exoskeleton is considered as advanced type of exoskeleton?

Explain about exoskeleton in arthropods.

Write the process of ecdysis in arthrodesis **(FSD 2021)**

What are the disadvantages of exoskeleton? **(Exercise Question i)**

16.4.3 Endoskeleton

Definition

Such type of skeleton, which lies inside the body and provides attachment to muscles externally, is called endoskeleton.

Composition

It is made of rigid connective tissue. This connective tissue consists of living cells embedded in the matrix of proteins called ***collagen***.

BONE

Definition

It is rigid form of connective tissue.

Composition

Its collagen fibers are hardened by deposition of calcium phosphate

Types of Bones

Bones supporting our arms and legs consist of an outer shell of compact bone, with spongy bone in the interior. Bones can also be divided into two types.

i) Compact Bone

Compact bone is dense, strong and provides an attachment site for muscles.

ii) Spongy Bone

Spongy bone is light, rich in blood vessels and highly porous. The cavities of spongy bone contain bone marrow where blood cells are formed.

Cells of Bone

Three cells are associated with a bone.

i) Osteoblasts (bone-forming cells)

ii) Osteocytes (mature bone cells)

iii) Osteoclasts (bone dissolving cells)

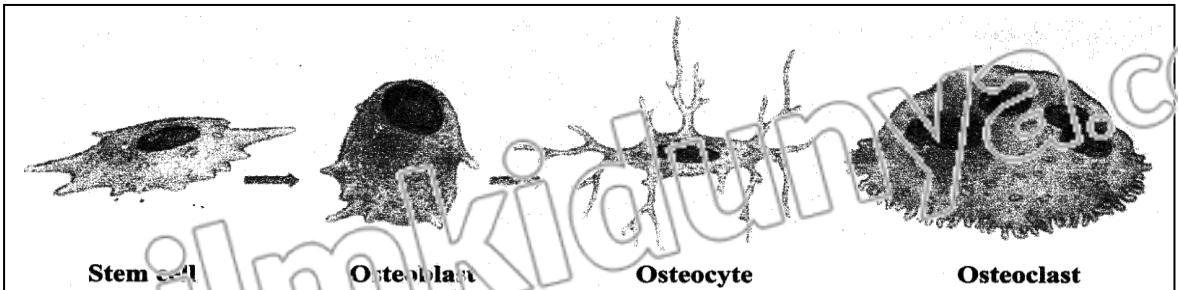

Fig. 16.3 Cells of bone

Role of Cells in Bone Development

Early in development, when bone is replacing cartilage, the osteoclasts invade and dissolve the cartilage. Then osteoblasts replace it with bone. As bones grow, the matrix of bone is hardened and the osteoblasts are gradually entrapped within it.

CARTILAGE

Definition

It is softer form of connective tissue.

It mostly covers ends of the bones at the joints and also supports the flexible portion of nose and external ear.

Composition

It is also a form of connective tissue. It covers ends of the bone at the joint and also support the flexible and external ears.

Cells of Cartilage

The living cells of cartilage are called ***chondrocytes***. These cells secrete flexible, elastic, non-living matrix collagen that surrounds the chondrocytes.

Types

There are two main types of cartilage.

i) Hyaline Cartilage

It is the most abundant type in human body. It is found at the moveable joints.

ii) Fibro Cartilage

It contains bundles of collagen fibers. It forms an external pinnae of ears and in the epiglottis.

QUESTIONS RELATED TO ABOVE ARTICLE

What is endoskeleton? Describe bone and cartilage.

What are the main differences between exoskeleton and endoskeleton?

(Exercise Question ix)

MAJOR FUNCTIONS OF SKELETAL SYSTEM

Some major functions of skeletal system are described below

i) Support & Shape

Bones support soft tissues and serve as attachment sites for most muscles and provide shape to the body.

ii) Protection

Bones protect critical internal organs such as brain, spinal cord, heart, lungs and reproductive organs.

iii) Movement

Skeletal muscles attached to bones help in movement.

iv) Mineral Homeostasis

Bones serve as reservoir for calcium, phosphorous, sodium and potassium. Through negative feedback mechanism, bones can release or take up minerals to maintain homeostasis.

v) Blood Cell Production

Red and white blood cells are produced in bone marrow (a connective tissue found within certain bones).

QUESTIONS RELATED TO ABOVE ARTICLE

Give importance of skeleton (LHR 2017)

Describe major functions of human skeletal system. (GRW 2021, LHR 2022)

How the skeletal system play a central role among different function of body? (MTN 2022)

List the main parts of axial skeleton. (Exercise Question x)

16.5 HUMAN SKELETON

Human skeleton can be divided into two parts i.e.

1) Axial Skeleton
2) Appendicular skeleton

16.5.1 AXIAL SKELETON

The axial skeleton includes;

a) Skull
b) Vertebrae
c) Ribs
d) Sternum

a) Skull

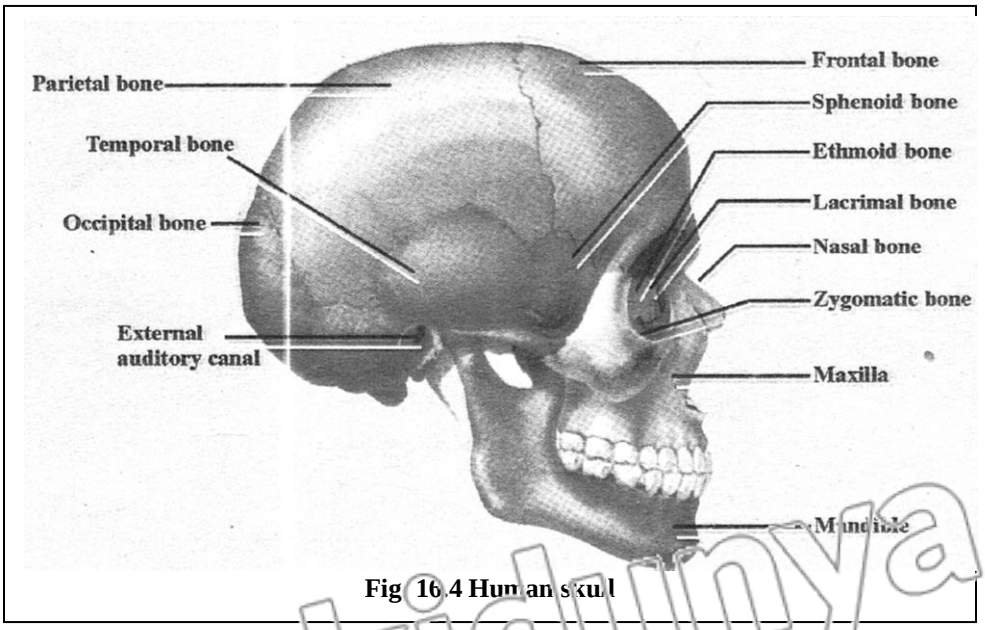

Fig 16.4 Human skull

It is made up of cranium and facial bones.

i) Cranium

The cranium consists of ***8 bones***, out of which 4 are unpaired and 2 are paired.

- ***Paired bones*** are parietal and temporal.
- ***Unpaired bones*** are frontal, occipital, sphenoid and ethmoid.

ii) Facial Bones

There are ***14 facial bones***, out of which 6 are paired and 2 unpaired.

- ***Paired Facial bones*** are maxilla, zygomatic, nasal, lacrimal, palatine and inferior concha.
- ***Unpaired bones*** are mandible and vomer.

Function

Major function of cranium is protection of brain.

b) Vertebral Column

It extends from skull to the pelvis to form backbone. It consists of ***33 vertebrae***. These vertebrae are named according to their location in the body i.e. cervical, thoracic, lumbar and pelvic.

- There are ***7 cervical vertebrae***, which lie in the neck region. First two cervical vertebrae are ***atlas*** and ***axis***.
- There are ***12 thoracic vertebrae*** located in the thoracic region.
- There are 5 ***lumbar vertebrae*** located in lumbar region.
- There are ***9 pelvic vertebrae*** located in pelvic region, which form two sets. ***Anterior 5*** vertebrae join to form ***sacrum*** and ***posterior 4*** vertebrae join to form ***coccyx***.

Function

- Vertebral column protects spinal cord.
- Vertebral column has four curvatures, which provide strength than the straight column.

c) Rib Cage

- It is also called as ***thoracic cage***.
- It is composed of ***12 pairs of ribs*** that articulate with the thoracic vertebrae.
- 10 of them connect anteriorly with sternum either directly or through the costal arch.
- Lower 2 pairs of ribs do not attach with sternum and are called '***floating ribs'***.

Function

Rib cage provides support to a semi-vacuum chamber called 'chest cavity'.

d) Sternum

A long flat bone in most vertebrates that is situated along the ventral midline of the thorax and articulates with the ribs. The manubrium of the sternum articulates with the clavicles in humans and certain other vertebrates, also called breastbone.

16.5.2 APPENDICULAR SKELETON

The appendicular skeleton consists of;

a) Pectoral girdle and appendages (fore limbs).

b) Pelvic girdle and appendages (hind limbs).

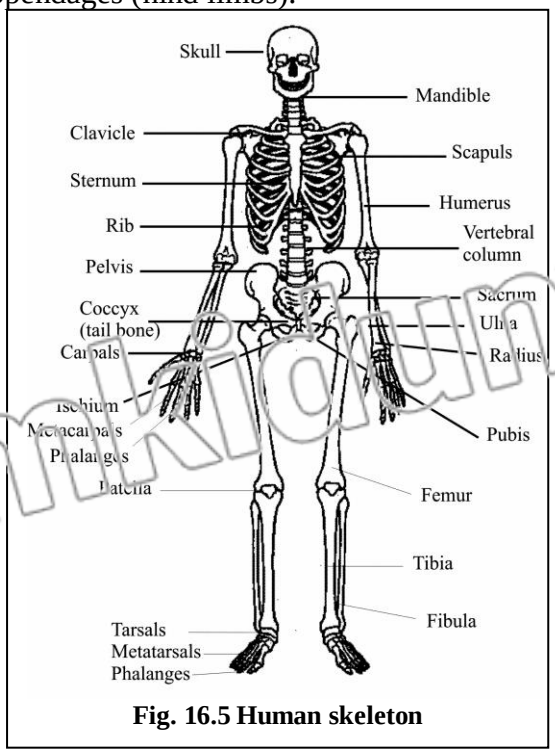

Fig. 16.5 Human skeleton

a) Pectoral Girdle and Fore Limb

(i) Pectoral Girdle

It comprises of scapula, suprascapula and clavicle. The clavicle connects scapula with sternum.

Function

Pectoral girdle connects forelimb with trunk.

(ii) Fore Limb

- The forelimb consists of humerus, radius and ulna, 8 carpals, 5 metacarpals and 14 phalanges.
- Humerus at proximal end forms ball and socket joint (***shoulder joint***) with scapula.
- Humerus at distal end forms hinge joint (***elbow joint***) with radius and ulna.
- The radius and ulna at their distal end form multistage joint (***wrist joint***) with eight wrist bones called carpals.
- Five metacarpals form the framework of palm of the hand. Five rows of the phalanges are attached to the metacarpals. They support the fingers.

b) Pelvic Girdle and Hind Limb

(i) Pelvic Girdle

It consists of two coxal (hip) bones. Each bone is formed by fusion of three bones ilium, ischium and pubis.

Function

- Pelvic girdle supports the pelvic region.
- Pelvic girdle attaches the hind limb to the vertebral column.

(ii) Hind Limb

It consists of 1 femur, 2 tibia and fibula, 7 tarsals, 5 metatarsals and 14 phalanges.

- Femur at its proximal end forms ball and socket joint (***hip joint***) with hipbone.
- Femur at distal end forms hinge joint (***knee joint***) with proximal ends of tibia and fibula.
- Distal ends of tibia and fibula form multistage joint (***ankle joint***) with eight tarsals.
- Tarsals are attached to 5 metatarsals. Five rows of the fourteen phalanges of the toes are attached with metatarsals.

QUESTIONS RELATED TO ABOVE ARTICLE

Write a note on human appendicular skeleton.

Discuss arrangement of vertebrae in vertebral column. Also describe rib cage. (LHR 2018)

Draw and label the human skull. (Exercise Question vi)

List the main parts of axial skeleton. (Exercise Question xii)

16.5.3 Joints

Definition

Place where two or more than two bones meet is called joint.

Major Functions

- They hold our skeleton.
- They help in mobility.

Classification

Joints are classified in two ways;

A) According to amount of movement

B) According to basic structure

A) According to amount of Movement

On the basis of the amount of movement allowed, joints are classified into three types.

i) Immovable Joints

Joints, which do not allow movements, are called immovable joints.

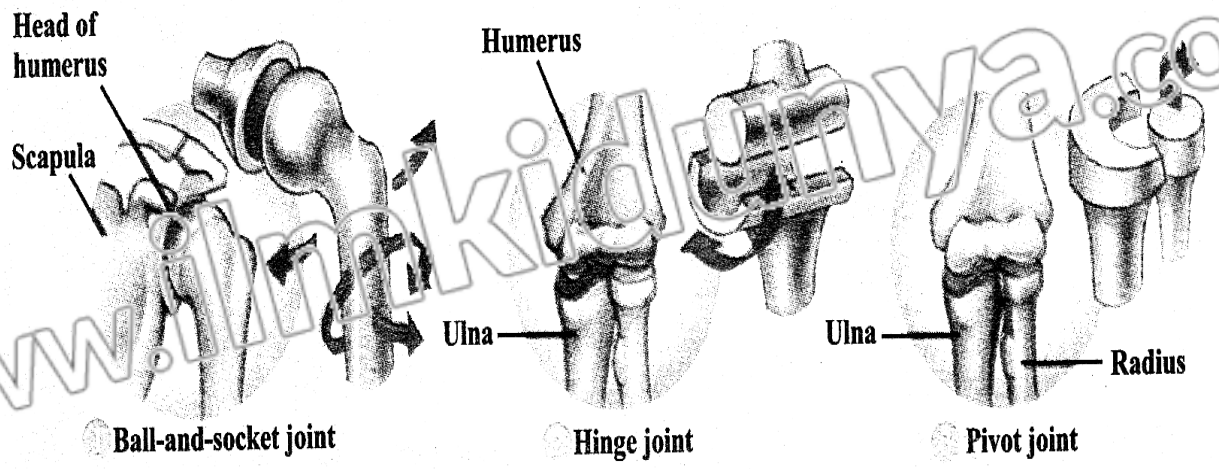

Fig. 16.6 three kinds of joints

Example

Joints of skull.

ii) Slightly Movable Joints

Joints, which allow slight movements are called slightly moveable joints.

Example

Joints of vertebral column.

iii) Freely Movable Joints

Joints, which allow free movements, are called freely movable joints.

Freely movable joints are of two types i.e. hinge joints and ball and socket joints.

Example

Knee joint, hip joint, shoulder joint and elbow joint.

B) According to Basic Structure

On the basis of basic structure, joints are classified into three types.

i) Fibrous Joints

These joints are held together by short fibers embedded in connective tissue are called fibrous joints.

Examples

Joints of skull, they fix teeth into the jaws.

ii) Cartilaginous Joints

Hyaline Cartilage formed joint between growing bones or such joints where hyaline cartilage is present and they allow little movements are called cartilaginous joints.

Example

Joints of vertebral column and joint where coxal bones meet in front of the pelvis.

iii) Synovial Joints

Joints in which cavity is filled with synovial fluid are called synovial joints.

Joint is surrounded by a layer of connective tissue called ***'fibrous capsule'*** and their inner layer the synovial membrane. Synovial membrane produces synovial fluid, which fills cavity and reduces friction between moving joints.

Some parts of capsule may be modified to form distinct 'ligaments', holding the bones together.

Classification of Synovial Joints

Based on structure and movements allowed, the synovial joints can be classified further into two major categories.

a) Hinge Joint

Joint that allows movements in two directions is called hinge joint.

At these joints, muscles are arranged in the same plane as that of joint. These joints usually have a pair of muscles.

Example

Elbow and knee joint

b) Ball & Socket Joint

Joint, which allows movements at several directions is called ball and socket joint.

Such joints have at least two pairs of muscles present perpendicular to each other. They provide maximum flexibility.

Example

Hip joint and shoulder joint.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe different types of joints.

What are joints? Explain various types of joints.

(LHR 2017, BWP 2019, MTN 2019, BWP 2021)

Define joints. How they are classified? Explain. (Exercise Question iv)

Distinguish between fibrous, cartilaginous and synovial joints. (Exercise Question xiii)

16.6 DEFORMITIES OF SKELETON

Human skeleton supports an upright body. Sometimes our skeletal system becomes weak and results in deformities.

The causes of deformation are variable. Some are described below.

16.6.1 Genetic Causes

Some of the deformities caused by genetic causes are;

i) Cleft Palate

It is a condition in which palatine processes of maxilla and palatine fail to fuse.

The persistent opening between the oral and nasal cavity interferes with sucking. It leads to inhalation of food into the lungs causing ***aspiration pneumonia***.

ii) Microcephaly

It is a condition with small sized skull caused by some genetic defect.

iii) Arthritis

Arthritis includes inflammatory or degenerative diseases of joints that are of more than 100 different types that damage the joints.

Osteoarthritis (O.A.) is the most common chronic arthritis, which is a degenerative joint disease also caused by genetic defects.

16.6.2 Hormonal Causes

Osteoporosis

It is a group of diseases in which bone resorption out paces bone deposits.

In this case, bone mass is reduced and chemical composition of matrix remains normal. It mostly occurs in aged women. Its major causes are

- Decreased estrogen level.
- Insufficient exercise
- Diet poor in calcium and protein
- Smoking

Estrogen replacement therapy (ERT) offers the best protection against osteoporotic bone fracture.

16.6.3 Nutritional Causes

There are two important nutritional diseases related to skeletal system.

i) Osteomalcia

Osteomalcia (soft bones) includes a number of disorders in which the bones receive inadequate minerals.

There is decreased deposition of calcium salts leading to softening and weakness of bones. Most commonly weight-bearing bones of legs and pelvis bend and deform. The main symptom is the pain when weight is put on affected bones.

ii) Rickets

- It is disease in children with bowed legs and deformed pelvis.
- It is caused by deficiency of calcium in diet or vitamin 'D'.
- It is treated by vitamin 'D' fortified milk and exposing skin to sunlight to cure disorders.

16.6.4 Miscellaneous

i) Disc Slip

Intervertebral Disc

Each intervertebral disc is a cushion-like pad composed of

- An inner semi-fluid ***'nucleus pulposus'***, which acts as rubber ball to give a disc its elasticity and compressibility.
- A strong outer ring of fibrocartilage ***'annulus fibrosus'***, which holds together successive vertebrae.

Major Function of Whole Disc

The disc acts as shock absorber during walking, jumping, running and to lesser extent to bend laterally.

Disc Slip & Its Complications

- Major cause of disc slip is severe or sudden physical trauma to spines for example from bending forward while lifting a heavy object.
- It usually involves rupture of annulus fibrosus followed by protrusion of spongy nucleus pulposus. Protrusion of nucleus pulposus is called ***herniation***.
- This herniated disc (commonly known as slipped disc) may press spinal cord or spinal nerves exiting from cord. It may generate severe pain or even destruction of these nervous structure.

Treatment

Disc slip is usually treated with bed rest, traction and pain-killer. If it fails, disc may be removed surgically.

ii) Spondylosis

It is a disease, which causes fusion of vertebral joint and immobility.

iii) Sciatica

It is characterized by stabbing pain radiating over the course of sciatic nerve.

Cause

It usually results due to injury of proximal sciatic nerve due to

- Fall
- A herniated disc
- Improper administration of an injection into the buttock.

Complications

Injury to nerve may result in a number of lower limb impairments depending on the precise nerve root injured.

- When sciatic nerve is completely transected, the legs become nearly useless. They cannot be flexed.
- All foot-ankle movements are lost.
- Recovery from sciatic injury is usually slow and incomplete.

iv) Arthritis

It is an inflammatory or degenerative disease that damages joints.

Symptoms

Its major symptoms are pain, stiffness and swelling of the joint.

Types

i) Acute arthritis, which results from bacterial invasion.

ii) Chronic arthritis, which is prolonged process and includes osteoarthritis, rheumatoid arthritis and gouty arthritis.

In both cases, synovial membrane, which lines the joint, is thickened; fluid production is decreased, which consequently leads to increased friction.

Treatment

Bacterial infection is treated with antibiotics, pain is treated with pain-killers and functional activity is maintained with physiotherapy.

QUESTIONS RELATED TO ABOVE ARTICLE

Discuss various deformities of skeleton in human.

Write note on disc slip and sciatica. (MTN 2021)

How is human skeleton deformed by trauma? Justify your answers using special reference of disc slip. (SWL 2022)

16.7 REPAIR OF BROKEN BONES

Despite remarkable strength, bones may break and the most common cause is fracture.

Causes of Fracture

Most fractures result from trauma that may twist or break the bones such as sports injuries, automobile accidents, falls etc.

In old age, bones become thin and weak and hence fractures occur more frequently.

Treatment of Fracture

A fracture is treated by reduction followed by realignment of the broken bone ends. Immobilization is also important in this context.

i) Reduction & Realignment

There are two types of reduction i.e. closed and open reduction.

- In ***closed reduction***, fracture space is reduced and bones ends coaxed back to normal position by physician's hand.
- In ***open reduction***, bone ends are secured together surgically with pins and wires.

ii) Immobilization

After reduction, fractured bone is immobilized by a cast or by traction to allow healing process to begin.

Healing Time

Normal healing time is ***8-12 weeks***, but it is much longer for large weight-bearing bones and for elderly people (due to poorer blood circulation).

Repair Process (Healing of Bones)

The repair of a simple fracture takes place in four phases.

1) Hematoma Formation

Hematoma is a clotted mass of blood at fracture site. When a bone breaks, the blood vessels in bone and its surroundings are torn and result in hemorrhage and hematoma formation.

Immediately after it, bone cells deprived of food begin to die and the tissue at the fracture site becomes swollen and hence painful.

2) Soft Callus Formation

New bone formed at fracture site is called callus. Initially it is soft, so called 'soft callus'. It begins to form in 3-4 weeks. During this phase;

- Capillaries grow into the hematoma and clear up debris.
- Fibroblast and osteoblast migrate into the fracture site and begin to construct bone.

3) Bony Callus Formation

Bone formation begins 3-4 weeks after injury and continues until a firm bony union is formed within 2-3 months.

During this phase, osteoblast and osteoclasts continue to migrate inward, multiply rapidly and gradually and convert soft callus into bony callus.

4) Remodeling

After several months, bony callus is remodeled by the excess material on the outside of the bone. Final structure of remodeled area resembles that of the original unbroken bone because it responds to the same set of mechanical stimuli.

QUESTIONS RELATED TO ABOVE ARTICLE

What is bone fracture? Discuss healing process of a simple bone fracture.
What is the structure of bone? How does repair of broken bones take place?
Describe the mechanism of repair of broken bone.
(DGK 2019, BWP 2019, DGK 2019, SGD 2021, MTN 2021, LHR 2021)

Explain the role of osteoclast in remodling of bone and describe the structure of compact bone. (Exercise Question xi)

16.8 MUSCLES

Definition

Muscles are contractile units of body.

These are associated with multicellular organisms and contain numerous filaments of special proteins i.e. actin and myosin.

Types

Vertebrates possess three types of muscles;

1) Smooth muscles
2) Skeletal muscles
3) Cardiac muscles

16.8.1 Smooth Muscles

i) Smooth muscles are visceral, non-striated and involuntary muscles.
ii) These are considered as earliest form of muscles.
iii) They are present throughout animal kingdom.
iv) Smooth muscle cells are long and spindle shaped with each cell containing single nucleus.
v) They have no striations.
vi) They are not under voluntary control.
vii) These are found in blood vessels, digestive tract and many other organs.

16.8.2 Cardiac Muscles

i) They are striated, involuntary cardiac and related to heart.
ii) They constitute most of the mass of heart walls.
iii) They are composed of chains of single cell, each with its own nucleus.
iv) Chains of cells are organized into fibers that are branched and interconnected.

16.8.3 Skeletal Muscles

These are the muscles, which are attached to skeleton and associated with the movement of bones.

i) These are consciously controlled, so are voluntary.
ii) These have alternate light and dark bands, so called striped or striated muscles.
iii) They are usually attached with bone through a bundle of collagen, non-elastic fibers, known as tendons.
iv) Biceps and triceps are examples.

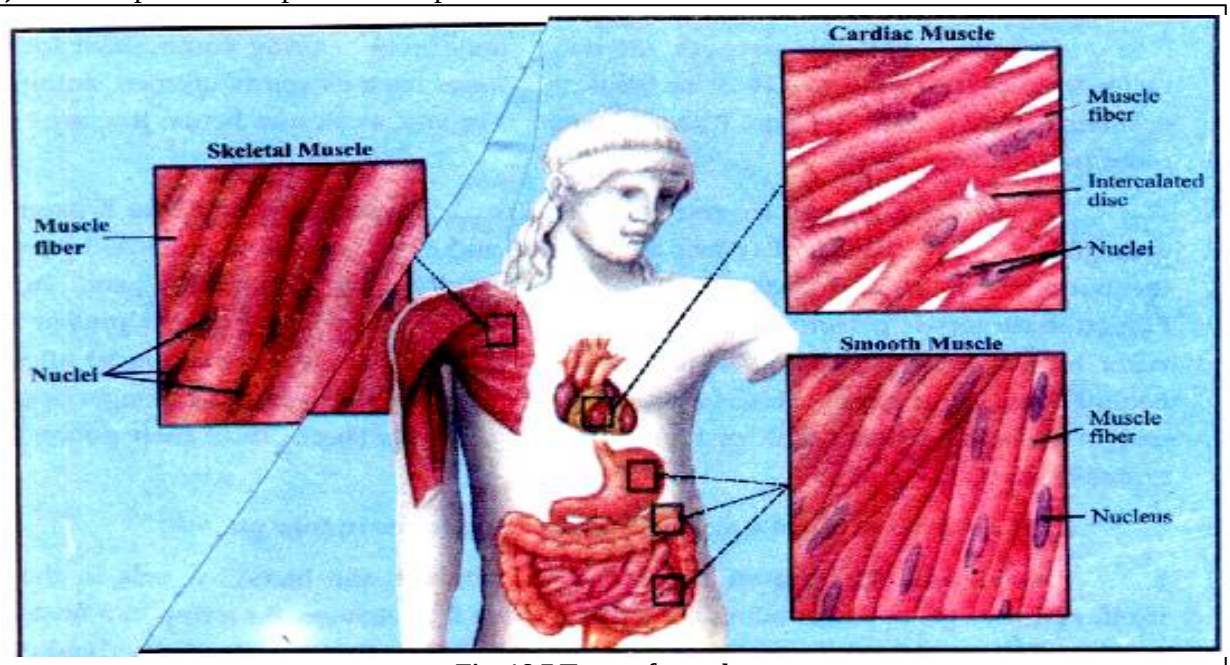

Fig. 16.7 Types of muscles

DIFFERENCES BETWEEN THREE TYPES OF MUSCLES

Property	Smooth	Cardiac	Skeletal
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	Spontaneous, stretch, nervous system, hormones	Spontaneous	Nervous system
Function	Movement of substances through hollow organs	Pumps blood	Moves skeleton
Voluntary control	No	No	Yes

QUESTIONS RELATED TO ABOVE ARTICLE

Describe the three types of muscles.

16.8.4 Structure of A Skeletal Muscle

1) Muscle Bundles

Each muscle consists of several muscle bundles.

2) Muscle Fiber

Each muscle bundle is composed of muscle fibers or cells.

- Muscle fiber is ***basic unit*** of muscle
- Each muscle fiber is long cylindrical cell with multiple oval nuclei arranged just beneath its sarcolemma (membrane of muscle fiber).

Some of their features are;

i) They are huge cells.

ii) Their diameter is ***10-100 µm***.

iii) **Sarcoplasm** of muscle fiber is similar to cytoplasm of other cell but it contains usually large amount of stored glycogen and unique oxygen binding protein called ***myoglobin*** (a red pigment that stores oxygen).

3) Myofibrils

When a muscle fiber is seen under high magnification, it is seen to contain a large number (1000-2000) smaller fibrils called myofibrils.

Some of their features are;

i) Diameter of a myofibril is about ***1-2 µm***.

ii) Myofibrils run in parallel fashion and extend entire length of cell.

iii) Bundles of these fibrils are enclosed by muscle cell membrane or ***sarcolemma***.

4) Sarcomere

The myofibrils consist of smaller contractile units called sarcomere.

"A sarcomere is the region of a myofibril between two successive Z-lines and is the smallest contractile unit of muscle fiber".

In each sarcomere, a series of dark and light bands are evident along the length of myofibril. They give striped appearance to muscle. These are described as;

i) The ***dark bands*** are called A (anisotropic) bands because they can polarize visible light.

ii) The ***light bands*** are called I (isotropic) bands because they are non-polarizing.

iii) Each A band has a lighter strip in its midsection called ***H-zone*** (H for 'hele' meaning bright).

iv) The H-zone is bisected by dark line called ***M-line***.

v) The I bands have mid-line called ***Z-line*** (Z for 'zwish' meaning between).

5) Myofilaments

Each myofibril is composed of alternate light and dark bands constituting thick and thin filaments.

i) Thick Filament

- It extends the entire length of ***A band***.
- It is made up of ***myosin***.
- It is about ***16 nm*** in diameter.
- Each myosin molecule has tail terminating in two globular heads. Myosin tail consists of two long polypeptide chains coiled together. The heads are sometimes called ***cross-bridges*** because they link thick and thin myofilaments during contraction.
- Each myosin filament is surrounded by six actin filaments on each side.

ii) Thin Filament

- It extends across the I band and partly into A band.
- It is made up of actin molecule.
- It is about ***7-8 nm*** diameter.
- The actin molecules are arranged in two chains, which are twisted around each other like twisted double strand of pearls.
- Twisting around the actin chains are two strands of another protein, called ***tropomyosin***.
- Another major protein in thin filament is ***troponin***. It is actually three polypeptide complex;

i) One binds to actin
ii) Second binds to tropomyosin
iii) Third binds calcium ions.

6) T-Tubule, Triad & Sarcoplasmic Reticulum

- Endoplasmic reticulum present in muscle fiber is called ***sarcoplasmic reticulum***.
- Sarcolemma forms an invagination at Z-line. This is called ***T-tubule***. Thousands of T-tubules of each muscle cell are collectively called ***T-system***.
- T-tubule alongwith its adjacent terminals of sarcoplasmic reticulum is called ***triad***.
- Sarcoplasmic Reticulum (S.R) is continuous system of sarco-tubules extending throughout the sarcoplasm around each myofibril. It is like endoplasmic reticulum but devoid of ribosomes and exhibits a highly specialized repeating pattern.

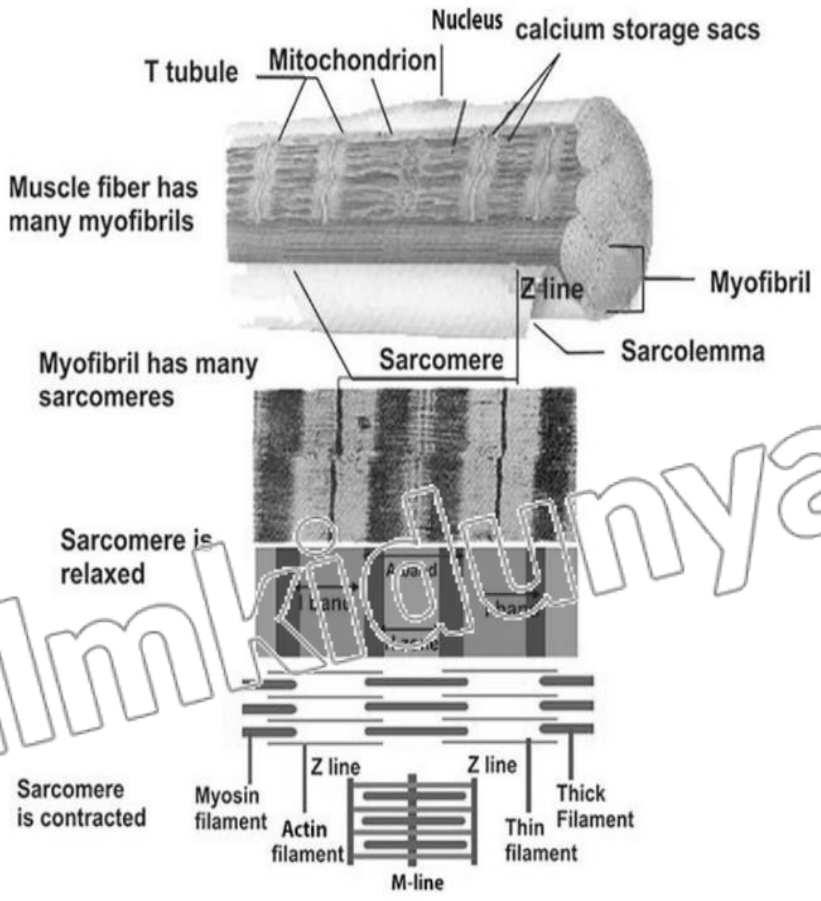

Fig.16.8 Ultrastructure of skeletal muscle fiber

16.8.5 Mechanism of Muscle Contraction

Sliding Filament Model

Sliding filament model of muscle contraction was presented by ***H.H uxley*** & ***A.F. Huxley***. According to this theory, "the thin filaments (actin) slide past the thick filaments (myosin) so that actin and myosin filaments overlap to greater degree'. Thus

- Z-lines are brought close together.
- I-bands shorten.
- H-zone disappears.

In this mechanism, cross bridges of thick filaments become attached to binding sites on the actin filament. The cross bridges then contract to pull the actin filament towards center of sarcomere.

QUESTIONS RELATED TO ABOVE ARTICLE

Give structure of skeletal muscle.
Give a detailed note on sliding filament model.
Give sliding filament model for muscle contraction.
Describe the structure of a skeletal muscle fibre. (GRW 2017)
What is the sliding filament model of muscle contraction? What does it explain? (LHR 2018)
Explain sliding filament model. How the bridges are controlled? (LHR 2019)
What are skeletal muscles? Discuss their structure in detail. (SWL 2021)
List the major parts of skeletal muscle fibre and write the function of each part. (BWP 2022)
What is the sliding filament model? What does it explain? (Exercise Question ii)

Controlling the Cross Bridges

- **When muscle is at rest**

Tropomyosin is disposed in such a way that it covers the sites on the actin chain where the head of myosin becomes attach.

- **When muscle is required to contract**

i) Calcium ions bind with troponin molecules and cause them to move slightly.
ii) It displaces the tropomyosin and exposes binding site for myosin head.
iii) Myosin head is attached to actin filaments, ATP is hydrolyzed and bridge goes to its cycle. This ATP is provided by large number of mitochondria present in each muscle cell. Above description shows that ATP is needed to break link between the Myosin Bridge and actin.

After death, the amount of ATP in the body falls and thus cross bridges cannot be broken and so they remain firmly bound. This results in the body becoming stiff, a condition known as ***rigor mortis***.

Control of Actin-Myosin Interaction by Ca^{++} Ions

Muscle contraction is initiated by nerve impulse arriving at the neuromuscular junction. All the fibers innervated by a single ***motor neuron*** constitute a 'motor unit' and contract simultaneously in response to action potential fired by motor neurons.

Different steps involved are;

i) Nerve impulse spreads over the sarcolemma of muscle fiber.
ii) Nerve impulse is carried through T-tubule to sarcoplasmic reticulum.
iii) Sarcoplasmic reticulum secretes Ca^{++} ions into the cytosol.
iv) Ca^{++} ions bind with troponin.
v) Tropinin displaces tropomyosin.
vi) Binding sites are exposed and cross bridges with myosin develop, which result in contraction.

All or None Response

Muscle contraction is based on 'all or none principle'. According to it a muscle fiber contracts, all of its myofibrils participate in contraction.

The degree of contraction depends upon the number of fibers that participate in contraction.

Energy for Muscle Contraction

Energy for muscle contraction comes from ATP.

- Stored glycogen in muscle cells produces glucose. Aerobic breakdown of glucose in muscle cells produces ATP.
- When more energy is required due to high metabolism, it is provided by another energy storing substance called creatine phosphate.
- Sometimes at high metabolism, ATPs are provided by anaerobic breakdown of glucose into lactic acid. Lactic acid accumulation causes muscle fatigue. At rest, 1/5 lactic acid is broken aerobically. Energy of this breakdown is used to change remaining 4/5 lactic acid into glucose.

Effect of Exercise on Muscle

When muscles work actively and continuously, they increase in size or strength and become more efficient and fatigue resistant.

Aerobic exercises such as swimming, jogging and fast walking result in several changes in skeletal muscles.

Different changes due to which muscle strengthening occurs are as follows.

i) Capillaries surrounding muscle fibers increase taking more nutrients.

ii) Mitochondria increase in number.

iii) Muscle fibers synthesize more myoglobin.

These changes make muscle more efficient and fatigue resistant.

Complete immobilization of muscle leads to muscle weakness and severe atrophy.

16.8.6 Problems Related To Muscles

1) Muscle Fatigue

Definition

It is a state of physiological inability to contract.

Cause

Muscle fatigue is mainly caused by

- Deficiency of ATP
- Excess accumulation of lactic acid
- Ionic imbalance

Mechanism

- When no ATP is available, contractures or states of continuous contractions result because the cross bridges are unable to detach.
- Lactic acid, which causes muscle pH to drop and muscle to ache, causes extreme fatigue by breaking glucose.

2) Tetany

Definition

Condition related with twitching and convulsions of muscles is called tetany.

Cause

Major cause is low calcium level in blood.

Mechanism

Low calcium level first causes excitability of neurons and results in loss of sensations. If tetany is untreated, system progresses to spasm of larynx, respiratory paralysis and ultimately death occur.

3) Cramp

Definition

Tetanic contraction of entire muscle is called cramp.

Cause

Major causes of cramp are

- Low blood sugar level.
- Electrolyte depletion
- Dehydration
- Irritability of spinal cord and neurons.

4) Tetanus

Definition

It is an infectious disease resulting in persistent painful spasm of some skeletal muscles.

Cause

Major cause is anaerobic bacterium *Clostridium tetani*.

Mechanism

This disease usually starts with stiffness of jaws and neck muscles and progresses to fixed rigidity of jaws ***(*lock jaw*)*** and spasm of trunk and limb muscles. This disease becomes fatal when involves respiratory muscles leading to respiratory failure.

This disease is rare in developed countries and major killer in developing countries where the mortality rate is 40%.

QUESTIONS RELATED TO ABOVE ARTICLE

Explain the following conditions. Muscle fatigue, tetany, tetanus, cramp.

16.9 ARRANGEMENT OF SKELETAL MUSCLES FOR SKELETON MOVEMENT

Parts of Muscle

A skeletal muscle has three parts;

i) Origin

It is the end of muscle, which remains fix when muscle contracts.

ii) Insertion

It is the end of muscle that moves the bone.

iii) Belly

It is the thick part of muscle between origin and insertion. It is the part, which shows contraction.

Examples of Skeletal Muscles

- Biceps brachii muscle arises by two heads from scapula and is inserted into the medial surface of radius bone.
- Brachialis takes origin from humerus and is inserted on ulna.
- Brachioradialus takes origin from humerus and is inserted on lateral side of radius.
- Triceps takes origin by three heads from scapula and humerus and is inserted on olecranon process of ulna.

Role of Connective Tissue in Musculoskeletal System

Connective tissue binds other tissues and helps to maintain body form by holding the various organs together.

Connective tissue fibrils have two specialized kinds.

i) Ligaments

These attach bone to bone and are slightly elastic.

ii) Tendons

These attach muscles to bones and are non-elastic.

16.9.1 Movement of Bones

- Majority of muscles tissues in our body is of skeletal muscles.
- Muscles produce movements by pulling bones through tendons.
- Most muscles pass cross joints and are attached at bones forming joints. When these muscles contract, movements are produced at joints.

Levered movement. Rigid external or internal skeletons are attached to muscles, which move parts of the skeleton at movable joints. Each bony "lever" is moved by an antagonistic muscle pair. One muscle reverses the action of the other, so that the lever can return to its original position.

Antagonistic Arrangement of Muscles

Such arrangement of muscles in which when one member of pair contracts, other relaxes and vice versa is called antagonistic arrangement of muscles.

At joints, these muscles work against each other by contraction. In this arrangement, one muscle reverses the effect of the other but does not contract simultaneously.

Out of total 650 muscles in human body, most of which occur in such pairs.

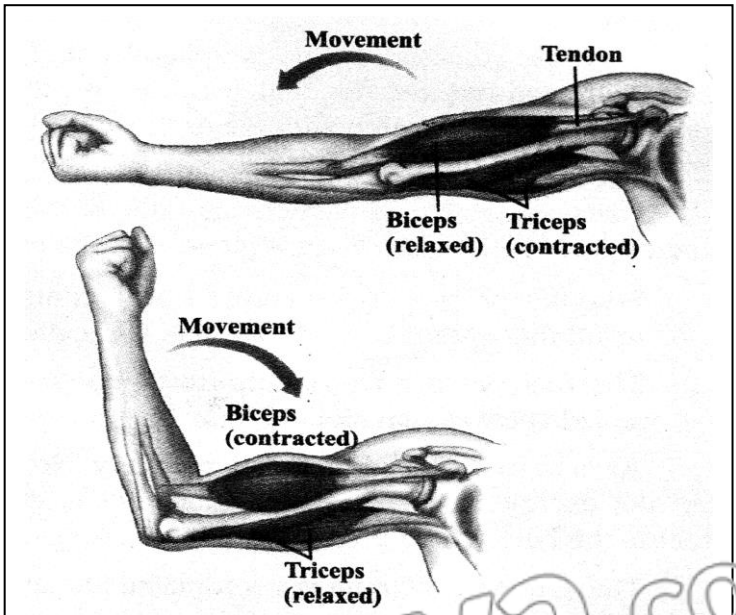

Fig.16.9 Working of hinge joint at elbow

Example

Best example of movement by antagonistic muscles is the movement of elbow joint by flexors (Biceps, Brachialis and Brachioradialis) and extensors (Triceps).

Biceps is superior muscle while brachialis and brachioradialis lie below biceps.

- When biceps, brachialis and brachioradialis contract, they lift radius and ulna and bend the arm at elbow.
- When triceps contracts, it straightens the arm at elbow.

QUESTIONS RELATED TO ABOVE ARTICLE

What are antagonistic muscles? Explain its working with the example of muscles at elbow joints.

Define Antagonism. Discuss the case of Elbow joint with their phenomenon.

(GRW 2019)

Describe a hinge joint and how it is moved by antagonistic muscles.

(Exercise Question iii)

16.10 LOCOMOTION IN PROTOCTISTA AND INVERTEBRATES

There is an immense variety of organisms with different mode of locomotion.

LOCOMOTION IN UNICELLULAR ANIMALS

16.10.1 Locomotion in *Euglena*

Introduction

Euglena is a protist. The characteristic movement of euglena is called euglenoid movement.

Locomotory Structure

Locomotion in euglena is brought about by whipping action of single ***flagellum*** located at anterior end. Euglena is able to change its direction by the active contractile ***myonemes***, which run along the length of its body.

Mechanism

- When flagellum moves backward, euglena moves forward but when flagellum moves forward, euglena does not move backward.
- Wave of activity is generated by flagellum itself and it passes in spiral fashion from its base to its tip. During this passage amplitude and velocity is increased.
- This movement of flagellum also causes euglena to rotate forward about its axis.
- Change in direction is caused by active contractile myonemes. When they contract, the shape of the body is changed as well as its direction. First body becomes short and wider at the anterior end then in middle and later at the posterior end.

16.10.2 Locomotion in Paramecium

Introduction

Paramecium is unicellular ciliate belonging to kingdom Protista. Movement in paramecium is called ***ciliary movement***.

Locomotory Structure

Paramecium moves with the help of cilia.

- Cilia are short, fine thread-like extensions of cell membrane.
- Length of cilia ranges from many microns to many hundred microns.
- Diameter of cilia ranges from 0.1 to 0.5 microns.

Structure of Cilium

- A cilium consists of nine peripheral double fibrils giving the appearance of 8-shape figure and two central smaller fibrils.
- All these fibrils run longitudinally through the cilium.
- These are covered with the extensions of membrane.

Mechanism

- The exact mechanism of movement of cilia is not known. However in 1955 ***Bradford*** suggested that movement of cilia is due to simultaneous contraction or sliding of double fibrils in two groups one after the other.

i) Five out of nine (5/9) double fibrils contract or slide simultaneously and bend or shorten cilium. It is called ***effective stroke***.

ii) Four out of nine double fibrils (4/9) contract and cilium becomes straight. It is called ***recovery stroke***.

- Energy for movement of cilia is provided from ATP. Enzyme present in cilia break up ATP to release energy.
- All the cilia do not move simultaneously, a bunch of cilia move in a progressive wave-like manner at a time. The wave starts at the anterior end and progresses in the backward. The action of cilia is coordinated and they beat together in a sequence to propel the animal in one direction.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe locomotion in Paramecium. (SGD 2019)

16.10.3 Locomotion in *Amoeba*

Introduction

Amoeba is unicellular organism belonging to phylum protozoa of kingdom protista.

Locomotory Structure

In amoeba, movement takes place by means of ***pseudopodia***.

Pseudopodia are finger like projections thrown in the direction of movement in which the cytoplasm flows and body moves in that direction.

Mechanism

The exact mechanism of pseudopodia is still debatable.

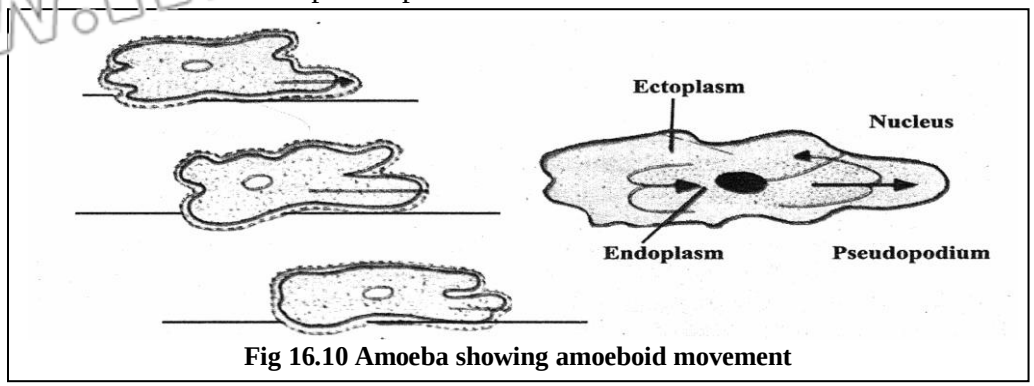

Fig 16.10 Amoeba showing amoeboid movement

QUESTIONS RELATED TO ABOVE ARTICLE

Explain locomotion in Amoeba.

LOCOMOTION IN SIMPLE MULTICELLULAR ANIMALS

16.10.4 Locomotion in Jelly Fish

Introduction

Jelly fish belongs to phylum coelenterata. It has an umbrella-like body called ***bell***.

Mode of Locomotion

Movement of Jelly fish is known as ***jet propulsion***.

Locomotory Organs

Muscles are involved along with hydrostatic pressure of water.

Mechanism

First water enters in the bell. Then bell contracts and water is forced out like a jet and the animal moves forward.

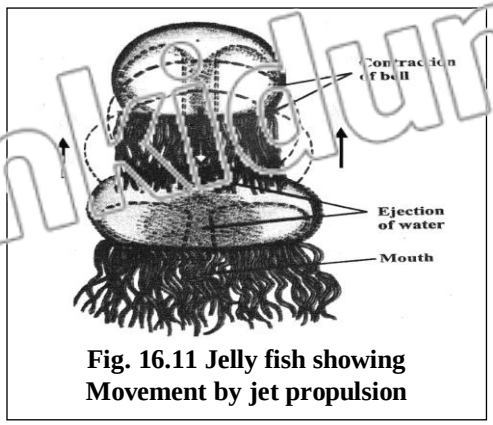

Fig. 16.11 Jelly fish showing Movement by jet propulsion

QUESTIONS RELATED TO ABOVE ARTICLE

Explain locomotion in jellyfish.

16.10.5 Locomotion in Earthworm

Introduction

Earthworm is an annelid (segmented worm).

Mode of Locomotion

Earthworm shows **accordion-like** movement.

Locomotory Organs

Both setae and muscles are involved.

Mechanism

Different steps occurring during locomotion are as follows

i) Earthworm becomes long and thin. The setae present on the lower side of anterior end come out, anchor and hold this end firmly.

ii) Now longitudinal muscles contract and circular muscles relax and body shortens thus pulling this portion forward.

iii) Then setae of posterior end come out and fix the animal on the ground.

iv) Now circular muscles contract, longitudinal muscles relax and body becomes thin and long.

In this way, earthworm moves from one place to the other.

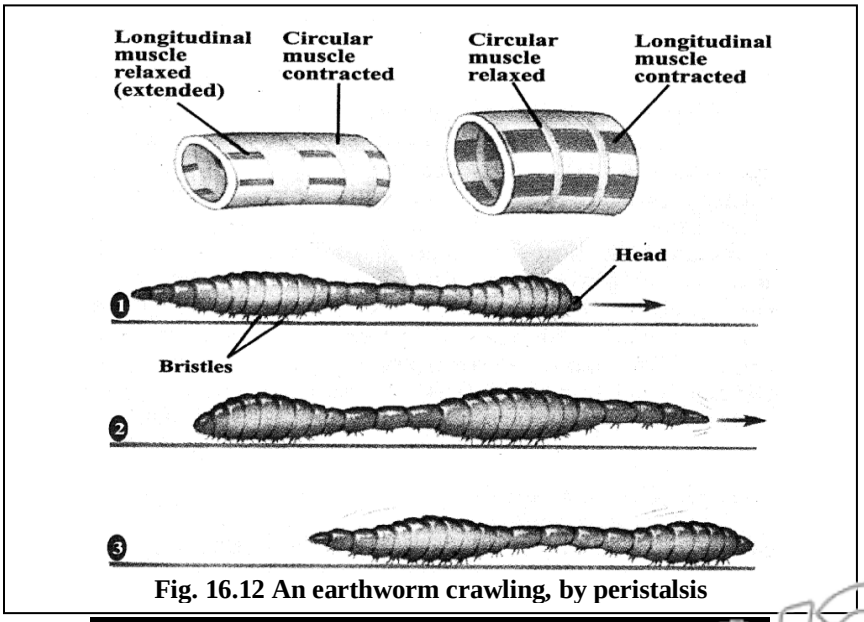

Fig. 16.12 An earthworm crawling, by peristalsis

QUESTIONS RELATED TO ABOVE ARTICLE

Explain locomotion in Earthworm.

16.10.6 Locomotion in Cockroach

Introduction

Cockroach is an insect belonging to phylum Arthropoda.

Mode of Locomotion

Mode of locomotion in cockroach is swift walking and flying.

Locomotory Organs

Locomotory organs for walking are legs and for flying are wings.

Mechanism of Walking

In walking, the legs are used on one side. The foreleg pulls the body forwards and hind leg pushes it in same direction. The middle leg of the opposite side acts as prop (lever). In the mean time, remaining three legs begins to move together and the process is repeated.

Mechanism of Flying

Out of the two pairs, the posterior pair of wings brings about the flight. These bear in air in such a manner that they support the body weight and drive it through the air.

16.10.7 Locomotion in Snail

Snails and mussels are molusks, which crawl or move very slowly by 'foot'.

16.10.8 Locomotion in Starfish

Introduction

Starfish belongs to phylum Echinodermata.

Locomotory Organ

Star fish move with help of tube feet. Tube feet are present on both sides of radial canal that extend upto tip of arm.

Mechanism

Tube feet extend when water is pumped into them. Then they fix themselves by suction cup with some object. Later on they shorten and pull the body in that direction.

In this way starfish moves in any direction.

Arms of the starfish also help in swimming.

16.11 LOCOMOTION AND SKELETON IN VERTEBRATES

In vertebrates, skeletal muscles and skeleton help in locomotion.

16.11.1 Swimming in Fishes

Swimming in water presents very different problems from walking on land like man or flying in air like bird.

Adaptation for Swimming

Different adaptations developed by fishes are described below.

1) Streamlined Body

Body of most of the fishes is streamlined, being tapered at both ends. Due to it water flows readily over the body surface and dragging is reduced to a minimum. Only fins project outward from the body.

It should be remembered that faster the fish is, more perfect is the streamlined.

2) Moist Scales

Dermal denticles of cartilaginous fish and scales of bony fish are kept moist by slimy exudation from mucous or oil glands. It considerably reduces friction between fish and water.

3) Fins

- Dorsal and ventral unpaired fins help to stabilize the fish.
- Paired pectoral and pelvic fins are used for steering and balancing the animals.
- Caudal or tail fins, in coordination with paired fins, provide forward movement of fish through water.

4) Air Bladder

Swim bladder in bony fishes provides buoyancy to them in water.

QUESTIONS RELATED TO ABOVE ARTICLE

Explain different swimming adaptations in fishes.

16.11.2 Locomotion in Amphibians

Their body is generally fish-like. They have two means of locomotion.

- They wriggle along the belly on the ground with the help of segmentally arranged muscles as it 'swims on land'.
- Few raise up their body on the legs which then propel them along as movable levers.

In ***anurans***, the entire skeleton and muscular system has become specialized for the peculiar swimming and jumping methods of locomotion by means of extensor thrust of both kinds of limbs acting together.

Frogs and toads also walk and hop on land due to their strong hind limbs.

QUESTIONS RELATED TO ABOVE ARTICLE

Write note on locomotion in Amphibians.

16.11.3 Locomotion in Reptiles

They move better than amphibians due to evolution of skeleton. They use method of walking and running.

Prehistoric Reptiles

Many prehistoric reptiles were bipedal i.e. they walked on hind limbs.

- They had a narrow pelvis and heavy outstretched tail for balance.
- Their front appendages were free to capture prey or fight with other animals.

Evolutionary Changes in Skeleton

i) Skeleton is highly ossified to provide greater support.

ii) They have cervical vertebrae. First two cervical vertebrae (atlas & axis) provide greater freedom of movement for head. The axis is modified for rotational movement.

iii) Ribs are highly modified. In snake, they have muscular connections to large belly scales to aid locomotion.

QUESTIONS RELATED TO ABOVE ARTICLE

Explain locomotion in Reptiles.

16.11.4 Locomotion in Air

The skeleton of birds is modified for flight.

Evolutionary Adaptations in Birds

i) They have bones with large air spaces which make them lighter.

ii) Forelimbs evolved into wings with very strong pectoral muscles, which pull the wings up and down.

iii) Sternum is modified to form keel. Keel is needed for the attachment of muscles.

iv) Body is covered with feathers which gives the wing a large surface area to keep the bird in air. They also keep their bodies warm, so that they can produce enough energy to fly.

v) The body is streamlined to reduce resistance of air. Feathers lie smoothly against body.

Mechanism of Flight in Birds

A bird can fly either passively by gliding or actively by flapping of wings.

A) Passive Flight

When birds glide, the wings act as aerofoil (An ***aerofoil*** is any smooth surface which moves through air at an angle to the air-stream).

The air flows over the wings in such a way that the bird is given lift. The amount of lift depends on the angle at which wing is held relative to the air-stream.

B) Active Flight

It occurs with flapping of wings. During lift air flows more quickly over curved upper surface of body.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe locomotion in air. (GRW 2018)

Discuss methods of locomotion in fish, land vertebrates and birds.

(Exercise Question xiv)

16.11.5 Locomotion in Mammals

They have most efficient way of support to body.

Modes of Locomotion

Mammals have following modes of locomotion due to modification in limbs.

1) Plantigrade

- Such mode of locomotion in which mammals walk on their sole with palm, wrist and digits all resting more or less on ground is called plantigrade.
- Examples are monkeys, apes, man and bear.

2) Digitigrade

- Such mode of locomotion in which mammals tend to walk on their digits only is called digitigrade.
- In them first digits is usually reduced or completely lost.
- They run faster than plantigrade.
- Examples are rabbits and rodents.

3) Unguligrade

- Such mode of locomotion in which mammals walk on the tips of toes modified into hoof is called unguligrade.
- It is the most swift type of locomotion.
- Examples are deer and goat.

QUESTIONS RELATED TO ABOVE ARTICLE

Give different types of locomotion in mammals.

16.11.6 Evolutionary changes in the arrangement of bones and related mode of locomotion in major groups of vertebrates

All vertebrates have common body plan with many differences in skeleton due to changes in habitat.

Adaptation in Fishes

Most fishes are propelled forward by means of muscle contraction which pass along the body from anterior to posterior producing a characteristic S-band locomotion, due to alternate contractions on both sides producing lashing movements which drive the fish forward through the water.

This type of locomotion is seen in cartilaginous fishes like dog fish and sharks.

Adaptations in Tetrapods (Amphibians and Reptiles)

In them legs emerge from the sides of the body and S-wriggle is retained as a part of the body. Girdle and limbs of tetrapods show clear cut homologies in fundamental structure.

- Tetrapod pelvic girdle is firmly attached to sacral region of the vertebral column.
- It is associated with three cartilaginous bones i.e. ilium, ischium & pubis.
- Acetabulum is located at junction of these bones which has articular surface for femur.
- Limbs (forelimb & hindlimb) are fundamentally similar.

Adaptations in Mammals

- In them legs project beneath the body providing more effective support.
- In running mammals e.g. horse, stride length and power are increased by arching the spine first upward with the limbs fully extended. In this way, the force produced by the back muscles is transmitted to ground.

Adaptations for flying in flying Vertebrates

Flight has evolved in three types of vertebrate i.e.

- Pterodactyls
- Birds
- Bats

➢ Flying requires more muscular effort than swimming and walking or running. They have wings with powerful pectoral muscles. Lifting action is possible because the tendon of the supra-coracoid muscle passes through an opening ***'the foramen triosseum'*** formed between the scapula, coracoid and clavicle bones and is attached to the upper surface of humerus.

➢ They have decreased number of bones and many are fused to increased strength.

➢ Shape of wings also influences speed and type of flight. For example long, narrow wings (gulls, sea birds) are ideal for gliding in air. Short, bread wings (garden birds) are effective for slow flapping flight. Bats have different bone pattern but same adaptation for flight.

QUESTIONS RELATED TO ABOVE ARTICLE

Write the major evolutionary adaptation in the lines of tetrapod. (Exercise Question vii)

KEY POINTS

Collagen

The collagen is an inelastic protein present in the collagen fibers whereas the collagen fibers are connective tissues in which fibers are suspended in the matrix of collagen protein.

Ligament

The two bones are attached at joint by ligament.

Types of arthritis

There are three type of arthritis.

(1) Osteoarthritis

It is a common type of arthritis. It mostly occurs in person with heavy body and older person. Mostly weight bearing joints like knee joints are affected by this arthritis. It can be simply treated by reducing the body weight or using of painkiller medicines.

(2) Rheumatic arthritis

It is chronic arthritis. It is causes by autoimmune reaction. The immune system of the body destroys the cartilage over bones of joint. Thus bones of joints become naked. These rub each other. Thus it causes inflammation of joint. It causes severe pain. This arthritis cannot be cured permanently. The painkillers give timely relief.

(3) Gouty arthritis

It is caused due to increase of uric acid level in blood. This uric acid deposits in the joint and causes extreme swelling and pain. It can be controlled by not using the diet rich in uric acid. Antiuric acid tablets can easily reduce the uric acid level in the blood.

Estrogen Replacement therapy (ERT)

In this case, the old female are given estrogen hormone regularly it reduces the deposition of calcium from the bone.

Myonemes in Euglena

The pellicle or body wall of euglena is divided into plates. These plates overlap each other. These overlapping plates are called Myonemes.

Flexor Muscles

Muscles that decrease the angle between bones on each side of a joint. They help in bending the elbow or knee. Flexors of forearm at elbow are: Brachialis, Brachioradialis and Biceps brachii.

EXERCISE

Q 1
Fill in the blanks.

i) Each muscle is enclosed by a membrane known as _____.
ii) Osteoporosis is caused by the decrease in the level of _____.
iii) The "molting" is controlled by a hormone _____.
iv) _____ is stored in the muscle cell as reserve food.
v) Collenchyma cells lack _____ in their primary wall.
vi) There are _____ vertebrae in the neck region of mammals.
vii) The most abundant protein in the muscle is _____.
viii) _____ connect a muscle to a bone.
ix) Thick muscle filament is composed of _____.

Ans

i) Epimysium
ii) Estrogen
iii) Ecdysone
iv) Glycogen
v) Secondary wall
vi) 7
vii) Actin & myosin
viii) Tendon
ix) Myosin

Q 2 **Write whether the statement is true or false and write the correct statement if false.**

i) The shoulder joint is a hinge joint. **(False)**
The shoulder joint is a ball & socket joint.
ii) Tendons connect bones together at joint **(False)**
Ligaments connect bones together at joint.
iii) Arthritis often accompanies aging. **(True)**
iv) Calcium provides energy to the muscle contraction. **(False)**
ATP provides energy to the muscle contraction
v) Most of the sclerenchymatous cells are non-living. **(Ture)**
vi) Visceral muscles are striated, involuntary and smooth. **(Flase)**
Visceral muscles are non-striated, involuntary and smooth

Q 3 **Each question has four options. Encircle the correct answer.**

i) **Which of these is a direct source of energy for muscle contraction?**
(a) ATP
(b) Creatine phosphate
(c) Lactic acid
(d) Both a and b

ii) **When muscle contracts?**
(a) Sarcomere increases in size
(b) Actin filament slides past myosin filament
(c) Lactic acid is produced
(d) Both a and b

iii) **Which of the following changes occur when skeletal muscle contracts?**
(a) The A band shortens
(b) The I band shortens
(c) The Z line slide farther apart
(d) The actin filament contract

iv) **Thin filament in myofibrils consist of:**
(a) Actin, tropomyosin, troponin
(b) Only actin
(c) Myosin
(d) Sarcomere

v) **The contraction of striated muscle is initiated by the release of energy in the presence of:**
(a) Acetyl choline
(b) Calcium ion
(c) Chloride ion
(d) Iron

vi) In the mammalian skeleton there is a distinct synovial joint between the:
(a) Bones of the cranium
(b) Humerus and ulna
(c) Sacrum and ilium
(d) Sternum and floating ribs

vii) Which of the following is a bone of axial skeleton?
(a) Rib
(b) Shoulder girdle
(c) Pelvis
(d) Femur

viii) Vertebral column includes:
(a) Sacrum
(b) The coccyx
(c) Cervical, thoracic and lumbar vertebrae
(d) All of the above

ix) In mammals the number of cervical vertebrae are:
(a) No definite number
(b) Seven
(c) Eleven
(d) Varies with the size of neck

x) Brain is protected by:
(a) Cranium
(b) Skull
(c) Orbits
(d) All of the above

xi) Which of the following is plantigrade?
(a) Rabbit
(b) Monkey
(c) Horse
(d) Carnivores

xii) Brachioradialis causes the up lift of:
(a) Radius
(b) Ulna
(c) Both a and b
(d) Humerus

xiii) Moultingecdysis occurs in arthropods at the:
(a) Immature stage
(b) Mature stage
(c) Both stages
(d) Do not undergo moulting

xiv) Muscle fatigue is caused by:
(a) CO_2
(b) The accumulation of Lactic acid
(c) Fumaric acid
(d) Ethyl alcohol

xv) Cardiac muscles are:
(a) Voluntary
(b) Involuntary
(c) Both a and b
(d) None of these

Answer key

i	**d**	**vi**	**b**	**xi**	**b**
ii	**b**	**vii**	**a**	**xii**	**a**
iii	**b**	**viii**	**d**	**xiii**	**a**
iv	**a**	**ix**	**b**	**xiv**	**b**
v	**b**	**x**	**a**	**xv**	**b**

Q 4 Short Questions.

i) What is the cause of cramp?

Ans. It is caused by:
- Low blood sugar level.
- Electrolyte depletion.
- Dehydration
- Irritability of spinal cord and neurons.

ii) What is difference between tetanus and muscle tetany?

Tetanus	Tetany
It is an infectious disorder.	It is a biochemical disorder.
It is caused by *Clostridium tetani*.	It is caused by hypocalcemia.
It results in painful spasms of some skeletal muscles.	It results in loss of sensation, muscle twitching and convulsions.
It can be fatal due to respiratory failure.	If untreated, it leads to spasm of larynx, respiratory paralysis and ultimately death.

iii) What is Ligament?

Ans. Ligaments: It is a form of connective tissue that attaches bone to bone and is slightly elastic.

iv) What is nutation?

Ans. Growth of tip of young stem in a zigzag fashion due to alternate changes in growth on opposite side of the apex is called nutation.

v) How many ribs do not attach with the sternum?

Ans. Last four ribs or lower two pairs of ribs do not attach to sternum. These ribs are known as floating ribs.

vi) How is rickets produced?

Ans. It is usually produced due to calcium or vitamin D deficiency in children. It is treated by vitamin D fortified milk and sun exposure.

vii) What is the cause of tetanus?

Ans. The term tetanus is used for an acute infectious disease caused by anaerobic bacterium *Clostridium tetani* resulting in persistent painful spasms of some skeletal muscles.

viii) How is muscle fatigue produced?

Ans. Muscle fatigue is a state of physiological inability to contract. Muscle fatigue results from relative deficit of ATP. When no ATP is available, contractures or states of continuous contraction result because the cross bridges are unable to detach. Excess accumulation of lactic acid and ionic imbalance also contribute to muscle fatigue. Lactic acid, which causes muscle pH to drop (and the muscle to ache) causes extreme fatigue by breaking glucose.

ix) Distinguish between the following.

Axial skeletal	Appendicular
The axial skeleton includes the skull, the vertebrae, ribs and sternum.	Appendicular skeleton consists of pectoral girdle and appendages (fore limbs), and pelvic girdle and appendages (hind limbs).
Phototactic stimulus	**Chemotactic stimulus**
The movements of entire cell or organism in response to stimulus of light.	The movements of entire cell or organism in response to stimulus of chemicals.
Example: Passive movement of chloroplast due to cyclosis.	**Example:** Movements shown by sperms of liverworts, mosses, ferns towards archegonia.
Osteocytes	**Osteoblasts**
These are the mature bone cells.	These are the bone forming cells. These replace cartilage with bone once it is dissolved by osteoclasts.
Brachialis	**Brachioradialis**
The muscle below bicep brachi involved in flexion. They are inserted in ulna.	The muscle below bicep brachi involved in flexion. These are inserted in radius.
Origin	**Insertion**
The end of muscle which remains fixed when muscle contract.	The end of the muscle that moves the bone when muscle contract.
Bone	**Cartilage**
It is the most rigid form of connective tissue. The collagen fibers of bone are hardened by deposition of calcium phosphate. Bones supporting your arms and legs consists of an outer shell of compact bone, the spongy bone in the interior. Blood vessels can pass through spongy bone.	It is much softer than bone. It covers ends of the bone at joints and also supports the flexible portion of nose and ears. No blood vessels penetrate into the cartilage.
Troponin	**Tropomyosin**
A major protein in thin filament bound to tropomyosin. It is actually a three polypeptide complex, one binds to actin, another binds to tropomyosin and third binds calcium ions.	One of the major muscle proteins, twisting around the actin chains in the form of two strands.

Q 5 Extensive Questions.

i) What are the disadvantages of exoskeleton?

Ans (see article 16.4.2)

ii) What is the sliding filament model? What does it explain?

Ans (see article 16.8.5)

iii) Describe a hinge joint and how it is moved by antagonistic muscles?

Ans (see article 16.9.1)

iv) Define joints? How they are classified? Explain.

Ans (see article 16.5.3)

v) Explain appendicular skeleton with the help of a diagram.

Ans (see article 16.5.2)

vi) Draw and label the human skull.

Ans (see diagram 16.5)

vii) Write the major evolutionary adaptation in the lines of tetrapod.

Ans (see article 16.11.6)

viii) Define secondary growth. Explain its significance.

Ans (see article 16.2.1)

ix) What are the main differences between exoskeleton and endoskeleton?

Ans (see article 16.4.2-16.4.3)

x) List the functions of skeleton.

Ans (see article 16.4)

xi) Explain the role of osteoclast in remodling of bone and describe the structure of compact bone.

Ans (see article 16.7-16.4.3)

xii) List the main parts of axial skeleton.

Ans (see article 16.5.1)

xiii) Distinguish between fibrous, cartilaginous and synovial joints.

Ans (see article 16.5.3)

xiv) Discuss methods of locomotion in fish, land vertebrates and birds.

Ans (see article 16.11.1-16.11.5)