Locomotion and Movement

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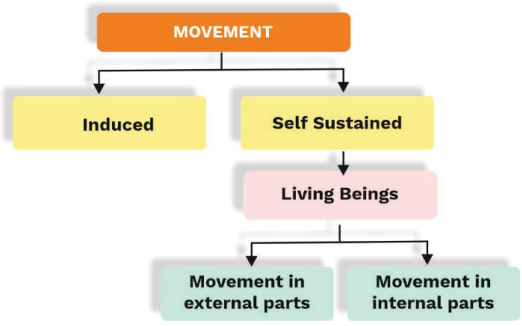
Locomotion and Movement

- Movement is one of the significant characteristics of living organisms.
- An act of moving an external body part (change in posture) or an internal body part by applying an internal force, i.e., force generated within the body of an organism is called **movement** (vital movement).
- Movement of the fingers for writing, forward bending of the spine to pick an object, clapping, facial muscle movements for expression of emotions, etc., are some of the examples of movement in external body parts, whereas movement in the wall of alimentary canal for forward pushing of food, movement of thoracic chamber during ventilation, movement of the wall of uterus during parturition, etc., are some examples involving movement of internal body parts in human beings.
- Non-living objects also show movements. But these movements are induced or imposed on them, i.e., movements of non-living objects occur due to external forces applied on them, e.g., movement of an automobile is induced by its engine, movement of wet clothes on a wire by wind, movement of a toy by batteries, etc.
- A change in location of an organism, i.e., **locomotion** is possible only by movement of either external body parts (hind limbs in human beings) or locomotory organelles (cilia in *Paramecium* and flagella in *Euglena*). Locomotion is essential for an organism to perform various activities like finding food, shelter or mate, escaping from predators, seasonal migration etc.
- Thus, movement is possible without locomotion, but locomotion is not possible without movement.

Definition

Movement (in living organisms): An act of moving an internal or external body part is called movement.



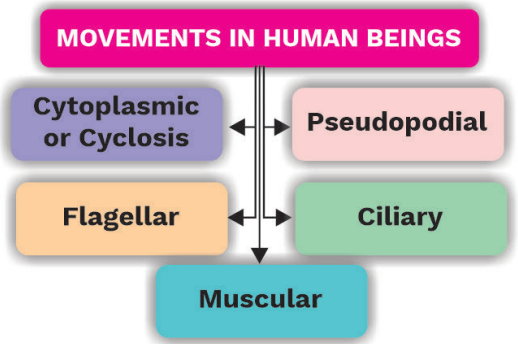
Definition

Locomotion: An act of change in an organism's location is called locomotion.

TYPES OF MOVEMENT IN HUMAN BEINGS

The following types of movements are shown by different cells in the human body:

- **Cytoplasmic Movement or Cyclosis**
  - Materials involved in metabolic reactions are distributed inside a eukaryotic cell due to continuous movement of its cytoplasm.
  - Activities of cytoskeletal elements like microtubules, actin filaments and intermediate filaments and changes in the **sol-gel state** within the cell are responsible for this movement.
  - Such cytoplasmic movement or **streaming** also helps in the change of shape of the cell by generating pseudopodia.
- **Pseudopodial Movement**
  - Outward extensions of the cell membrane along with the cytoplasm in a eukaryotic cell make structures called as **pseudopodia** (false feet).
  - These pseudopodia are responsible for locomotion and movements related to capturing of foreign bodies in many human cells like **macrophages** and **neutrophils** (phagocytes).
  - Pseudopodial movement is also called **amoeboid movement** as locomotion and food capture in *Amoeba* is brought about by the generation of pseudopodia.
- **Ciliary Movement**
  - Cilia are short, hair-like locomotory organelles which occur numerously in many prokaryotic (bacteria) and eukaryotic (*Paramecium*) cells.
  - The cilia beat actively (dependent on ATPase activity) in a coordinated manner from basal body to the tip by sliding movement of microtubules in their axonemes.
  - This coordinated beating of cilia creates a current to move materials present on the luminal surface of cells in one direction.



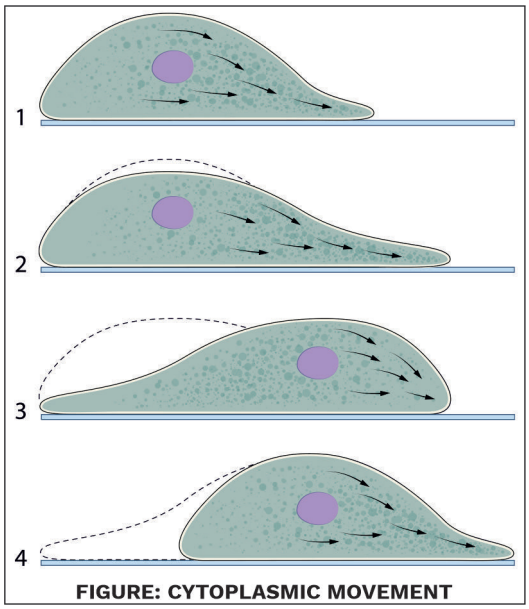


FIGURE: CYTOPLASMIC MOVEMENT

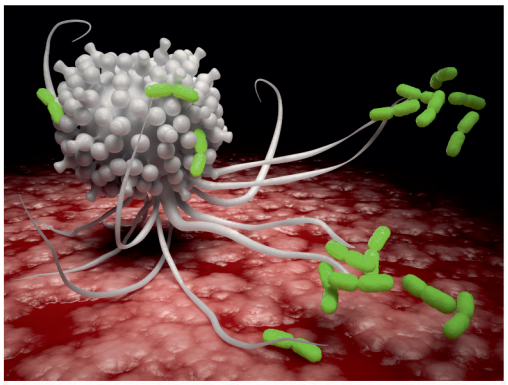


FIGURE: PSEUDOPODIAL MOVEMENT BY A MACROPHAGE

- In human body, cells containing cilia, perform a wide range of functions. The human **respiratory tract** contains about $10^7/mm^2$ of cilia which functions to clean the respiratory passage by moving the mucus (containing trapped foreign particles) in outward direction i.e., towards the nasal and oral cavity.
- **Fallopian tubes** in human females have an epithelium of ciliated and non-ciliated cells. Cilia are also found in the cells of the **endometrium**. The presence of cilia in the female reproductive tract aids in transport of secondary oocyte to the isthmus-ampullary junction (fertilisation site in fallopian tube) and in the movement of zygote towards the uterus. The **uterine cilia** help the sperms to travel up to the fallopian tubes.
- Similarly, cilia present in the **rete testis** and **vasa efferentia** of the male reproductive system helps in the movement of spermatozoa to reach epididymis.
- In the **brain ventricles,** the cerebrospinal fluid is circulated by the beating of cilia present on the surfaces of **ependymal cells.**

- **Flagellar Movement**
  - Although structurally same, flagella differ with cilia in number and size. These are long, filamentous or thread-like cell organelles which are comparatively less in number.
  - The undulating, wave-like slow flagellar movement is shown by the tail of human **sperm.** The sliding of microtubules in the axoneme of sperm's tail produces flagellar movement which gives motility to the sperms to move in the female reproductive tract.
- **Muscular Movement**
  - All **muscles** present in human body contract and relax to bring about voluntary and involuntary movement.

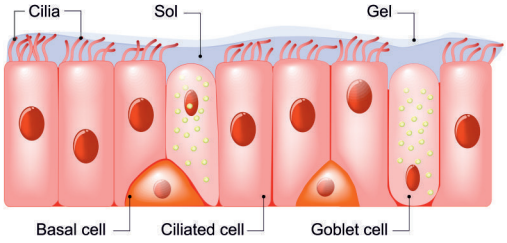


FIGURE: CILIA PRESENT IN NASAL MUCOSA

Definitions

Endometrium: Inner lining of the uterus.

Ependymal cells: Ependymal cells are ciliated squamous or columnar cells forming an epithelial layer which lines the ventricles of the brain and the central canal of the spinal cord. Ependymal cells are a type of neuroglial cells.


FIGURE: HUMAN SPERMS SHOWING FLAGELLAR MOVEMENT

THE MUSCULAR SYSTEM

- In human beings, locomotion and movement of body parts are brought about by coordinated activity of the muscular system, nervous system, and skeletal system.
- The muscular system consists of different types of muscles which work in close association with the skeletal system to produces movements like running, writing, standing, sitting, walking, bending, etc.

MUSCLES

- Muscles originate from the embryonic **mesoderm**.
- All muscles present in the muscular system are made up of specialized cells called as **muscle fibres**.
- These fibres have special properties like contractibility, excitability, and conductivity by which they bring about movement in the body.
- There are more than **600** muscles in the body contributing about **40%** of the total body weight.
- The contraction and relaxation of muscles bring about various activities in the human body like speaking, mobility of body parts, maintenance of body posture, breathing, circulation by beating of heart, vision, regulation of body temperature, urination, movement of food for digestion, childbirth, etc.

Characteristics of Muscles

- **Contractability:** A muscle fibre has an ability to contract on receiving a stimulus from a nerve. The contraction of muscles is due to the presence of contractile proteins like actin and myosin in their sarcoplasm.
- **Excitability:** The property of a muscle fibre to respond to different stimuli is called excitability. A muscle can be excited to contract by chemical, nervous, electrical or mechanical stimuli.

Gray Matter Alert!!!

- **Largest muscle:** Gluteus maximus
- **Smallest muscle:** Stapedius
- **Longest muscle:** Sartorius
- **Strongest muscle:** Masseter
- **Hardest working muscle:** Heart
- **Busiest muscle:** Extraocular muscles (eye muscles)

Gray Matter Alert!!!

Skeletal muscle fibres can stretch to as much as three times their contracted length.

- **Conductivity:** The spread of a stimulus received by a muscle fibre to all its parts is called conductivity.
- **Threshold stimulus:** To contract, a muscle fibre should receive a stimulus of a specific strength. This is called a threshold stimulus. A stimulus with lower strength or intensity than the threshold stimulus will not be able to produce contraction in a muscle.
- **Bowditch's Law (All or None Law):** According to this law, a muscle fibre will not contract on receiving a stimulus below its threshold stimulus and will show maximum contraction in response to the threshold stimulus irrespective of the strength or intensity of the stimulus. Because of this property of a muscle fibre, this law is also called as all or none law.
- **Muscle Twitch:** When stimulated by a single stimulus equivalent to or greater than the threshold stimulus, a muscle fibre shows single contraction. This quick, single contraction of a muscle fibre is called as a muscle twitch.

  A muscle twitch occurs in three phases:
  - **Latent Phase:** This period is characterised by conversion of stimulus into chemical excitation, and it's spread throughout the muscle fibre. It is about **0.01** seconds in skeletal fibres.
  - **Contraction Phase:** The period for which the muscle fibre remains contracted is called the contraction phase. It is about **0.04** seconds in skeletal muscle fibres.
  - **Relaxation Phase:** It is the period required by a muscle fibre to come back to its resting state. It is about **0.05** seconds for a skeletal muscle.
- **Refractory Period:** The resting period during which a muscle fibre does not respond to a second stimulus after the previous excitation.

Keywords

- Contractability
- Excitability
- Conductivity
- Extensibility
- Elasticity

Rack your Brain

What causes muscle twitching?

It is about **0.002-0.005** second in the skeletal muscles.

- **Summation:** On receiving a weak stimulus, the smaller **motor units** of a muscle are stimulated first as compared to the larger motor units. As the strength of the stimuli increases, larger motor units are then stimulated causing the muscle to contract. This phenomenon is called as summation or **the size principle**. This occurs because the small motor neurons in the spinal cord have more excitability than the larger motor neurons. This makes the smaller motor units contract first followed by the contraction in the larger motor units. Also, the different motor units contract alternately thus, providing smooth contraction even at low frequencies of nervous stimuli.
- **Extensibility:** The ability of muscles to get stretched to a small degree is called extensibility.
- **Elasticity:** The property of a muscle to go to its original length when relaxed is called elasticity.
- **Muscle tone or Muscle tonus:** To maintain body posture and health of a muscle, certain muscle fibres always undergo alternate contraction even in a relaxed state which creates **muscle tension** at rest. This property of muscles is called as muscle tone. It enables a muscle to respond to a stimulus quickly.
- **Tetanus (Muscle Tetanus):** When a motor nerve provides stimulus at a rapid rate to the muscle it innervates, there is a continuous or sustained contraction produced in the muscle. Such a state of contraction is called tetanus.
- **Muscle Tension:** Muscle tension is the force generated by a muscle when it contracts. There are two types of muscle tensions:
  - **Isometric Contraction:** In an isometric contraction, the muscle contracts against a **load** without shortening its length. It occurs

Previous Year's Question

The muscular contraction in which the tension remains the same and the mechanical work is also done is called
(1) isotonic contraction
(2) tetanus
(3) isometric contraction
(4) single muscle twitch

FIGURE: ISOMETRIC CONTRACTION (PUSHING AGAINST A WALL)

when the load is greater than the force (muscle tension) generated by the contraction of the muscle, e.g., **pushing against a wall.**

- **Isotonic Contraction:** In an isotonic contraction, the muscle contracts and shortens against a load. It occurs when the force generated on contraction of the muscle is greater than the load, whereas the load remains the same throughout muscle contraction (fixed load), e.g., **lifting a weight.**

FIGURE: ISOTONIC CONTRACTION (LIFTING A WEIGHT)

Table. Differences between Isometric and Isotonic Contraction

Isometric Contraction	Isotonic Contraction
Length of the muscle does not change, i.e., shortening of the muscle fibre does not occur.	Length of the muscle changes, i.e., the muscle shortens.
The load is greater than the muscle tension	The load is fixed
Muscle tension is produced without any visible movement in the body part	Visible movement in body part without any change in the muscle tension
Example: Pushing against a wall	Example: Lifting a weight

- **Muscle Fatigue**
  - The inability of a muscle to continue producing the same force of contraction after being active over a long period of time.
  - Muscle initially use aerobic respiration to generate energy to contract. After prolonged contraction, when the oxygen becomes limiting, the muscle switch to anaerobic

respiration to fulfil the energy requirement for further contraction.

- **Lactic acid** is produced during **anaerobic respiration** which accumulates in the muscle cells to cause fatigue.
- Fatigued muscles experience **pain.** The site of fatigue is the junction between motor nerve endings and the muscle fibres.
- A muscle can experience fatigue due to the absence of oxygen, loss of nutrients supply, accumulation of lactic acid or absence of glycogen.
- More oxygen is consumed during strenuous exercise as compared to slow movement of body.

FIGURE: MUSCLE FATIGUE

- **Rigor Mortis:**
  - After death, the cellular metabolism in the muscle fibres comes to a rest, due to which ATPs are not produced any further.
  - Absence of ATP does not allow the actin-myosin complexes to separate in a muscle fibre.
  - Thus, once contracted (due to **actin-myosin interaction**) the muscles fail to relax.
  - This rigidity or **stiffening** of muscles after death is called rigor mortis.
  - It usually disappears as protein degradation starts about 24 hours after death.

FIGURE: RIGOR MORTIS

- **Treppe (Staircase Effect):**
  - When a muscle starts to contract, the initial muscle contraction is of less strength as compared to the strength of the later contractions. This gradual increase in the strength of muscle contractions is called treppe. The primary cause of staircase effect is the gradual increase in release of calcium ions from sarcoplasmic reticulum and slow restoration of the ions immediately.
- **Origin and Insertion:**
  - The end of a muscle which is attached to a **fixed** or less movable bone is called its origin.

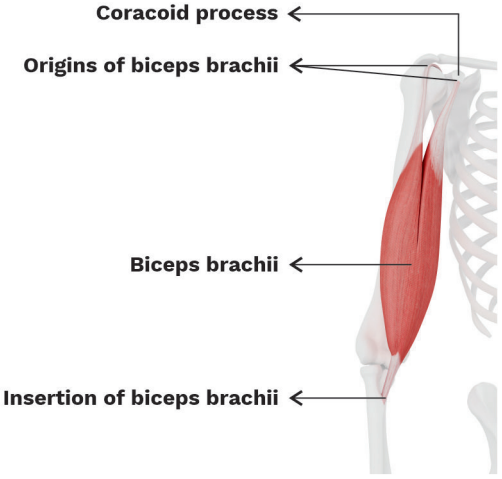


FIGURE: ORIGIN AND INSERTION OF BICEPS BRACHII

- The end of a muscle which is attached to a **movable** bone is called its insertion.

- **Tendons:**
  - Fibrous connective tissue which are made up of collagen and function to attach a muscle to a bone.
  - **Achilles tendon** is the largest and strongest tendon in the body which connects the calf muscles to the calcaneus bone (heel bone).
- **Motor Unit:**
  - A motor unit comprises a single motor neuron which leaves the spinal cord and divides into branches to innervate many muscle fibres to make them contract simultaneously.
  - On an average, about **80-100** muscle fibres may be present in a motor unit.

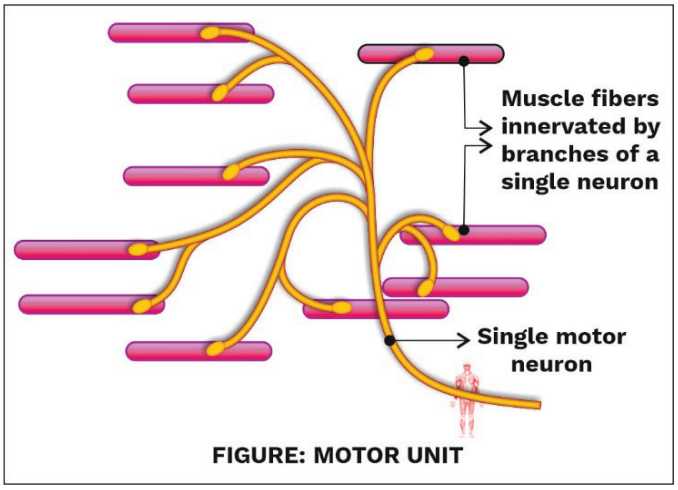


FIGURE: MOTOR UNIT

  - Small muscles that contract rapidly show presence of more nerve fibres in them, whereas large muscles which require less fine control, show hundreds of muscle fibres in a motor unit.
- **Hypertrophy:**
  - The condition involving an overall increase in the total mass of a muscle.

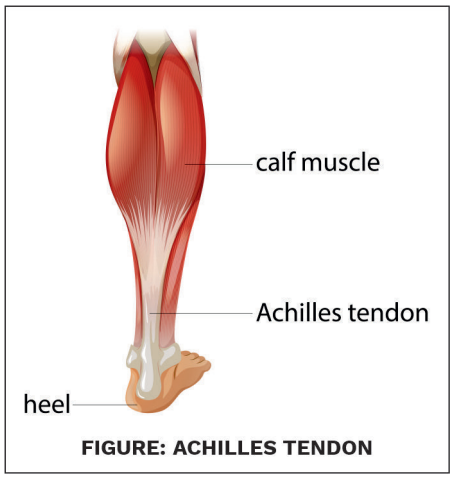


FIGURE: ACHILLES TENDON

Definition

Motor Unit: Functional unit of a muscle, consisting of all the muscle fibres which are innervated by a single motor neuron is called a motor unit.

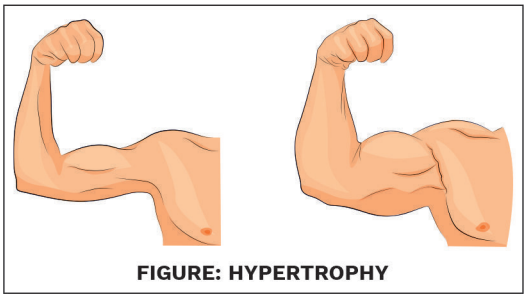


FIGURE: HYPERTROPHY

- This occurs due to increase in number of actin and myosin filaments in each muscle fibre, resulting in an increase in size of individual muscle fibre of a muscle (fibre hypertrophy).
- Significant muscular hypertrophy is visible within **6-10** weeks by only a few strong muscular contractions each day.

- **Atrophy:**
  - Reduction in the total mass of a muscle is called atrophy.
  - It occurs when there is decrease in the size of individual muscle fibre.
  - If a muscle is not used for many weeks, its contractile proteins undergo degradation by large protein complexes called as **proteasomes** which perform proteolysis of unneeded proteins.

Gray Matter Alert!!!

Ubiquitin is a protein which specifically labels muscle cells to be targeted for proteasomal degradation.

Rack your Brain

Muscles present in the wall of blood vessels are voluntary or involuntary?

TYPES OF MUSCLES

- Muscles are classified based on their location and functions.
- Based on the location, there are three types of muscles: skeletal, smooth and cardiac muscles.

Skeletal Muscles

- Skeletal muscles are associated with the skeletal system and so they are found along with bones of forelimbs and hindlimbs e.g., biceps, triceps, quadriceps, hamstrings etc. These are also present in upper part of oesophagus, pharynx and tongue.
- These are controlled by the **central nervous system** (used as per the will of human beings). Thus, skeletal muscles are also called as **voluntary muscles**.
- Structurally, these muscles are made up of elongated, **cylindrical**, **multinucleate** (syncytial) and **unbranched** muscle cells or muscle fibres which are enclosed by a membrane of sarcolemma over their cell membrane.

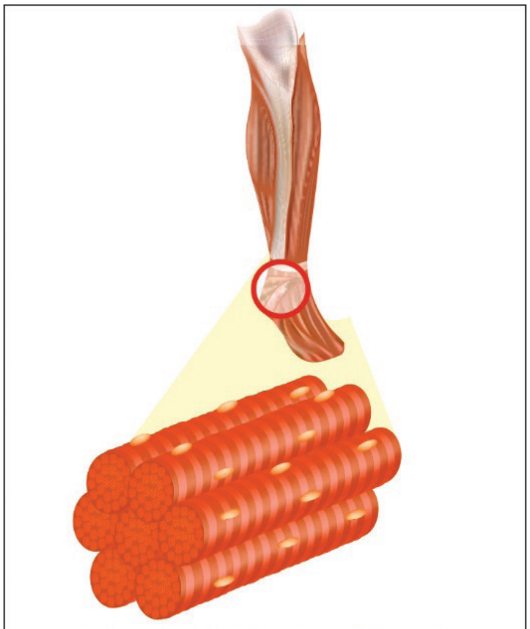


FIGURE: SKELETAL MUSCLE

- Each muscle fibre consists of myofibrils having striated appearance due to the presence of light and dark bands. Thus, skeletal muscles are also called as striated muscles.
- Skeletal muscles show **rapid contractions** and fatigue faster.

Smooth Muscles

- Smooth muscles are associated with the **visceral organs** of the body, e.g., urinary bladder, intestine, diaphragm, walls of blood vessels, walls of intestine, lower part of oesophagus, stomach, arrector pilli muscle of hair, iris of eye etc. Therefore, these muscles are also named as visceral organs.
- These muscles are controlled by the **autonomic nervous system**. Thus, smooth muscles are also called as **involuntary muscles**.
- Structurally, these muscles are made up **elongated, spindle-shaped, uninucleate** and **unbranched** muscle fibres and their cell membrane is not enclosed by sarcolemma.
- Smooth muscles are also called unstriated muscles since the muscle fibres do not contain light and dark bands.
- Smooth muscles show **slow contractions** and do not fatigue easily.

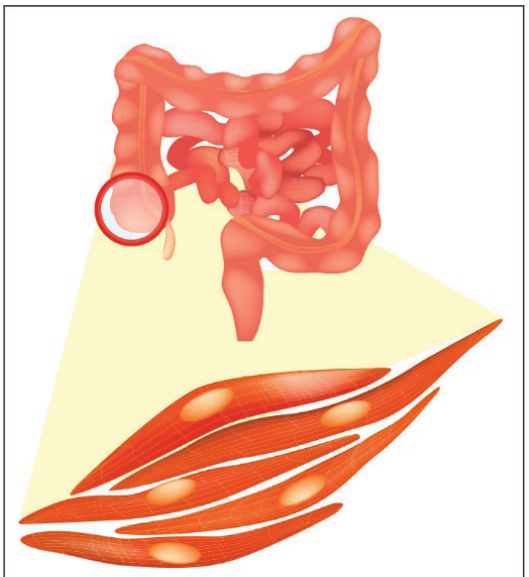


FIGURE: SMOOTH MUSCLE

Cardiac Muscles

- Cardiac muscles are present in the human **heart**.
- The signals for contraction of cardiac muscles are generated within the heart (**myogenic**). Thus, these muscles are also involuntary in nature. Although, stimuli from the central nervous system and autonomous nervous system can alter the heartbeat.
- Structurally, the cardiac muscles consist of elongated, cylindrical, uninucleate and branched muscle fibres. Such muscle fibres are not enclosed by sarcolemma.

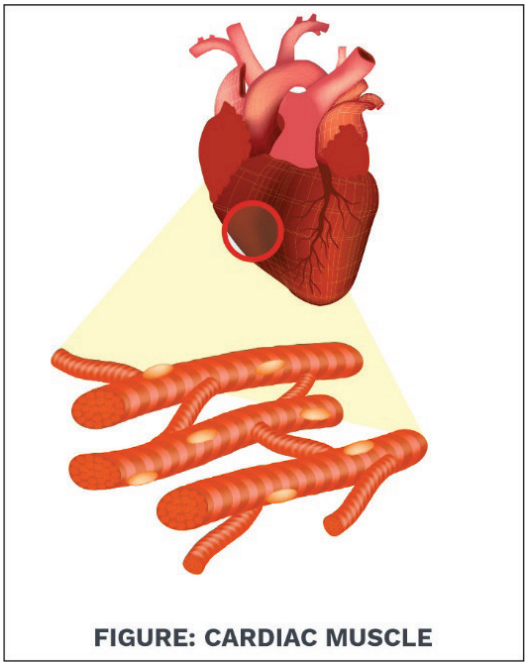


FIGURE: CARDIAC MUSCLE

- Certain lateral branches, called **oblique bridges** join the cylindrical cardiac muscle fibres for faster spread of the signals of contraction.
- These muscles are also striated because of the presence of light and dark bands. At intervals, special areas of cell membrane of two adjacent muscle fibres make dark **intercalated discs** which help to transmit contraction signals from one cardiac muscle cell to another.
- Cardiac muscles show **rapid contractions** and never fatigue.

Previous Year's Question

Muscles of the heart are
(1) voluntary, striated
(2) voluntary, smooth
(3) involuntary, striated
(4) involuntary, smooth

Table. Differences between Skeletal, Smooth and Cardiac Muscle Fibres

Skeletal Muscle Fibres	Smooth Muscle Fibres	Cardiac Muscle Fibres
Associated with skeletal system	Associated with visceral organs	Associated with heart
Cylindrical	Spindle-shaped	Cylindrical
Unbranched	Unbranched	Branched (Oblique bridges)
Multinucleate (Syncytial)	Uninucleate	Uninucleate
Striated (with light and dark bands)	Unstriated	Striated (with intercalated discs)
Voluntary	Involuntary	Involuntary
Fatigue faster	Do not Fatigue	Never Fatigue

Skeletal Muscle Fibres	Smooth Muscle Fibres	Cardiac Muscle Fibres
Examples: Muscles associated with bones like biceps, triceps, quadriceps, upper part of oesophagus, pharynx and tongue etc.	Examples: Muscles in the urinary tract, diaphragm, walls of blood vessels, walls of intestine, lower part of oesophagus, stomach, arrector pilli muscle of hair, iris of eye etc.	Example: Muscles of heart

Red and White Muscles

There are two types of skeletal muscles: red and white.

Red Muscle Fibres (Slow or Tonic Muscle Fibres)

- Red muscle fibres contain large amounts of myoglobin, an iron-containing protein which functions like haemoglobin present in the RBCs. Presence of **myoglobin** gives the characteristic red colour to these muscle fibres. Oxygen binds with myoglobin to form **oxymyoglobin** and remains stored in the fibres to be used during muscle contractions.
- They are highly **vascularised** i.e., the red muscle fibres have an extensive blood vascular system where numerous capillaries supply extra amounts of oxygen.
- In size, these fibres are small and **thinner** than the fast fibres.
- There is a presence of **high** number of **mitochondria** to generate more energy in the form of ATP.
- Slow fibres do not have an elaborate system of sarcoplasmic reticulum.
- Mostly aerobic respiration occurs in these muscle fibres. Therefore, production of lactic acid is very less.
- Thus, these fibres can contract for a considerably

Definition

Myogenic: Contraction signals originating from muscles tissue.

Rack your Brain

Why do muscles get fatigue?

longer period (slow and **sustained contraction**) without getting fatigued.

- Glycogen is not stored in these fibres to much extend.
- Examples: Red muscle fibres are more developed in **runners and cyclists**. The extensor muscle (back muscle) in humans consists of slow muscle fibres to remain active for long hours to keep the body erect.
- These muscle fibres are also present in the long and slow flying birds like kites and migratory birds like Siberian cranes.

FIGURE: GROUP OF MARATHONERS WITH WELL-DEVELOPED RED MUSCLE FIBRES

White Muscle Fibres (Fast or Twitch Muscle Fibres):

- These muscle fibres are named white muscle fibres as they are deficit of myoglobin and thus, are pale-yellow in colour.
- The white muscle fibres are less extensively supplied with blood capillaries, thus showing the secondary importance of oxidative metabolism in these fibres.
- The fast muscle fibres are longer and thicker as compared to the slow muscle fibres.
- An extensive system of sarcoplasmic reticulum is present in the fast muscle fibres to release large amounts of calcium ions for initiation of muscle contraction.
- Fast muscle fibres mostly generate energy by the process of anaerobic glycolysis, thereby producing and accumulating more lactic acid.
- Thus, these muscle fibres can contract for shorter period (**fast contraction**) and get fatigued much faster.
- Glycogen is stored in these fibres as energy source.
- Examples: White muscle fibres are more in athletes performing sprints or short distance running. Muscles used to move eyeballs in humans have white muscle fibres.
- These fibres are present in birds which fly fast

FIGURE: SPRINTERS WITH WELL-DEVELOPED WHITE MUSCLE FIBRES

Rack your Brain

Why are muscles red in colour?

but for a short distance like sparrow.

Table. Differences between Red and White Muscle Fibres

Red Muscle Fibres	White Muscle Fibres
Abundant myoglobin present	Less amount of myoglobin present
Dark red colour	Pale-yellow colour
Smaller and thinner	Larger and thicker
Abundant mitochondria present	Less amount of mitochondria present
Highly vascularised to supply more oxygen to mitochondria	Supplied with less blood vessels
Sarcoplasmic reticulum less in number	Extensive system of sarcoplasmic reticulum present
Less calcium ions released in sarcoplasm	More calcium ions released in sarcoplasm
Aerobic respiration occurs to liberate energy	Anaerobic respiration occurs to liberate energy
Less production and accumulation of lactic acid	More production and accumulation of lactic acid
Contract for a longer period (slow and sustained contraction)	Contract for short duration
Slow rate of contraction	Fast rate of contraction

Red Muscle Fibres	White Muscle Fibres
Do not get fatigued easily	Get fatigued very soon
Example: Marathon runners	Example: Sprinters

Types of Muscles According to their Functions

- **Flexor:** Muscles which bend a part over another, e.g., **biceps** for the movement of hand to mouth for feeding.
- **Extensor:** Straightening of a bent part, e.g., **triceps** for the movement of hand away from mouth.
- **Adductor:** It brings the limbs towards midline or axis of the body, e.g., **latissimus dorsi** (brings the arms towards body).
- **Abductor:** It pulls the limbs away from midline or axis of body, e.g., **deltoid** (pulls the arm away from body).
- **Pronator:** It rotates the forearm to turn the palm downward or backward, e.g., pronator quadratus in the forearm.
- **Supinator:** It rotates the forearm to turn the palm upward or forward e.g., **Supinator** in human forelimbs.
- **Depressor:** It lowers a body organ, e.g., **depressor anguli oris** (depresses angle of mouth).
- **Elevator or Levator:** It raises a part of the body, e.g., **levator anguli oris** (raises the angle of the mouth).
- **Sphincter (Constrictor):** It closes an opening or aperture, e.g., **sphincter ani** (closes the anus).
- **Rotator:** It rotates the part of a body, e.g., **pyriformis** (raises and rotates the thigh in many directions).
- **Invertor:** It turns the sole inwards.
- **Evertor:** It turns the sole outwards.

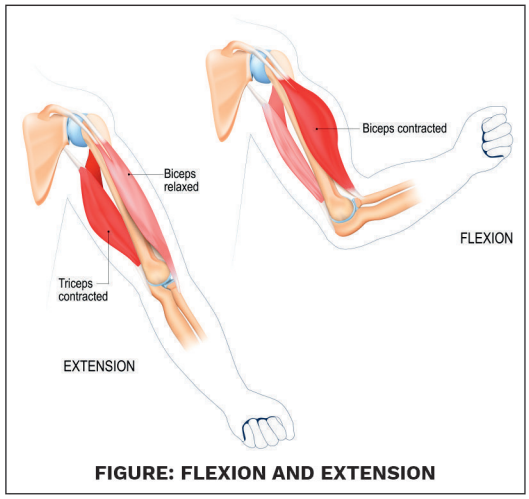


FIGURE: FLEXION AND EXTENSION

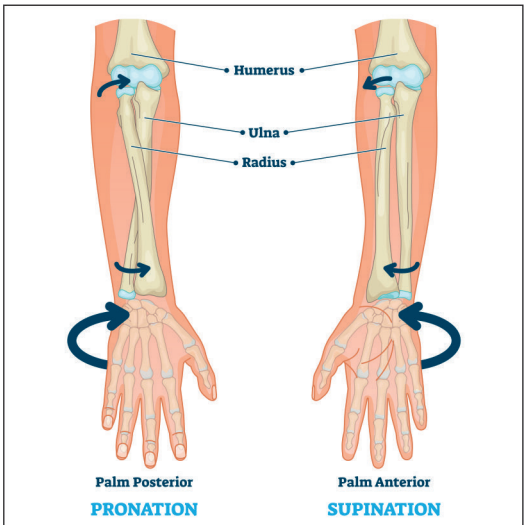


FIGURE: PRONATION AND SUPINATION OF HUMAN FOREARM

Antagonistic Muscles

- A pair of muscles present over the same joint which on contraction produce opposite movements are called antagonistic muscles.
- The two antagonistic muscles do not contract simultaneously but do so alternately.
- Example: **Biceps** and **triceps** for allowing elbow movement. Biceps is a flexor muscle which lies in front of humerus. Triceps is an extensor muscle which lies behind humerus. Contraction of biceps raises the forearm, while contraction of triceps causes straightening of forearm.

Definition

Antagonistic Muscles: A pair of muscles present over the same joint which on contraction produce opposite movements are called antagonistic muscles.

DETAILED STRUCTURE OF SKELETAL MUSCLES

- A whole skeletal muscle is covered externally by a sheath of connective tissue called the **epimysium.**
- Under the epimysium, many muscle bundles or fasciculi are present having a large number of muscle fibres.
- Each muscle bundle or fasciculus/fascicule/ fascicle has an outer connective tissue covering called the **perimysium.**
- Each muscle fibre (about 10-80 μm in diameter) present inside a fasciculus is further surrounded by a thin connective tissue layer called the **endomysium.**
- On the outer surface, a skeletal muscle cell is lined by sarcolemma which encloses the muscle cell's cytoplasm or the sarcoplasm. Since, a skeletal muscle cell has a multinucleated sarcoplasm, it is also called as a **syncytium.**
- Besides many nuclei arranged towards the periphery, the sarcoplasm also contains agranular endoplasmic reticulum **(sarcoplasmic reticulum)** that helps in storage of large amount of calcium ions for muscular contraction, abundant mitochondria to produce ATP, glycogen, lipid droplets, myoglobin, and myofibrils.
- Large number of parallelly arranged filaments called **myofibrils** or **myofilaments** are present in the sarcoplasm which make a complex of contractile proteins.

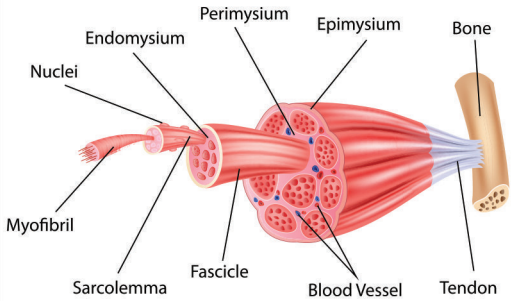


FIGURE: STRUCTURE OF SKELETAL MUSCLE

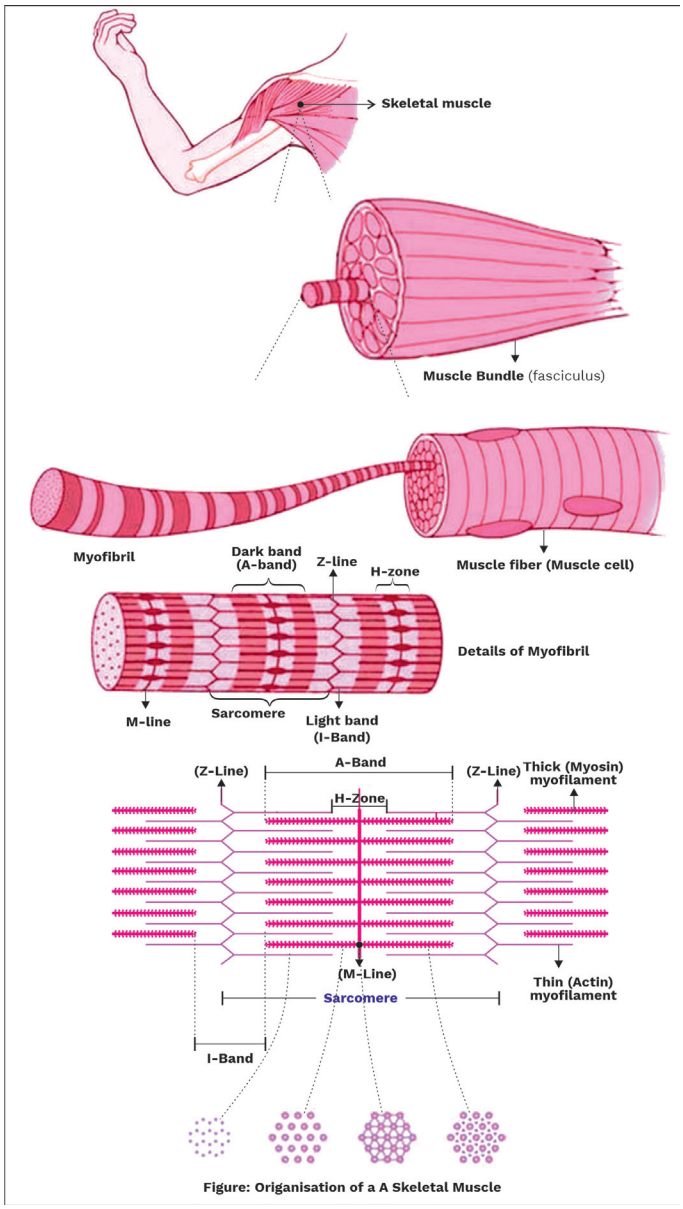


Figure: Origanisation of a A Skeletal Muscle

- Each myofibril bears alternate light and dark bands on it.
- Dark bands are doubly refractive under polarised light. They are called **anisotropic** or **A-bands** and contain contractile proteins called myosin.
- Light bands are non-refractive in polarised light. They are called **isotropic** or **I-bands** and

Previous Year's Question

What is a sarcomere?
(1) Part between two A-line
(2) Part between two I-line
(3) Part between two Z-line
(4) Part between two H-line

Previous Year's Question

The functional unit of contractile system in striated muscle is—
(1) Sarcomere
(2) Z-Band
(3) Cross bridges
(4) Myofibril

are made up of actin, tropomyosin, and troponin proteins.

- Both actin and myosin are polymerised proteins which are positioned longitudinally along the axis of the myofibrils and are parallel to each other.
- Accordingly, there are two types of myofibrils or myofilaments in a muscle fibre which are arranged parallel to each other, i.e., **thick myofilaments** and **thin myofilaments.**
- Thick myofilaments are made up of **myosin** proteins and thin myofilaments are made up of **actin** proteins along with **tropomyosin** and **troponin.**
- At the centre of A-band or thick myofilament, an **H-zone** (Hensen's zone) is present. An M-line is present in the middle of the H-Zone.
- At the centre of I-band or thin myofilament, a Z-line is present. Z-line, also called **Z-disc** or Krause's membrane, is made of filamentous proteins.
- The part of the myofibril between two successive Z-lines is called **sarcomere.** Sarcomere is the functional unit of muscle contraction.
- Each sarcomere is about 2μm in length in a resting muscle fibre.

Structure of Contractile Proteins

- **Thick (myosin) myofilaments** are formed from many monomeric proteins called **meromyosins.**
- A myosin molecule has a molecular weight of 480,000 and consists of **six polypeptide chains.**
- There are two heavy polypeptide chains each with a molecular weight of 200,000 which wrap around each other to form a double helix. They form **heavy meromyosin** or **HMM.**
- The rest four polypeptide chains are the light chains with a molecular weight of 20,000 each. They constitute **light meromyosin** or **LMM.**
- Each heavy chain has one of its ends folded into a globular polypeptide structure called the

Previous Year's Question

The H-zone in the skeletal muscle fibre is due to

(1) extension of myosin filaments in the central portion of the A-band
(2) the absence of myofibrils in the central portion of A-band
(3) the central gap between myosin filaments in the A-band
(4) the central gap between actin filaments extending through myosin filaments in the A-band

Previous Year's Question

Which of the following is the contractile protein of a muscle?

(1) Tropomyosin
(2) Tubulin
(3) Myosin
(4) All of these

myosin head. Therefore, the double helix myosin molecule has two free myosin heads at one end. The other end makes its tail.

- Each myosin head is associated with two light chains. Thus, two myosin heads bear four light polypeptide chains. Tail is exclusively formed of HMM while, head is formed of both HMM and LMM.

Gray Matter Alert!!!

There is no cross-bridge head in the centre of the thick myofilament for about 0.2 um as the hinged arms extend away from the centre.

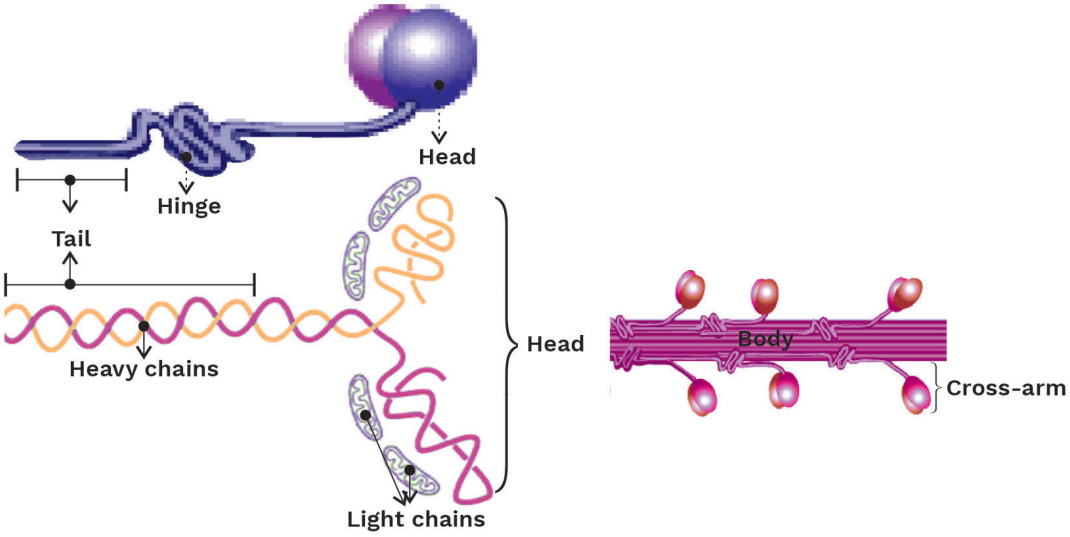


FIGURE: DIAGRAMMATIC REPRESENTATION OF THICK MYOFILAMENT

- Tails of the molecules are bundled together to form the body of the myosin filament.
- Myosin heads along with a part of the myosin body called **'arm'** hang outward as **cross-bridges** in all the directions from the thick filament. These cross-bridges are flexible at two ends due to the presence of hinges.
- Myosin filaments of a sarcomere are connected to one another in the region of their **M-line.** The connections are called **M-bridges.**
- Free ends of myosin filaments are also attached to Z-discs by very fine filaments of protein **titin.**

Definition

Cross-bridge: Protruding arm and a head of a myosin together makes a cross-bridge.

- The globular myosin head acts as an active adenosine triphosphatase **(ATPase)** enzyme and has binding sites for ATP and actin protein.
- **Thin (actin) filaments** consist of two filamentous **F-actins** helically wrapped to each other. Each F-actin is a polymer made of monomers which are in-turn made of a globular protein, **G-actin.** G-actin bears active sites of ADP. These active sites stagger on the two F-actin strands and appear as one active site on the actin filament about every 2.7 nm. The cross arms on myosin interact with these active sites to form cross bridges.

Gray Matter Alert!!!

Titin (one of the largest protein molecule in the human body) are filamentous proteins which have a spring like property. Titin stabilizes the thick filament, centre it between the thin filaments, prevent overstretching of the sarcomere, and to recoil the sarcomere like a spring after it is stretched.

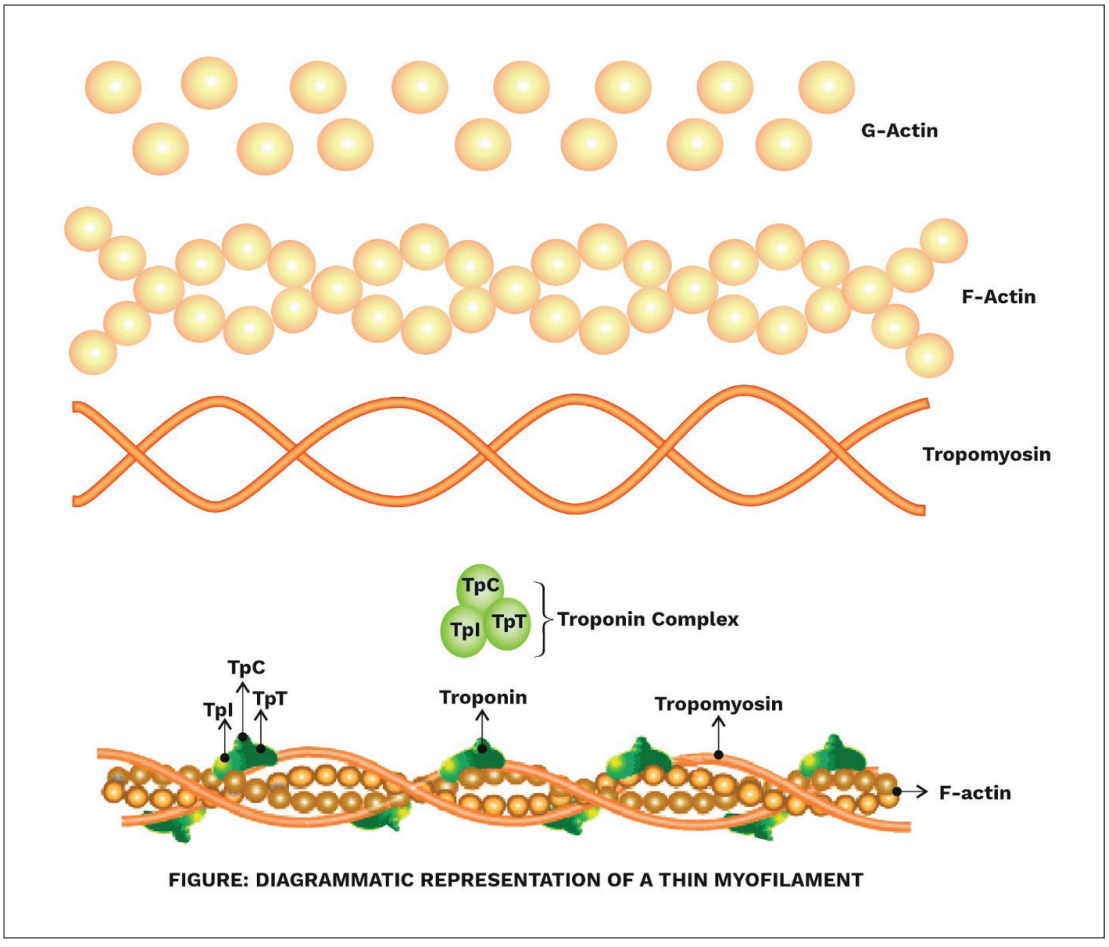


FIGURE: DIAGRAMMATIC REPRESENTATION OF A THIN MYOFILAMENT

- Two filaments of another protein **tropomyosin** form a double helix and present over the actin myofilament. In a relaxed muscle, the tropomyosin proteins are placed over the active sites of the actin filaments to avoid contact between actin and myosin filaments.
- A complex of three loosely bound protein subunits called **troponin** keeps the active sites on actin filament masked by attaching tropomyosin to actin filament. **Troponin I (TpI)** has strong affinity for actin, **troponin T (TpT)** binds to tropomyosin while, **troponin C (TpC)** is a calcium-binding polypeptide.
- For muscle contraction, Ca^{2+} ions bind to TpC which causes conformational changes in it. This in turn makes the tropomyosin experience conformational changes that uncovers the active sites on the actin molecules.

Previous Year's Question

The contractile protein of skeletal muscle involving ATPase activity is

(1) Troponin
(2) Tropomyosin
(3) Myosin
(4) Actin

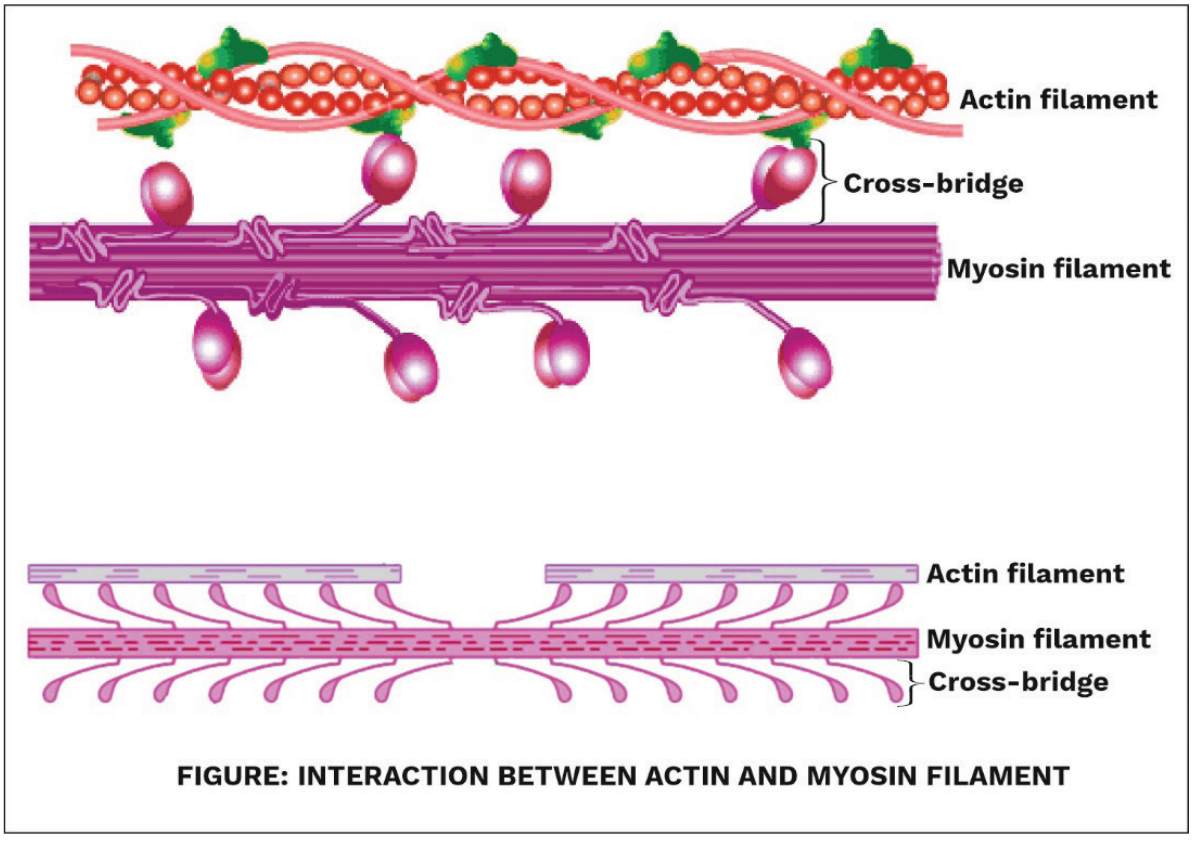


FIGURE: INTERACTION BETWEEN ACTIN AND MYOSIN FILAMENT

Mechanism of Muscle Contraction

- The mechanism of muscle contraction was proposed independently by A.F. Huxley and H.E. Huxley in 1954 as **Sliding Filament Theory.**
- According to sliding filament theory, for a muscle to contract, actin filaments must slide over the myosin filaments with the help of their lateral heads called cross-bridges which result in a **decrease** in the size of **I-bands** and narrowing or even disappearing of **H-zone,** thus resulting in **shortening** of the **sarcomere.**
- There is **no change** in the size of **A-band.**
- The lengths of the thick myofilaments and the thin myofilaments do not change.

Previous Year's Question

Which statement is correct for muscle contraction?

(1) H-zone decreases
(2) Length of A-Band increases
(3) Length of I-Band increases
(4) Length of two Z lines increases

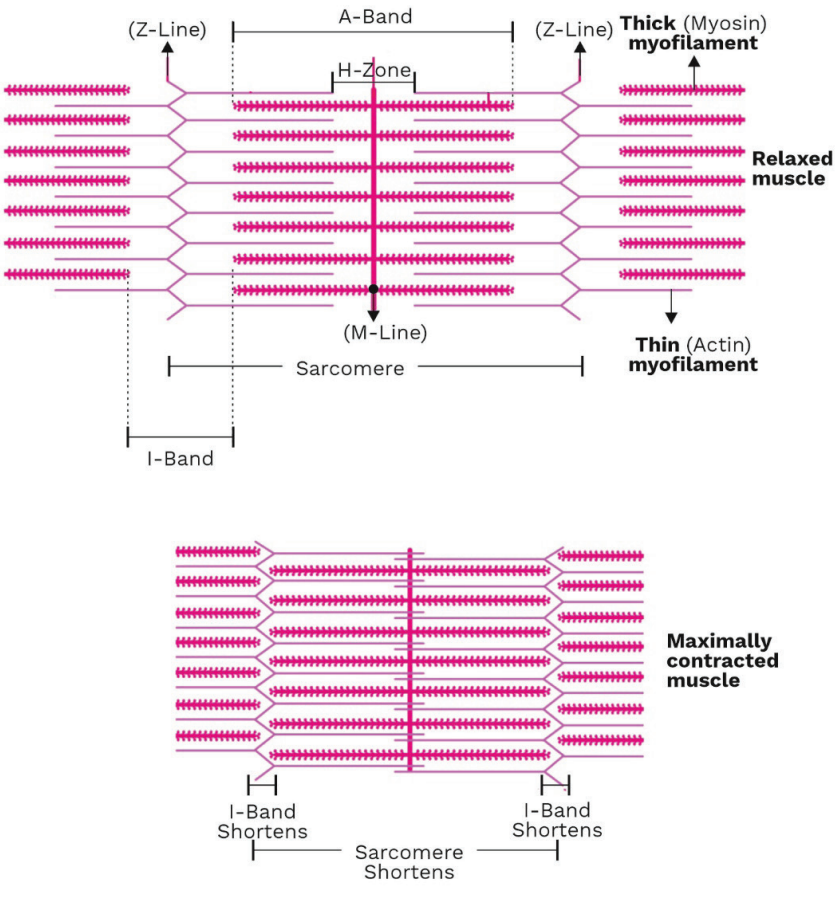


FIGURE: MUSCLE CONTRACTION

Electrical and Biochemical Events in Muscle Contraction

- For making a skeletal muscle **contract,** the central nervous system sends signals via a motor neuron.
- The neural signal reaches to the junction between the motor neuron and the sarcolemma of the muscle cell **(neuromuscular junction).**
- Synaptic vesicles present in the nerve endings release neurotransmitter **acetylcholine** in the synaptic cleft (space between the nerve ending and the sarcolemma).
- Acetylcholine interacts with the protein receptors present on the sarcolemma and changes its resting potential by allowing inward movement of sodium ions and outward movement of potassium ions across it, thus generating an **action potential.**
- This action potential is transmitted to sarcoplasmic reticulum and stimulates the release of **Ca^{2+} ions** from the sarcoplasmic reticulum.
- Ca^{2+} ions bind with Troponin C (TpC), which in-turn causes the tropomyosin to detach from the actin filament, thereby exposing the active sites over actin filaments and activate heads of myosin filaments to bind to these active sites.
- Activation of the myosin head is brought about by the activity of ATPase in the presence of calcium ions and **magnesium ions.** ATPase enzyme breaks ATP into ADP and inorganic phosphate, which releases energy in the myosin head. The energized myosin heads form cross-bridges to bind to actin.
- The cross-bridges pull the attached actin filaments towards the centre of A-band. The actin filaments appear to slide over the myosin filaments.
- The **Z-lines,** to which actin filaments are attached, are also **pulled inwards.** This causes the sarcomere to shorten.

Gray Matter Alert!!!

Electrical and biochemical events in muscle contraction were studied by Albert Szent Gyorgi (1942).

Gray Matter Alert!!!

In a muscle fibre, only 2–4 mM of ATP is present which is quickly hydrolysed into ADP and inorganic phosphate during muscle contraction. Further ATP molecules are formed from creatine phosphate in most vertebrates with the help of enzyme creatine phosphokinase. Later, ATP molecules are generated in the muscle cells due to aerobic respiration.

- Decrease in the length of the sarcomere results in the contraction of the muscle.
- There is no shortening of actin and myosin filaments during muscle contraction, however, the size of I-band and H-zone decreases.
- As a new ATP binds to the myosin head, the cross-bridge breaks to bring back the myosin head in a relaxed state. The next contraction will follow with subsequent **hydrolyses of ATP** by the ATPase enzyme of the myosin head and the entire cycle of cross-bridge formation and sliding of actin filaments over myosin filaments will be repeated.

Previous Year's Question

During muscle contraction
(1) chemical energy is changed into electrical energy
(2) chemical energy is changed into mechanical energy
(3) chemical energy is changed into physical energy
(4) mechanical energy is changed into chemical energy

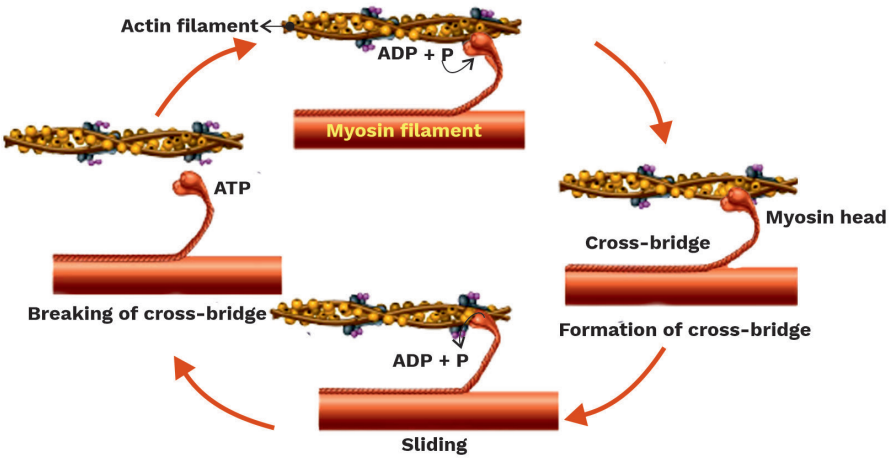


FIGURE: FORMATION AND BREAKING OF CROSS-BRIDGE BETWEEN ACTIN AND MYOSIN FILAMENTS

- At the time of relaxation, **$Na^+ - K^+$ pump** becomes operational and restores the resting potential of the sarcolemma which makes the Ca^{2+} ions to actively pass back into sarcoplasmic reticulum.
- This makes the tropomyosin and troponin molecules to again block the active sites on the actin filaments. ATPase of myosin head is inactivated, and the I-bands return to their original size as the Z-lines move back to their original position. This causes the muscles to **relax.**

Previous Year's Question

Electron microscopic studies of the sarcomeres have revealed that during muscle contraction
(1) the width of A-band remains constant
(2) the width of the H-zone becomes smaller
(3) the width of I-band increases
(4) the diameter of the fibre increases

Cori's Cycle

- **Carl Ferdinand Cori** and **Gerty Theresa Cori** in 1947 proposed the Cori's cycle which involved cyclic movement of glucose between muscle fibres and liver cells.
- During anaerobic respiration, lactic acid is produced in muscle fibres. The accumulation of lactic acid causes muscle fatigue.
- To avoid muscle fatigue, lactic acid is drained out in the blood and transported to the hepatocytes, where majority of the lactic acid (**about 80%**) is converted to glycogen.
- The remaining **20%** lactic acid is enzymatically oxidized to water and carbon dioxide. It is followed by hydrolysis of glycogen to glucose which is drained in the blood to be transported back to the muscles, where it again converts into glycogen and is stored for future use.
- This cycle does not allow significant amount of lactic acid accumulation in the muscle fibres and thus, protects the neuro-muscular junction and avoid prolonged muscle fatigue.

Definition

Neuromuscular junction: The junction between a nerve fibre and a muscle fibre is called neuromuscular junction or motor end plate.

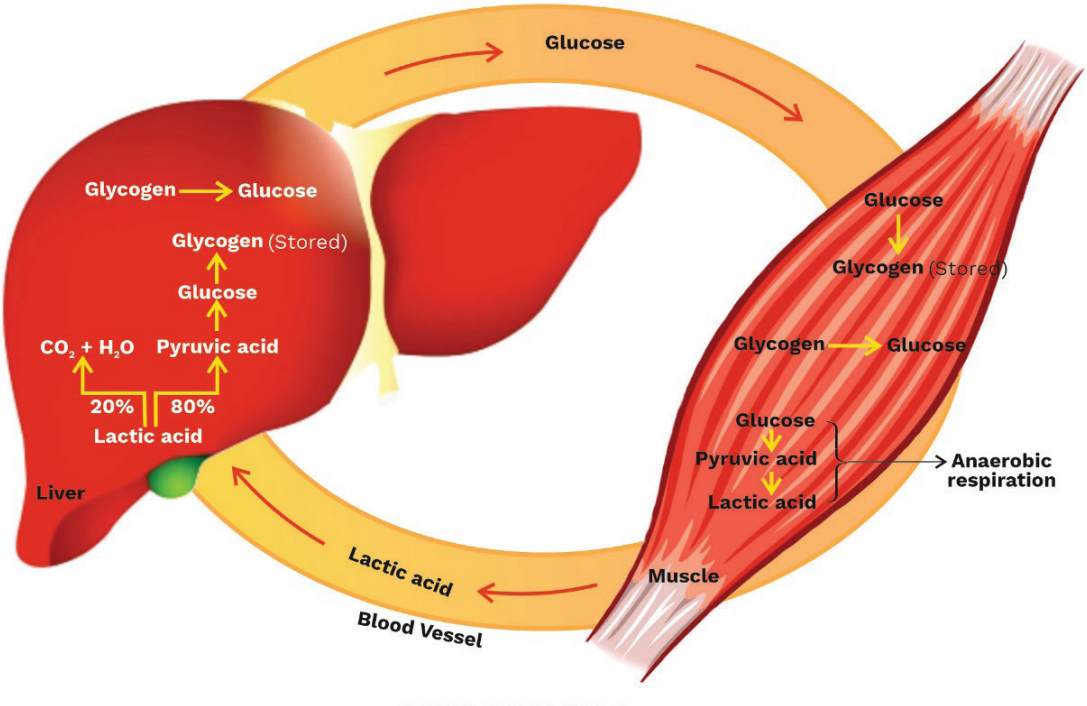


FIGURE: CORI'S CYCLE

Oxygen Debt

- While performing **strenuous exercises,** there is a decrease in oxygen availability to the muscles due to rapid consumption of oxygen to carry out aerobic respiration to generate more energy for rapid contractions.
- To meet the increased oxygen demand, the muscles switch to anaerobic respiration and produce lactic acid.
- The muscles also use oxygen from **oxymyoglobin** and take up phosphate by dephosphorylation of **creatine phosphate.**
- During relaxation or resting period, the extra oxygen is made available to the fibres by increasing the rate of breathing.
- The consumption of extra oxygen after strenuous exercises to recover is called **oxygen debt** of the muscles.
- This extra oxygen is used in regenerating the oxymyoglobin, oxidizing the **lactic acid** and restoring the lost ATP and creatine phosphate.

Disorders of Muscular System

- **Muscular Dystrophy**
  - Muscular dystrophies are **hereditary diseases** involving progressive weakness and damage of skeleton muscles.
  - It occurs due to mutation in the ***Dystrophin* gene** present on the X-Chromosome.
  - Dystrophin protein is responsible for connecting the cytoplasm to the extracellular matrix via the cell membrane of a muscle fibre. It relays contraction signals from the nerves to the calcium storage (sarcoplasmic reticulum) of muscle fibres.
  - The absence of *Dystrophin* does not allow calcium ions to release from the sarcoplasmic reticulum, thus, inhibiting muscle contraction. It also allows excess calcium ions to enter through the sarcolemma resulting in enzymatic destruction of contractile proteins.
  - This results in **weakness of muscle fibres** and eventually in their degradation. General

Rack your Brain

Regular exercise decreases oxygen debt. Why?

Gray Matter Alert!!!

***Dystrophin* gene:** *DMD* gene or *Dystrophin* gene is the largest human gene which provides information to make dystrophin protein.

Definitions

Myotonia: It is a neuromuscular condition which involves impairment of muscle relaxation.
Spasm: It is a sudden and involuntary contraction of muscle.
Cramp: It is an involuntary, forcible and painful contraction of a muscle that usually lasts longer.

symptoms include progressive muscle weakness, frequent falls, difficulty in running and jumping, muscle pain, delayed growth, mental disabilities, etc.

- **Myasthenia Gravis:** It is an **autoimmune disease** in which the body produces antibodies against a transport protein associated with sodium channels. Thus, neural signals are not transported at the neuromuscular junctions resulting in the absence of contraction in the muscles. The muscles experience paralysis and become weak.
- **Tetany:** Rapid involuntary contractions in muscles due to decrease in calcium ion concentrations **(hypocalcemia)** in the extracellular fluid. It is characterised by spasms, cramps, muscular twitching and hyperactive nervous reflexes (hyperreflexia) etc.

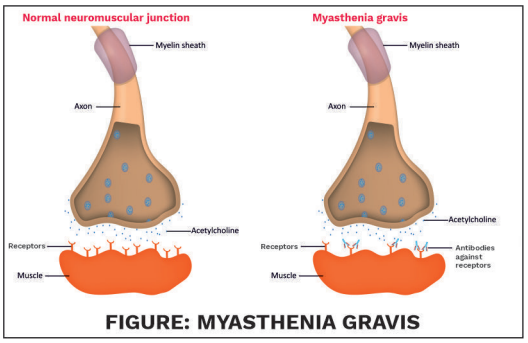
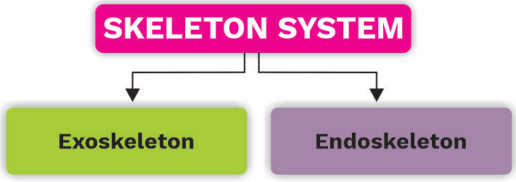


FIGURE: MYASTHENIA GRAVIS


FIGURE: TETANY

HUMAN SKELETAL SYSTEM

- The word skeleton corresponds to the hard, internal or external structures which provide shape, support and protection to the body of an organism.
- External skeleton is called the **exoskeleton,** e.g., nails and hair.
- Internal skeleton, also known as the **endoskeleton**, consists of specialised connective tissue called skeletal tissue which consists of cartilage and bones of **mesodermal origin**.
- Bones provide attachment sites for skeletal muscles. The voluntary muscles are attached to bones by **tendons**. Thus, both the skeleton system and muscular system work under the control of neural system to bring about movement and locomotion in human beings.
- The skeletal system provides protection to visceral organs of the body, e.g., brain is covered by skull, lungs and heart are protected by the rib cage, spinal cord is protected by the vertebral column, etc.



Definition

Tendon: A band of connective tissue with collagen fibres which connects a muscle to a bone.

- Bones also function to amplify sound waves in the ear, store fat and minerals and help in the formation of blood (**haemopoiesis**).
- The **cartilaginous rings** present in the trachea and bronchi avoid collapsing of the respiratory airway.

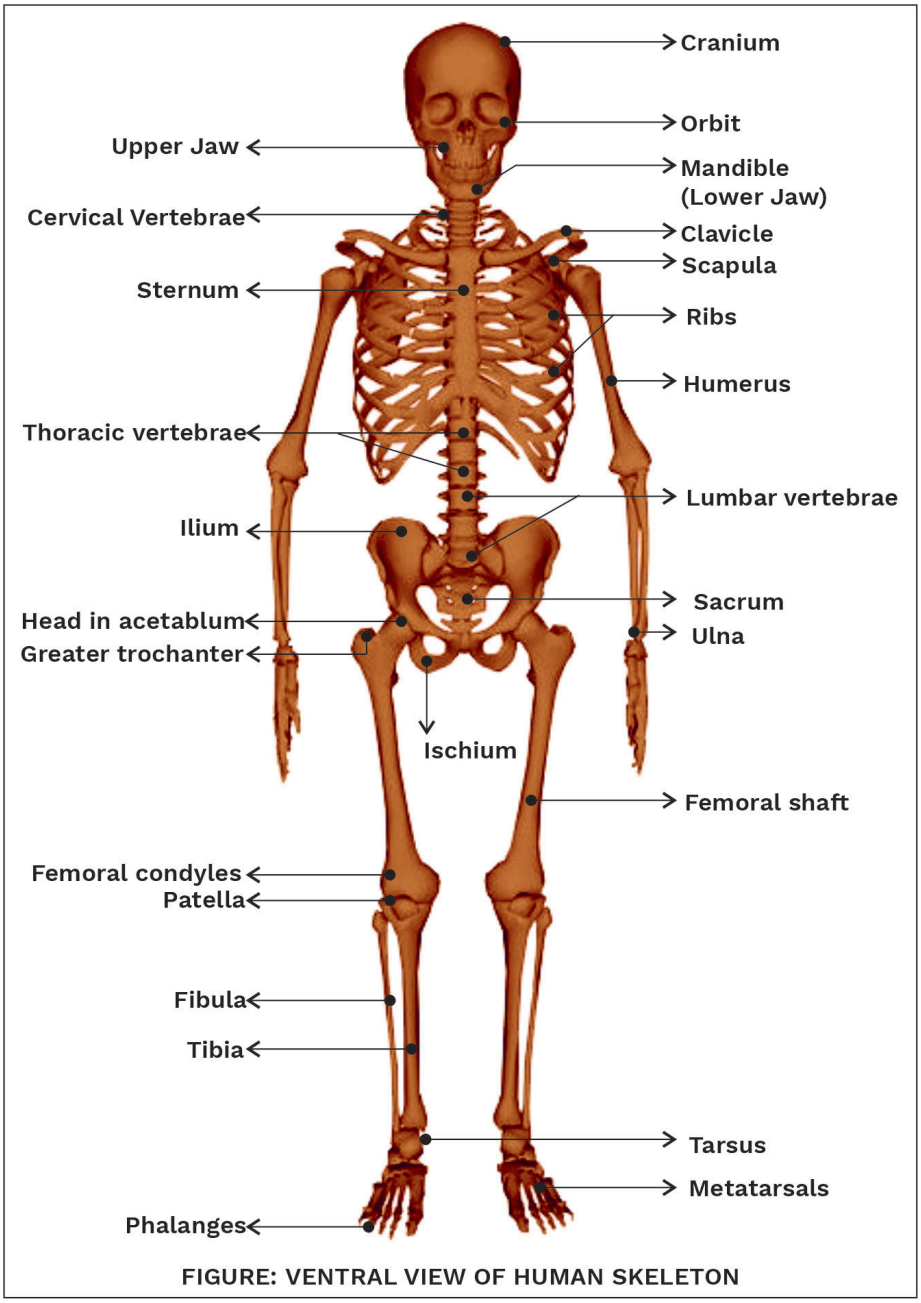


FIGURE: VENTRAL VIEW OF HUMAN SKELETON

- The human skeleton is made of **206 bones** which are arranged into the axial and appendicular skeleton.

AXIAL SKELETON

- The axial skeleton is present along the middle longitudinal axis of the body.
- There are **80 bones** in axial skeleton which form four different structures — skull, vertebral column, sternum and ribs.

SKULL

- The skull forms the skeleton around the human head and consists of **29 bones** and four parts— cranium, facial bones, hyoid bone and ear bones.

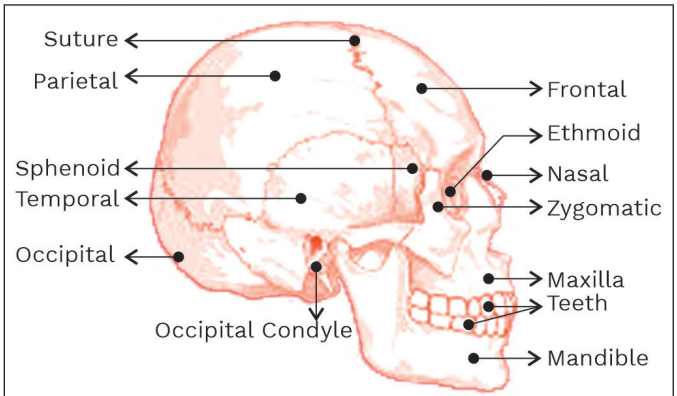


FIGURE: SKULL OF HUMAN

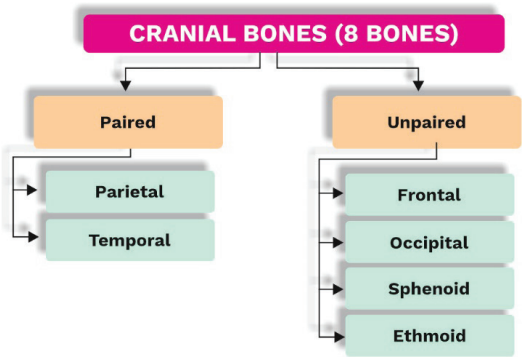
- The skull provides protection to the brain, support to the eyes, throat and tongue, bears nasal chambers, helps in mastication of food by the jawbones, helps in receiving and amplifying sound, etc.

Cranium

- Cranium is also called as the **brain box** as it encloses and protects the brain.
- Bones which make the cranium are called as cranial bone.

Gray Matter Alert!!!

In infants, the skull possesses some incompletely ossified soft regions or soft membranous gaps between cranial bones called **fontanelles** (fonticuli).



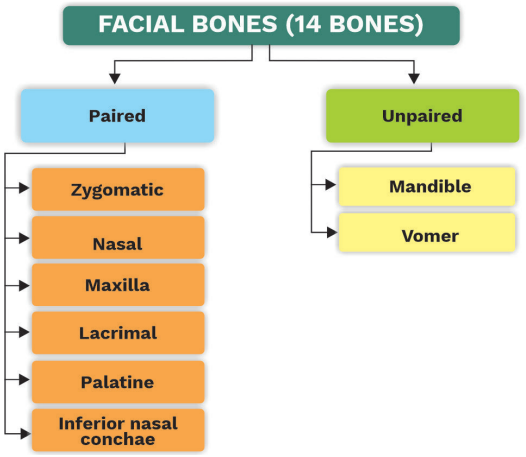
- There are **8 cranial bones** which are joined together by **sutures**. They include one **frontal** bone, one **occipital** bone, one **sphenoid** bone, one **ethmoid** bone, two **parietal** bones and two **temporal** bones.
- Posteriorly, the skull has an opening called **foramen magnum** through which the brain connects with the spinal cord.
- Laterally, foramen magnum consists of two protuberances called the **occipital condyles** (**dicondylic** condition in human) which articulate with the first cervical vertebra, the **atlas** by a hinge joint.

Ear Ossicles

- Each middle ear has three small bones called as the **ear ossicles** which help in sound amplification. Ear Ossicles are helpful in the amplification of sound by 20–22 times.
- Thus, there is a total of **6 ear bones** namely, the outer **malleus** (hammer-shaped), the middle **incus** (anvil-shaped) and the innermost **stapes** (stirrup-shaped).

Facial Bones

- There are **14 bones** which forms the skeletal framework of the face.
- Facial bones include two **zygomatic** bones, two **nasal** bones, two **maxilla** (upper jaw), two **lacrimal** bones, two **palatine** bones, two **inferior nasal conchae**, one **mandible** (lower jaw) and one **vomer**.



Hyoid Bone

- Hyoid bone is also called as the **tongue bone** as it is present at the base of tongue and above the larynx.
- It does not articulate with any bone and provides attachment site for certain muscles of tongue.
- Upper portion of hyoid bone is the greater cornu, whereas its lower portion is called the lesser cornu.

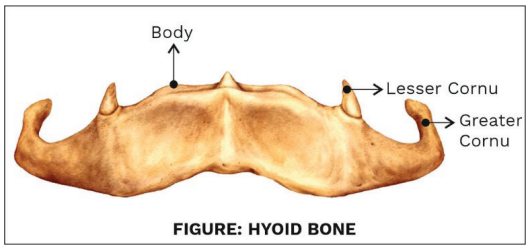


FIGURE: HYOID BONE

VERTEBRAL COLUMN

- The vertebral column is a collection of **33 vertebrae** or **26 bones** joined to each other by intervertebral disc of fibrocartilage to form two forward and two backward curves, which occupies the mid-dorsal region of the human body.
- These vertebrae collectively make the **backbone** of the human body.

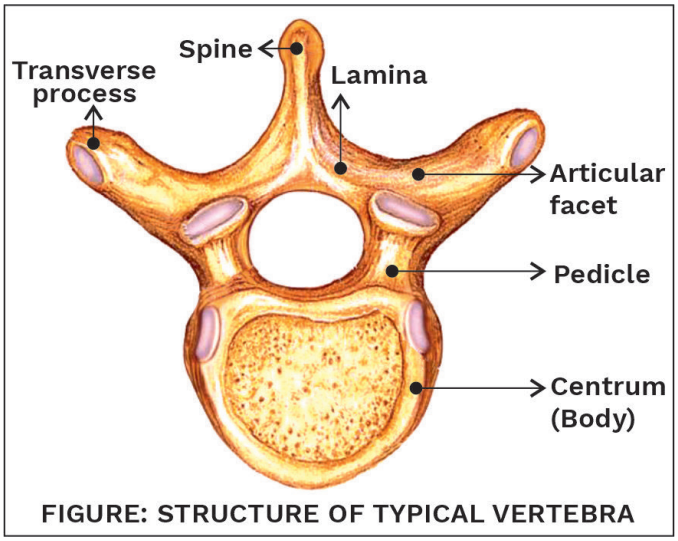


FIGURE: STRUCTURE OF TYPICAL VERTEBRA

- All vertebrae show some common characteristics like presence of an anteriorly placed **centrum** (a large, disc-like body) and the posteriorly positioned **neural arch** which surrounds a cavity called the vertebral foramen.
- The vertebral foramen of 24 vertebrae together make the vertebral (neural) canal which encloses the spinal cord.
- Neural arch has two rounded pedicles in front and two flattened laminae at the back.
- A **neural spine** (spinous process) occurs dorsally at the tip of neural arch, whereas **two transverse processes** occur on the sides.
- Articular facets (articular processes) occur at the bases of transverse processes. There are two superior articular facets or **pre-zygapophyses**

Definition

Foramen: Oval opening in the body for the passage of blood vessels, nerves, etc., between two structures, especially in a bone.

Previous Year's Question

The vertebra which bears the whole weight of the skull is
(1) axis
(2) sacral
(3) cervical
(4) atlas

and two inferior articular facets or **post-zygapophyses**.

- Vertebral column is curved at four places which form four curvatures to have a balanced body posture.
- **Cervical curvature** is present in the neck region and is anteriorly convex, whereas the thorax curvature is present in the thoracic region and shows anterior concavity. **Lumbar curvature** can be seen in the abdominal region and is anteriorly convex. The last curvature occurs in the pelvic region and is called as the **sacral curvature** which shows anterior concavity.

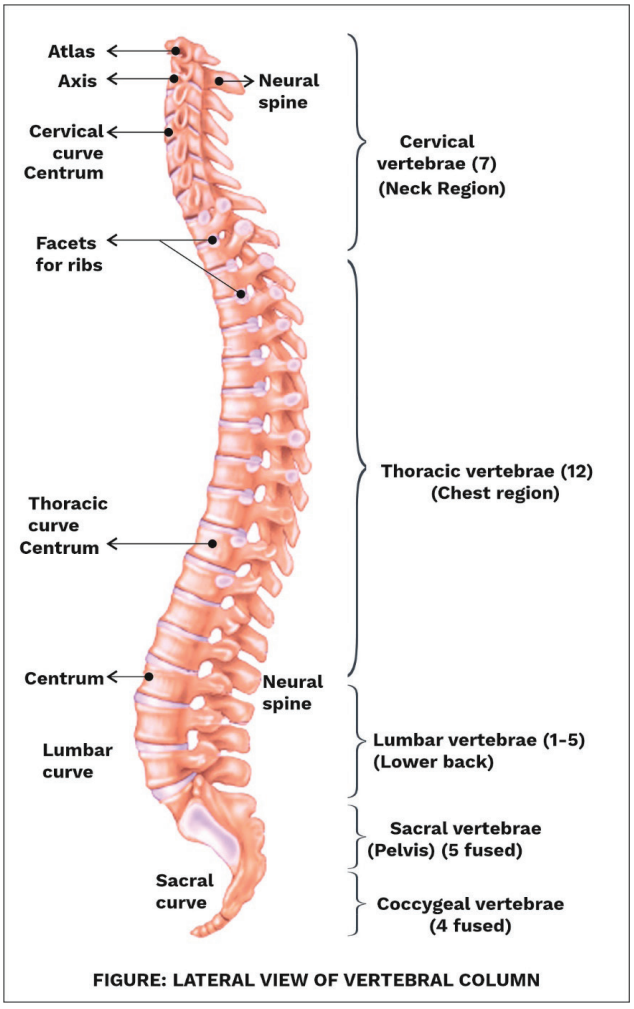


FIGURE: LATERAL VIEW OF VERTEBRAL COLUMN

Previous Year's Question

The number of vertebrae present in cervical, thoracic, lumbar, sacral and coccyx regions respectively are

(1) 12, 7, 5, 1, 1
(2) 1, 7, 5, 12, 1
(3) 7, 5, 1, 12, 1
(4) 7, 12, 5, 1, 1
(5) 5, 12, 7, 1, 1

Previous Year's Question

Lumbar vertebrae are found in

(1) neck region
(2) abdominal region
(3) hip region
(4) thorax

- Vertebral column protects the spinal cord, supports the head, provides the attachment site for ribs and girdles, allows forward and backward bending due to the presence of **intervertebral discs** and provides a strong support for the suspension of visceral organs in the body cavity.
- The vertebral column is made of five types of vertebral groups, namely, cervical vertebrae, thoracic vertebrae, lumbar vertebrae, sacrum and coccyx **($C_7T_{12}L_5S_5C_4$).**

Cervical Vertebrae

- The cervical vertebrae are positioned in the neck region and are **seven** in number.
- The first and the second cervical vertebrae are called as **atlas** and **axis** respectively.

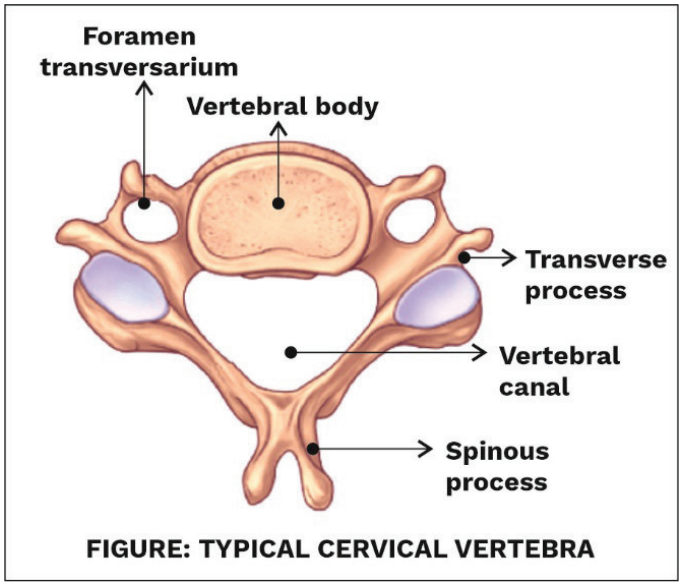
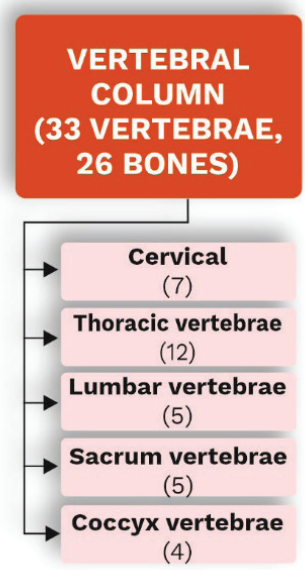


FIGURE: TYPICAL CERVICAL VERTEBRA

- Atlas has a reduced centrum and neural spine. It also consists of concave superior articular facets to fit over the two occipital condyles. This articulation provides the **nodding movement** of the head. Atlas has circular inferior articular facets and a median facet for odontoid process of axis.

Previous Year's Question

Cervical vertebrae are located in
(1) thoracic region
(2) abdominal region
(3) neck region
(4) lumbar region



Rack your Brain

What causes nodding movement of the head?

- The second cervical vertebra is called axis, which consists of an **odontoid process.**
- The articulation of odontoid process of the axis and odontoid canal of the atlas results in **sideways rotation** of the head.
- **Foramen transversarium** is present at the lower portion of transverse processes of cervical vertebrae, which forms a canal through which the blood vessels from the heart reach the brain and vice versa.

Previous Year's Question

The major function of the intervertebral discs is to
(1) absorb shock
(2) string the vertebrae together
(3) prevent injuries
(4) prevent hyperextension

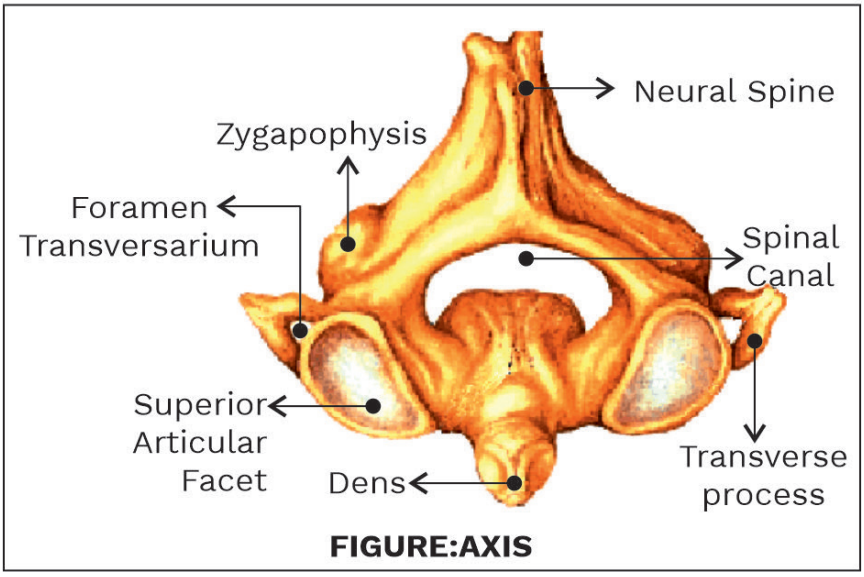


FIGURE:AXIS

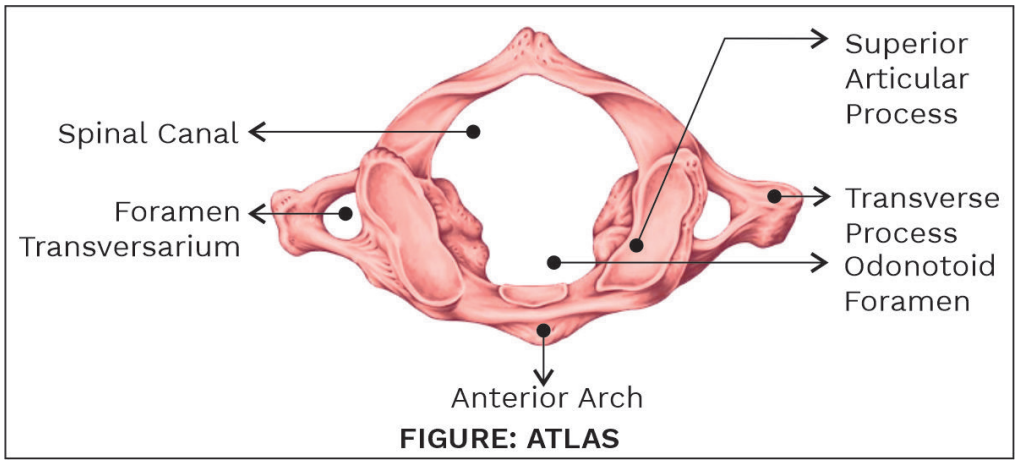


FIGURE: ATLAS

Thoracic Vertebrae

- The thoracic vertebrae are stronger and larger than the cervical vertebrae with long neural spines and attachment sites for ribs.
- There are **twelve** thoracic vertebrae which articulate with the ribs to protect the visceral organs like lungs and heart.
- Transverse processes of the thoracic vertebrae have facets for attachment with the tubercles of ribs.
- Complete facets are present in the first and the last thoracic vertebrae for articulation with the rib heads, whereas in the last three thoracic vertebrae, facets are absent.

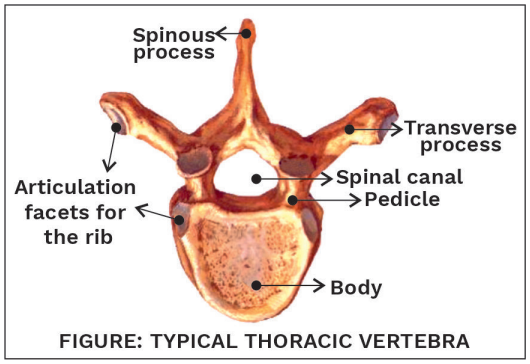


FIGURE: TYPICAL THORACIC VERTEBRA

Lumbar Vertebrae

- Abdominal lumbar vertebrae are the strongest, thickest and the largest among all the vertebrae and are **five** in number.
- They consist of short and thick transverse processes and horizontal neural spines.

Sacrum

- The sacrum is a curved bone, present in between the innominate bones of the pelvic girdle.
- It is formed by the fusion of **five sacral vertebrae**.
- The spinal nerves exit through spaces present in the sacral bone called as sacral foramina.

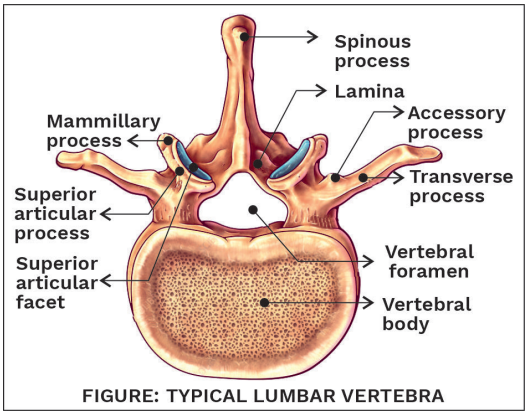


FIGURE: TYPICAL LUMBAR VERTEBRA

Coccyx

- Coccyx is a small, triangular, terminal bone of the vertebral column which is formed by the fusion of **four** coccygeal vertebrae.
- It is also called as the **tail bone**.

Sternum

- The sternum or the **'breast bone'** is ventrally positioned in the centre of the thoracic cage and has articulation sites for the first seven pairs of ribs. It protects the internal organs of the thoracic cavity.

- Manubrium, body and xiphoid process are the three parts of the sternum.
- **Manubrium** is the uppermost part of the sternum and articulates with the clavicles (collar bones) and first pair of ribs.
- **Body** is the middle part of the sternum and looks like the blade of a dagger. Second to seventh pair of ribs attaches with the body of sternum.
- **Xiphoid process** is the lowermost tip of the sternum.

Ribs

- The lateral part of the thoracic cage is formed by **twelve pairs** of ribs which are joined to vertebral column posteriorly and with sternum anteriorly.

Previous Year's Question

The number of floating ribs in the human body is
(1) 3 pairs
(2) 2 pairs
(3) 6 pairs
(4) 5 pairs

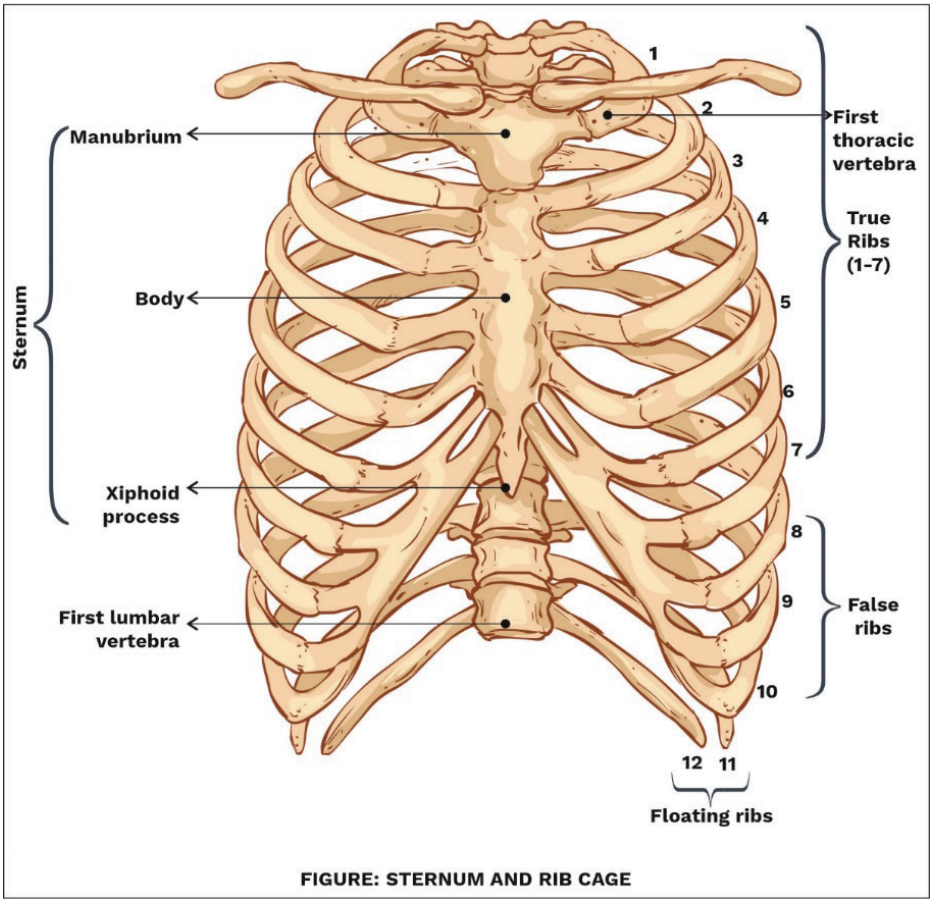
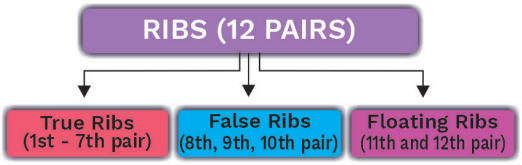


FIGURE: STERNUM AND RIB CAGE

- Ribs function to protect the heart, lungs and kidneys. They also help in breathing by providing attachment sites for the intercostal muscles.
- Generally, a rib consists of a long, bony **vertebral part**, which articulates with the facets of thoracic vertebrae and a short **sternal part** which is made of hyaline cartilage and articulates with the facets of the sternum.
- The vertebral part of the rib consists of a **head region** which consists of facets for articulation with the thoracic vertebrae, a constricted **neck region**, a **tubercle** which articulates with the transverse and a main body or **shaft** which has an angle where its curvature changes.
- Ribs are divided into three types depending on their articulation with the sternum:
- **First seven pairs** of ribs are called **true ribs** as they are directly attached to the sternum as well as vertebral column.
- The **8th, 9th** and **10th** pair of ribs are called **false ribs** as they are attached indirectly to the sternum by articulating with the **costal cartilage** of the seventh pair of ribs.
- The **11th** and **12th** pairs of ribs are called **floating ribs**. They are named so because their one end is joined to vertebral column whereas the other end is free, i.e., not joined to the sternum, directly or indirectly. They protect the kidneys.



Gray Matter Alert!!!

Because of the presence of two points of attachment on the dorsal side to attach vertebral column, ribs are called bicephalic (dicephalic).

APPENDICULAR SKELETON

- Appendicular skeleton is present laterally in the body.
- There are a total of **126 bones** in the appendicular skeleton which form the girdles and limbs of the body.
- There are two girdles (pectoral and pelvic) and two pairs of limbs (forelimbs and hindlimbs) in the human body.

Previous Year's Question

The 8th, 9th and 10th pair of ribs are known as false ribs because their external portions are attached to
(1) xiphisternum
(2) costal cartilage of 7th rib
(3) they have no costal cartilage
(4) they are not true ribs

Pectoral Girdle

- Each pectoral girdle is also called **shoulder girdle** and consists of two bones, one clavicle and one scapula.
- Clavicle (**collar bone**) is an elongated bone which shows two curvatures. It is attached to the manubrium medially. Laterally, it connects with acromion process of scapula.

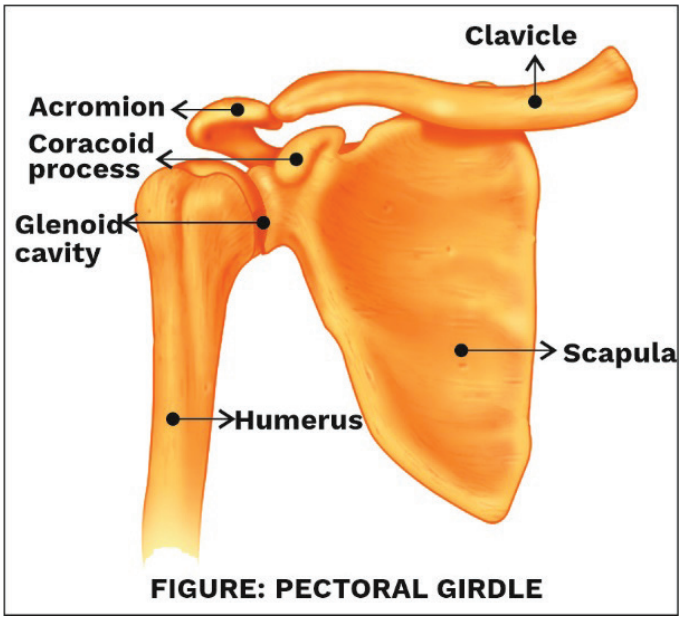


FIGURE: PECTORAL GIRDLE

- Scapula (**shoulder blade**) is a triangular bone, having a sharp ridge and a sharp protuberance called spine, and extends on the backside of thorax between second and seventh ribs.
- The end of the spine possesses a thick **acromion process**. The acromion process forms an articulation site for the clavicle.
- The anterior surface of the scapula has a projection called the **coracoid process** which provides attachment site for the tendons of the muscles.
- Scapula contains a lateral, shallow articulating surface called **glenoid cavity** for articulation with the head of the humerus.

Previous Year's Question

Which of the following components is a part of pectoral girdle?
(1) Sternum
(2) Acetabulum
(3) Glenoid cavity
(4) Ilium

Previous Year's Question

An acromian process is characteristically found in the mammals in
(1) pelvic girdle
(2) pectoral girdle
(3) skull
(4) sternum

Pelvic Girdle

- Pelvic girdle is also called **hip girdle** and consists of two **innominate bones** (hip bones) which are joined together by **pubis symphysis** having white fibrous cartilage.

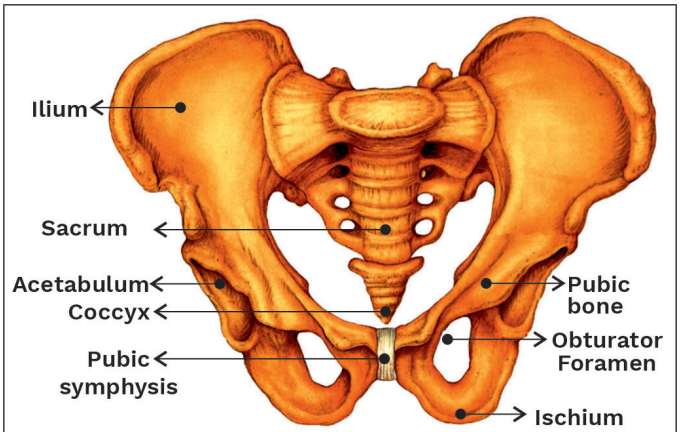


FIGURE: ANTERIOR VIEW OF PELVIS

- Each innominate bone is made by the fusion of three different bones which are named as the **ilium**, the **ischium** and the **pubis**.
- Acetabulum is a deep depression on the outer surface of the innominate bone which makes an articulation site for femur.
- A large foramen called **obturator foramen** occurs between pubis and ischium through which blood vessels and nerves pass.
- Pelvic girdle is attached posteriorly to sacrum.
- Ilium possesses two depressions, a small lesser sciatic notch and large greater sciatic notch (sciatic nerve is the longest nerve in the human body that passes through the greater sciatic notch).

Bones of Forelimbs

- The three parts of each forelimb (upper arm, forearm and the hand) collectively consist of **30 bones**—one humerus (in each upper arm), one radius and one ulna (in each forearm) and

Previous Year's Question

The pectoral and pelvic girdles and the bones of limb form
(1) axial skeleton
(2) appendicular skeleton
(3) visceral skeleton
(4) outer skeleton

Definition

Knuckles: The rounded prominence of a joint of a finger, especially one of the articulation of a metacarpal with a phalanx, when the finger is bent.

twenty-seven different bones in each hand.

- The head of the **humerus** articulates with the glenoid cavity of the pectoral girdle. The body (shaft) of the humerus consists of deltoid tuberosity (**deltoid ridge**). Distal end of humerus has a pulley-like **trochlea** for the attachment of ulna bone and a convex **capitulum** for the attachment of radius bone.
- **Radius** and **ulna** are the two bones of the forearm. Radius lies towards the thumb side and ulna towards the little finger side. Radius is shorter than ulna and articulates with the humerus from its head. Its lower end consists of two articular facets for attachment with carpals.
- The upper or proximal end of ulna is elongated to form an **olecranon process** that produces elbow joint.
- Distal end of ulna has one facet for attachment with the carpal.
- Each **hand** consists of **27 bones**. Out of these, **8 bones** are present in the wrist (**carpals**), **5 bones** occur in the palm (**metacarpals**) and **14 bones** occur in the fingers (**phalanges**).
- The 8 bones of the carpals which are arranged in two rows are scaphoid, lunate, triquetrum, pisiform (in the first row) and trapezium, trapezoid, capitate and hamate (in the second row).

Bones of Hindlimbs

- There are **30 bones** in each hindlimb which include one femur (in the thigh), one tibia and one fibula (in the shank), one patella (over the knee) and twenty-six different bones in the foot.
- **Femur** (longest and strongest bone) articulates with the acetabulum of the pelvic girdle through its upper rounded head. Along with the head, femur also consists of a neck, curved shaft and two ridges, greater trochanter and lesser trochanter. Its distal end has a central groove and two lateral condyles.

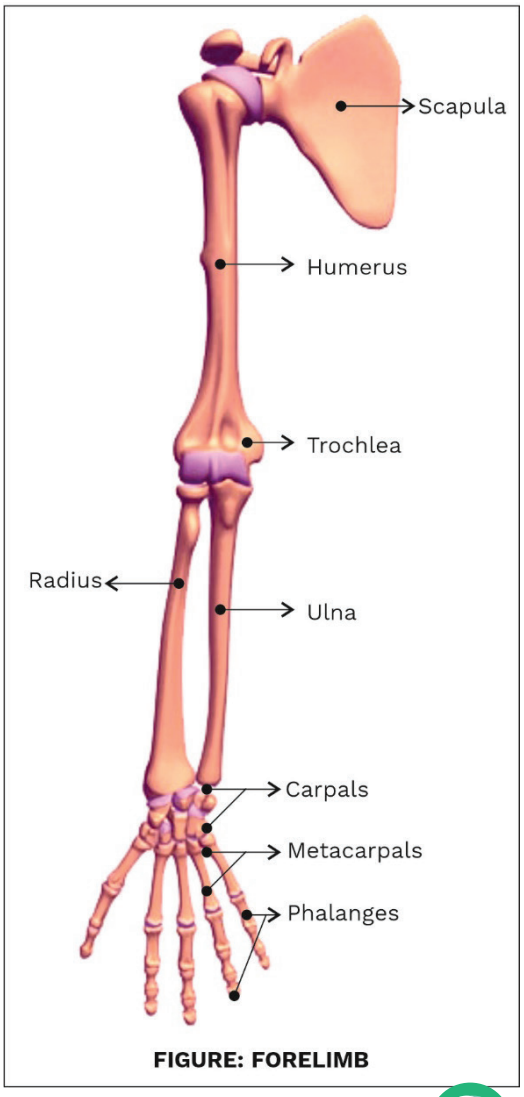


FIGURE: FORELIMB

Previous Year's Question

The total number of bones in each limb is
(1) 24
(2) 30
(3) 14
(4) 21

- A triangular disc-shaped **patella** or kneecap fits over intercondylar groove.
- **Tibia** is longer and thicker and is placed medially. It fits over the condyles of femur by concave facets present in its proximal end.
- **Fibula** is a shorter and thinner bone of shank.
- Each foot has **7 bones** in the ankle (tarsals), **5 bones** in the sole (metatarsals) and **14 bones** in the toes (phalanges).
- Tarsals consist of calcaneus, talus, cuboid, navicular and three cuneiform bones.
  Patella is formed by the ossification in the tendon of quadriceps femoris muscle.

TYPES OF BONES

- According to shape and size, the bones are classified into four types:
  - Long bones, e.g., femur, humerus
  - Short bones, e.g., carpals, tarsals
  - Flat bones, e.g., scapula, sternum
  - Irregular bones, e.g., hip bone
- According to the place of origin, the bones are classified into four types:
  - **Cartilage Bones:** These bones develop as a result of ossification of the cartilage, e.g., humerus and femur.
  - **Investing Bones:** These bones develop in dermis of skin as thin plates, e.g., frontal, parietal, nasal and vomer.
  - **Sesamoid Bone:** It is a bone formed by the ossification in tendons, e.g., patella.
- According to the texture, bones are classified into two types:
  - **Spongy Bone:** These light-weighted bones are also called trabecular or cancellous bone and have numerous trabeculae consisting of red bone marrow in its matrix and are highly vascularised. These occur inside epiphysis and metaphysis of long bones, interior of vertebrae flat bone or skull and ribs.

Gray Matter Alert!!!

Fibula does not support body's weight. It only provides stability to the ankle joint along with tibia.

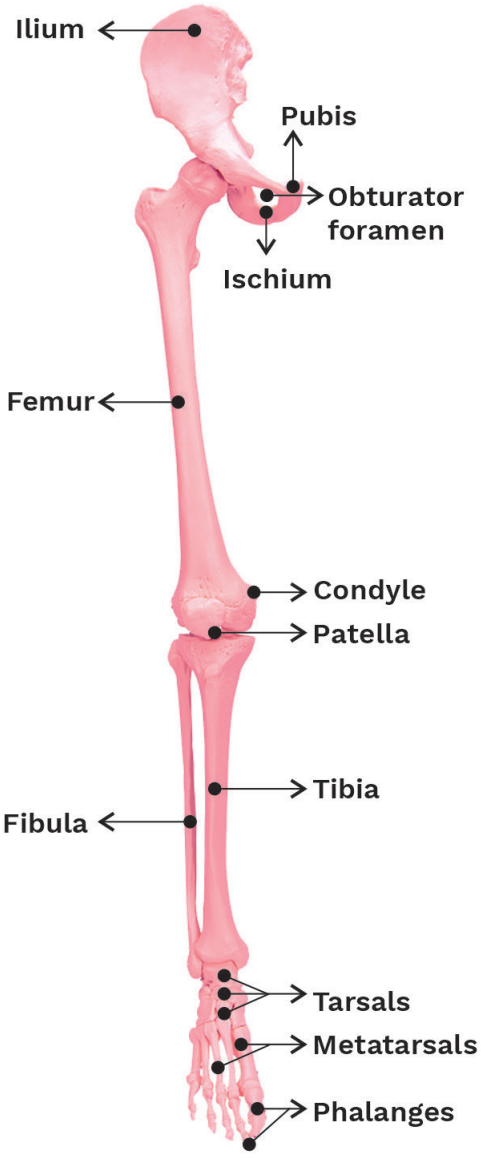


FIGURE: HINDLIMB

- **Compact Bone:** These bones are also called periosteal or dense bone that usually occurs in the outer part of all bones especially in the shaft of long bones, clavicle, scapula, bones of limbs. They have a continuous matrix from outside to inside except for narrow supply channels. The bone contains numerous Haversian systems.

JOINTS

- Points of **articulation** between two bones are called joints.
- On the basis of mobility, joints are classified into three types: fibrous, cartilaginous and synovial joints.

Fibrous or Immovable Joints (Synarthroses)

- No movement occurs along the fibrous joints as the articulating ends of the bones involved in the fixed joint are interlocked firmly and held together by collagen fibres.
- Fixed or fibrous joints are of three subtypes—**suture**, **syndesmosis** and **gomphosis**.
- Fibrous joint occurs in the skull in between the bones of the skull (sutures), amongst ilium, ischium and pubis of the pelvic girdle, between teeth and jawbones.

Cartilaginous or Imperfect Joints (Amphiarthroses)

- These joints have very less mobility due to presence of a disc of fibrocartilage between the articular ends of the bones involved.
- Cartilaginous joints occur in between the centra of two vertebrae (intervertebral discs), pubic symphysis, ribs and sternum.

Synovial or Perfect Joints (Diarthroses)

- These joints allow considerable number of free movements in one or more directions. Ends of

Previous Year's Question

The type of joint between the human skull bones is called
(1) cartilaginous joint
(2) hinge joint
(3) fibrous joint
(4) synovial joint

Previous Year's Question

What will happen if the ligaments are torn?
(1) Bones will move freely at the joint and no pain
(2) Boneless movable at the joint and pain
(3) Bone will become unfixed
(4) Bone will become fixed

bones consist of synovial membranes which have synovial cavity, filled with a synovial fluid. This fluid acts as a cushion and absorbs the shock.

- There are different types of synovial joints in the body.
  - **Ball and Socket Joint:** In this joint, a ball like end of one bone articulates with the socket like end of the other bone and thus, shows most movement in many directions, e.g., shoulder joints, hip joints.
  - **Hinge Joint:** The articulating convex end of one bone fits into the concave articulating end of the other bone and thus, allows movement in only one plane, e.g., knee, elbow, ankle, interphalangeal joints and the joints between the occipital condyles of the skull and the atlas vertebra.
  - **Angular Joint:** Angular joint has an oval shaped condyle at the end of one bone which articulates with the elliptical cavity present in the other bone, permitting back and forth and side to side movement. Therefore, this joint is also called ellipsoid or condyloid joint, e.g., metacarpophalangeal joints.
  - **Gliding Joint:** The articulating ends of both the bones involved in the joint are flat which allows only back and forth and side to side movements (gliding or sliding movements), e.g., joints between carpels and wrist, tarsals and ankle, sternum and clavicle. Superior and inferior articular facets of adjacent vertebrae form gliding types of joints.
  - **Pivot Joint:** The articulate end of one bone is either rounded or pointed which fits into a shallow depression of the articulating end of other bone which allows rotation movement in one plane, e.g., joint between atlas and axis vertebrae for side-to-side movement of head, joint between the upper end of radius and ulna bone (radio-ulnal joint).

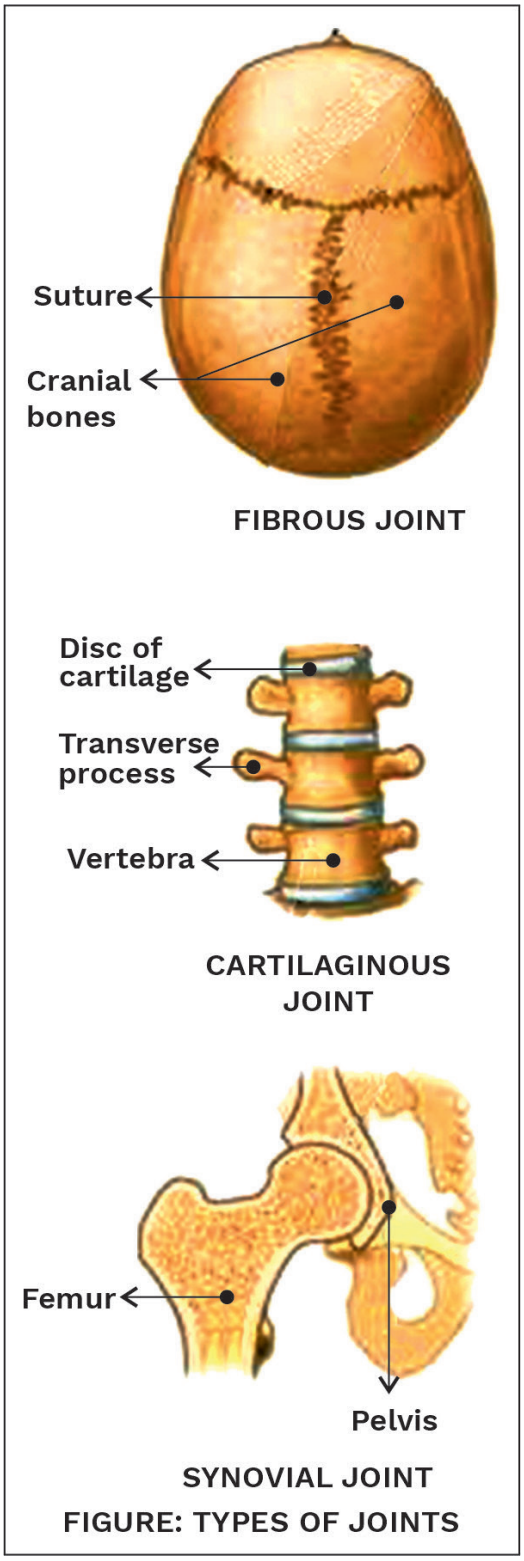


FIGURE: TYPES OF JOINTS

- **Saddle Joint:** There is a projection at articulate end of one bone which fits in a saddle-shaped depression of the articulate end of the other bone, allowing free movement same as in an ellipsoid joint, e.g., joint between carpal and metacarpals of human thumb.

DISORDERS OF SKELETAL SYSTEM

Arthritis

It is a painful inflammation of joints caused by infection, allergy, deficiency or hormonal imbalance. There are three types of arthritis—rheumatoid arthritis, osteoarthritis and gouty arthritis.

- **Rheumatoid Arthritis**
  - It is an autoimmune and inflammatory disease caused by the inflammation of synovial membrane in the synovial joints leading to thickening and excessive production and secretion of synovial fluid.
  - This creates painful joints by putting pressure on them.
  - The presence of rheumatoid factor which resembles immunoglobulin IgM, conforms to rheumatoid arthritis.
  - Synovial membrane secretes an exudate called pannus which forms abnormal granules over the membrane which causes erosion of cartilage surface.
  - This results in the ossification of fibrous tissue attached with the bones.
  - This causes extremely painful movements ultimately immobilising the joint.
  - Heat treatment and physiotherapy are helpful in the early stages. Completely damaged joints are replaced surgically.
- **Osteoarthritis**
  - Commonly occurring in old age, osteoarthritis is characterised by degenerative changes in the joints because of loss of articular cartilage at the synovial joint.

Previous Year's Question

The joint between atlas and axis is called
(1) angular joint
(2) hinge joint
(3) pivot joint
(4) saddle joint

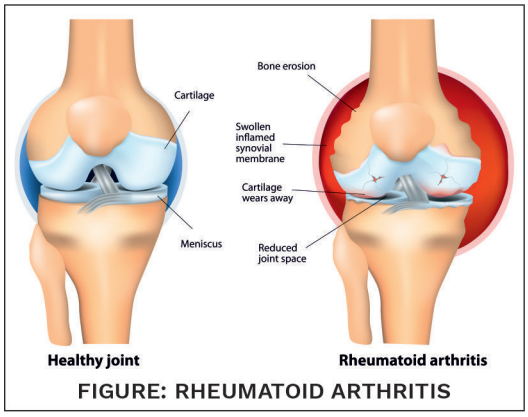


FIGURE: RHEUMATOID ARTHRITIS

Definitions

Ossification: The formation of bone.
Articulation: The juncture between two bones.

Gouty Arthritis or Gout

- It is a disease associated with increased uric acid concentration in blood. Excess uric acid is converted into monosodium urate crystals that precipitate from the blood and become deposited in joints and other tissues resulting in the disease.

Osteoporosis

- It is characterised by bone mass reduction due to the loss of minerals and fibres from the bone matrix resulting in making the bones fragile, painful and prone to fracture.
- Post-menopausal hormonal imbalance in women, decreased organic matter in bones at old age, pregnancy, hormonal imbalances, prolonged cortisone treatment, dietary deficiency of Ca^{2+} and vitamin D are some of the various reasons for osteoporosis.

Dislocation

- The displacement of any articular surface of joint from its normal position, like coming out of ball-like head from the socket of the other bone. Ligaments are also damaged. There is a severe pain and inflammation. Movement is restricted. Resetting of the joint is required.

Strain

- Twisting of tendons between bone and muscle. It is less severe.

Sprain

- It is twisting, stretching or tearing of ligaments. Ligament has poor power of regeneration. It causes severe pain. It is a minor disorder which can however, become chronic.

Keywords

- Rheumatoid Arthritis
- Rheumatoid factor
- Pannus
- Osteoarthritis
- Osteoporosis
- Bursitis

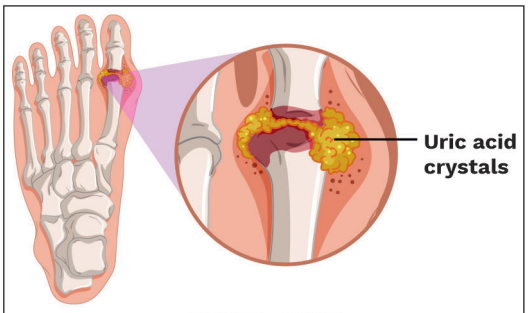


FIGURE: GOUT

Definition

Ligament: A band of connective tissue with collagen fibres which connects one bone to another bone.

Note: Fracture

- It is a break in a compact bone due to mechanical injury. It is very rare in children because their bones have more organic matter and are quite flexible.
- Fracture is common in old age because of less organic matter and more inorganic matter, as the bones become hard and brittle.
- Fracture is of the following types:
  - **Simple:** Bone is completely broken into two parts but the overlying skin is not broken and the bone is not exposed to the air.
  - **Compound (Open):** Bone completely breaks into two parts and the fractured pieces pierce into the skin to be exposed to the air.
  - **Comminuted:** When a bone breaks down into more than two pieces, it is called multiple or comminuted fracture.
  - **Avulsion:** It occurs when a small chunk of bone attached to a ligament gets pulled away from the main part of the bone.
  - **Green Stick Fracture:** When a bone undergoes simple crack, but the bone remains intact. It is very common in children, having high recovering power.

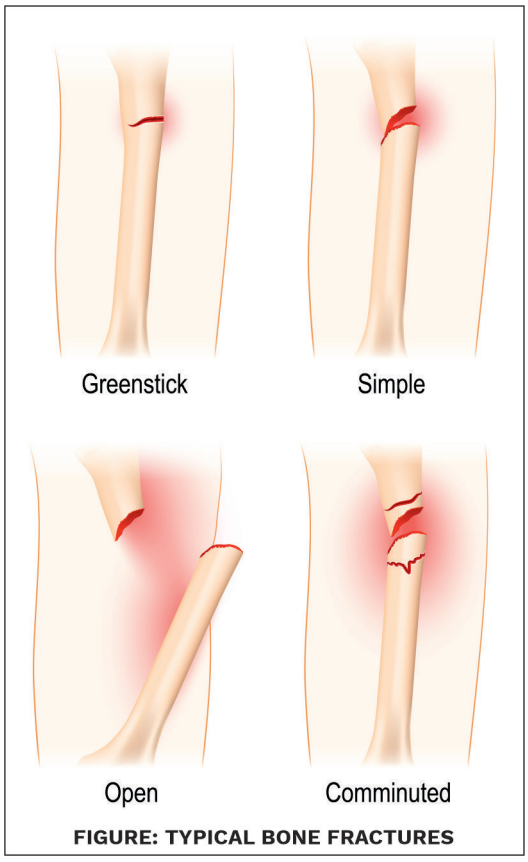
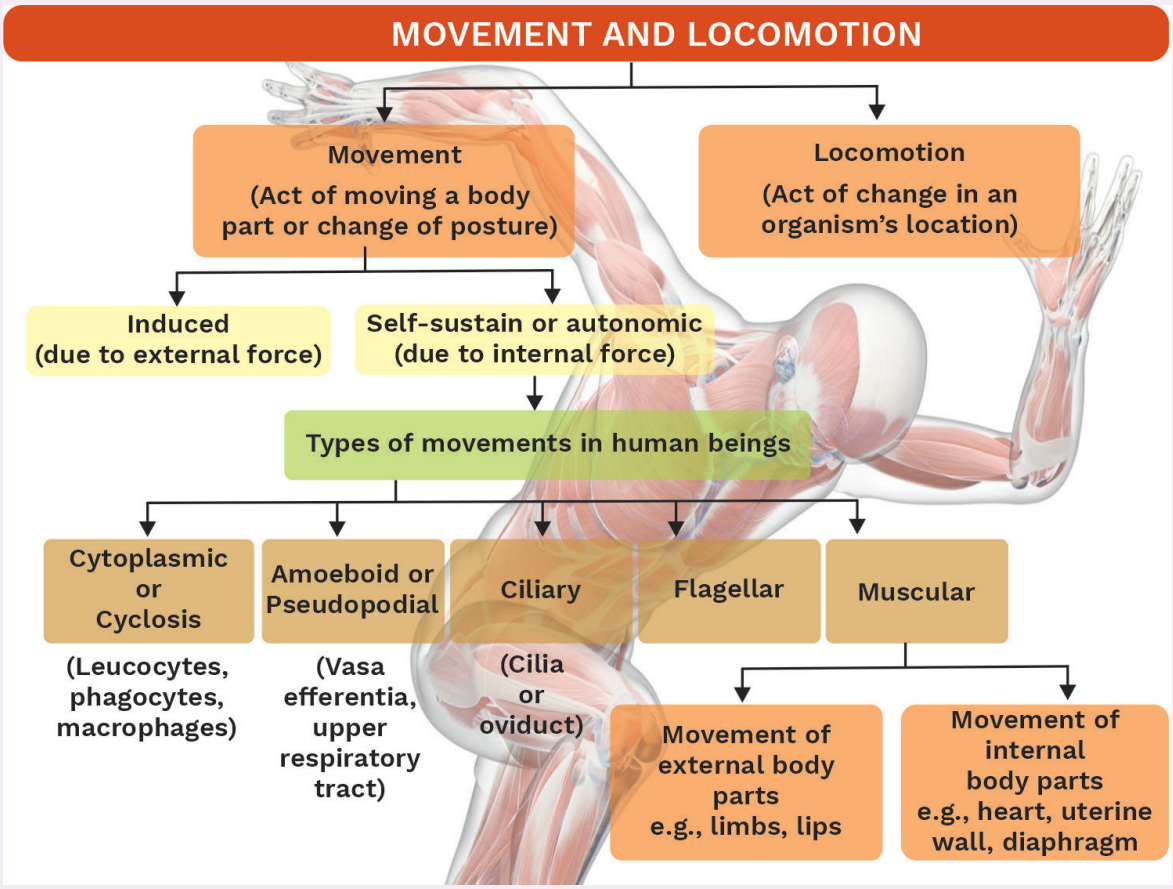
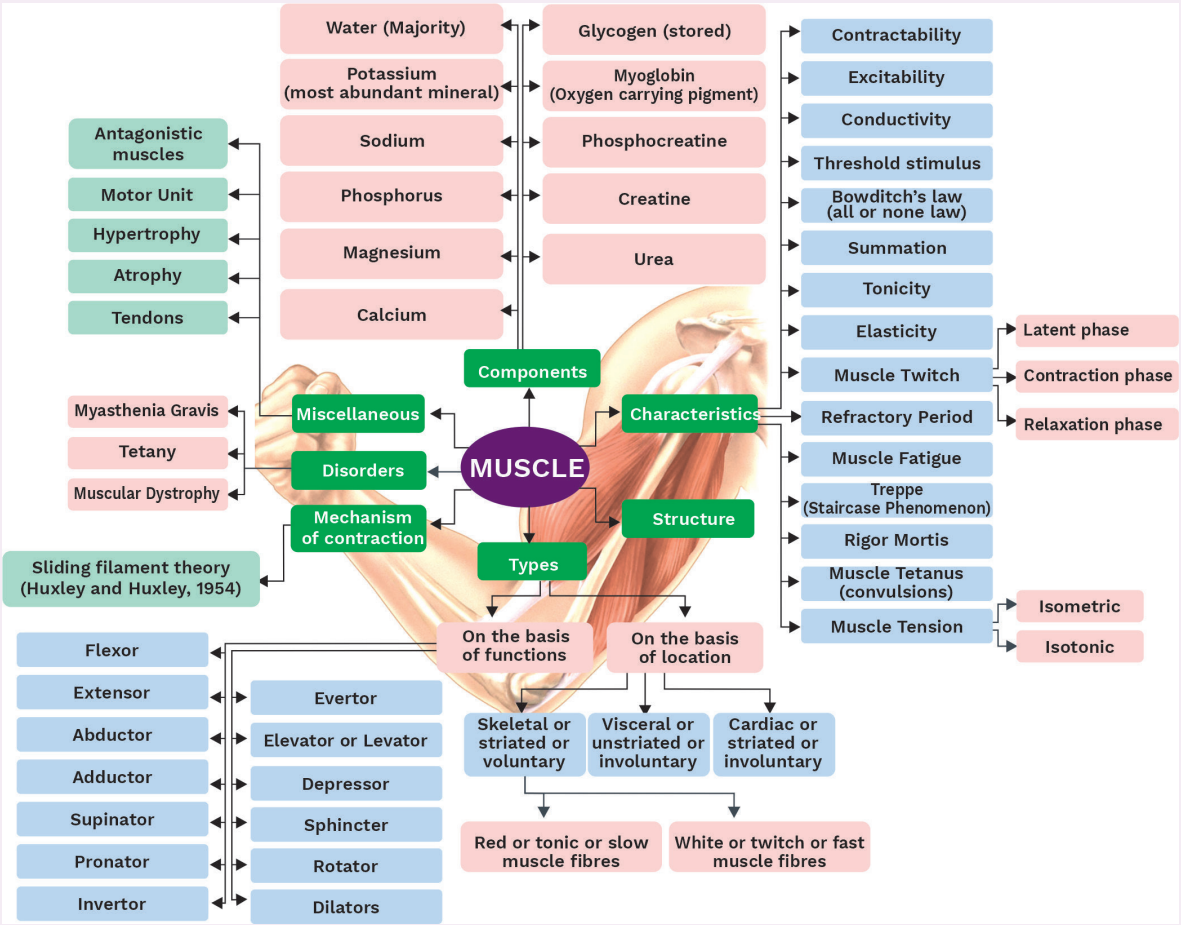


FIGURE: TYPICAL BONE FRACTURES

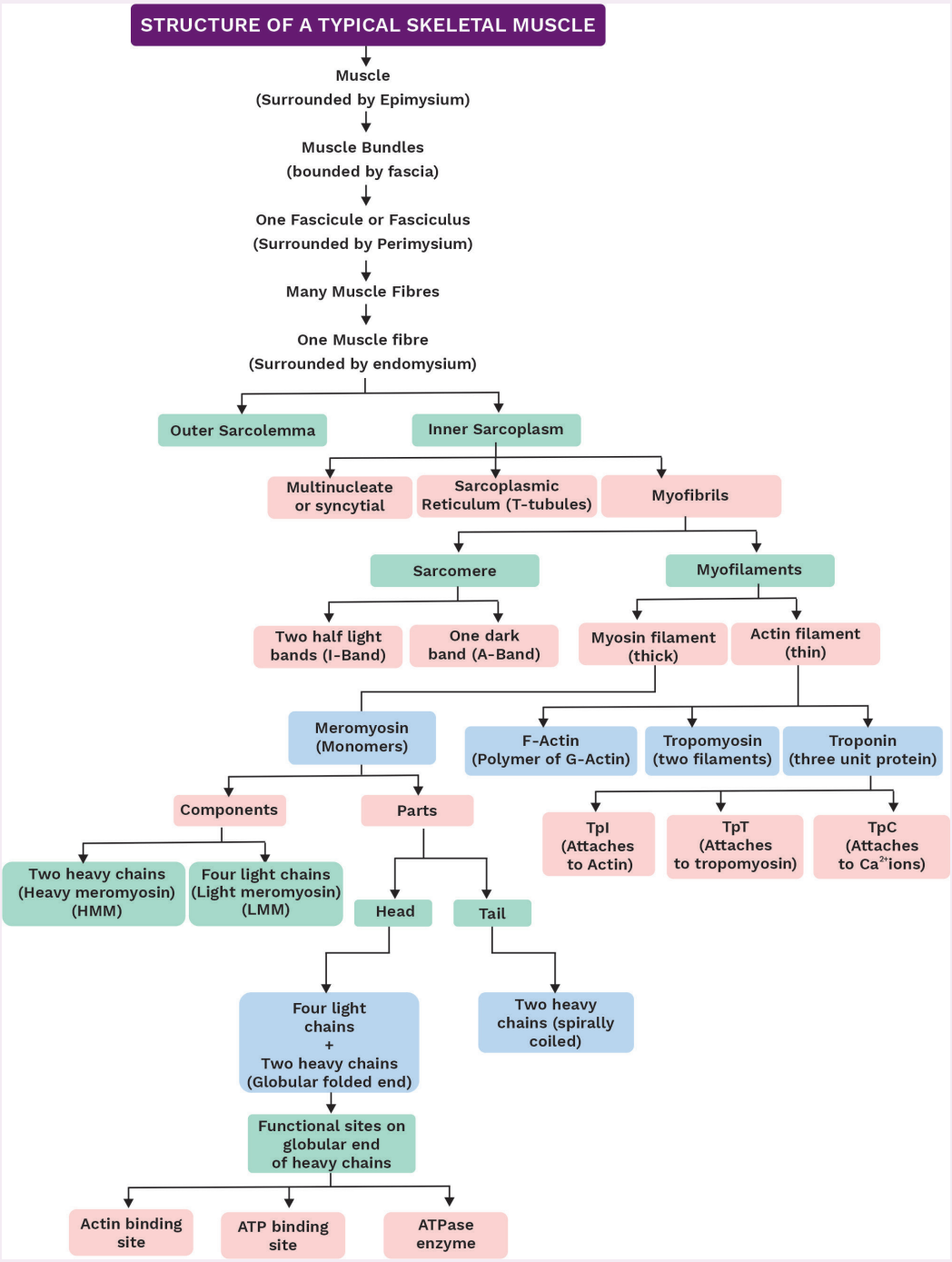
Summary


MOVEMENT AND LOCOMOTION
Movement
(Act of moving a body part or change of posture)
Locomotion
(Act of change in an organism's location)
Induced
(due to external force)
Self-sustain or autonomic
(due to internal force)
Types of movements in human beings
Cytoplasmic or Cyclosis
(Leucocytes, phagocytes, macrophages)
Amoeboid or Pseudopodial
(Vasa efferentia, upper respiratory tract)
Ciliary
(Cilia or oviduct)
Flagellar
Muscular
Movement of external body parts
e.g., limbs, lips
Movement of internal body parts
e.g., heart, uterine wall, diaphragm

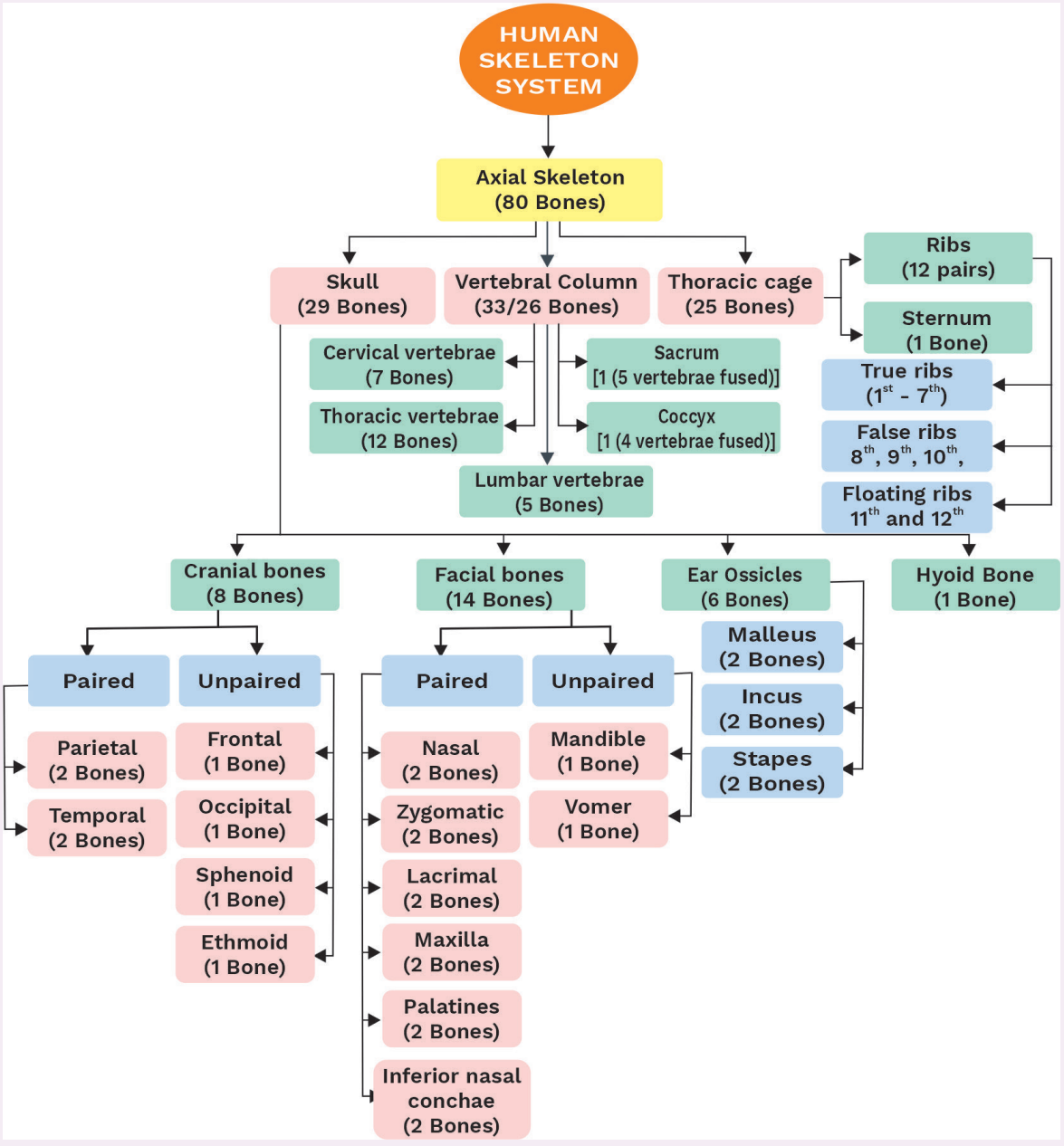
Summary


MUSCLE
Components
Water (Majority)
Potassium (most abundant mineral)
Sodium
Phosphorus
Magnesium
Calcium
Glycogen (stored)
Myoglobin (Oxygen carrying pigment)
Phosphocreatine
Creatine
Urea
Characteristics
Contractability
Excitability
Conductivity
Threshold stimulus
Bowditch's law (all or none law)
Summation
Tonicity
Elasticity
Muscle Twitch
Latent phase
Contraction phase
Relaxation phase
Refractory Period
Muscle Fatigue
Treppe (Staircase Phenomenon)
Rigor Mortis
Muscle Tetanus (convulsions)
Muscle Tension
Isometric
Isotonic
Miscellaneous
Antagonistic muscles
Motor Unit
Hypertrophy
Atrophy
Tendons
Disorders
Myasthenia Gravis
Tetany
Muscular Dystrophy
Mechanism of contraction
Sliding filament theory (Huxley and Huxley, 1954)
Structure
Types
On the basis of functions
Flexor
Extensor
Abductor
Adductor
Supinator
Pronator
Invertor
Evertor
Elevator or Levator
Depressor
Sphincter
Rotator
Dilators
On the basis of location
Skeletal or striated or voluntary
Visceral or unstriated or involuntary
Cardiac or striated or involuntary
Red or tonic or slow muscle fibres
White or twitch or fast muscle fibres

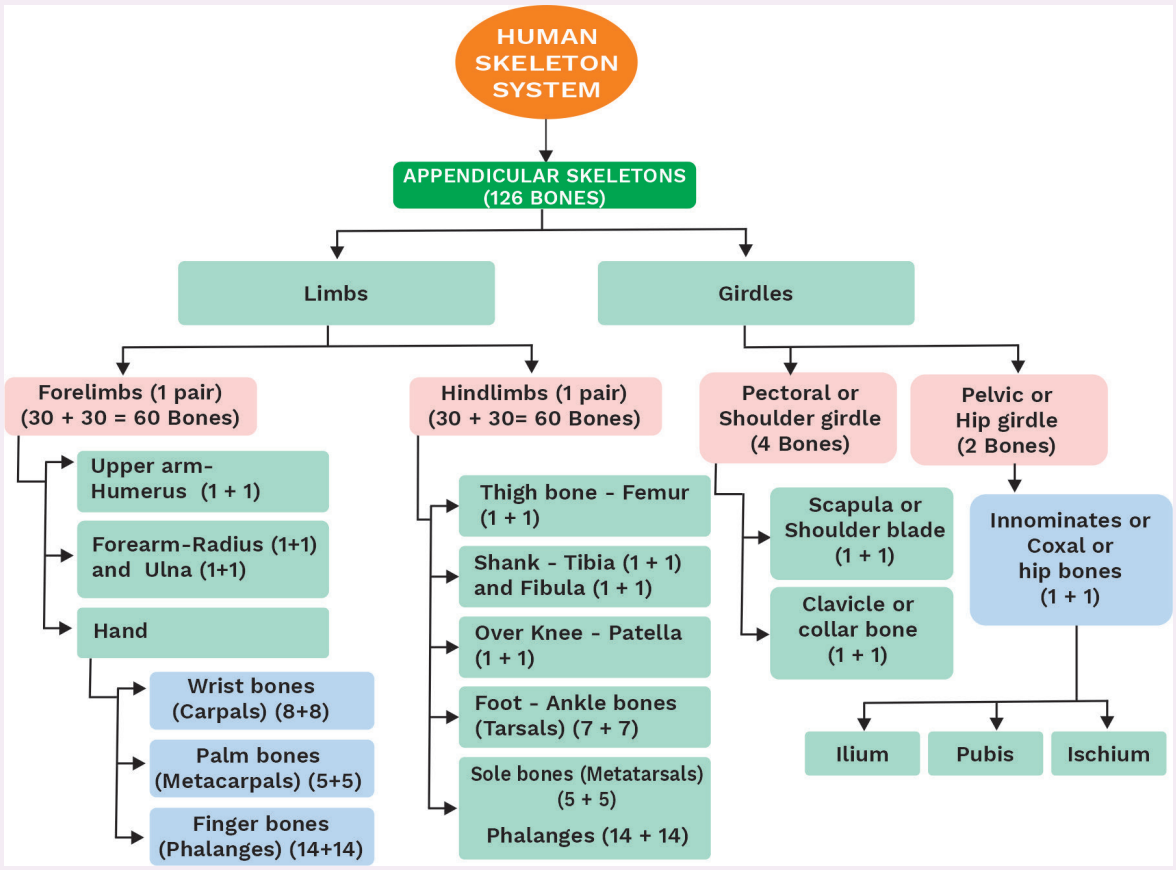
Summary

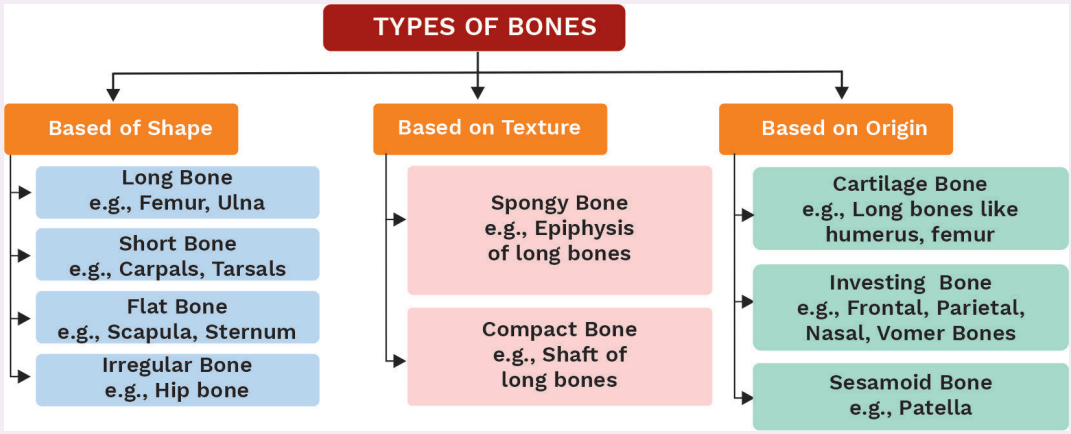

STRUCTURE OF A TYPICAL SKELETAL MUSCLE
Muscle
(Surrounded by Epimysium)
Muscle Bundles
(bounded by fascia)
One Fascicule or Fasciculus
(Surrounded by Perimysium)
Many Muscle Fibres
One Muscle fibre
(Surrounded by endomysium)
Outer Sarcolemma
Inner Sarcoplasm
Multinucleate or syncytial
Sarcoplasmic Reticulum (T-tubules)
Myofibrils
Sarcomere
Myofilaments
Two half light bands (I-Band)
One dark band (A-Band)
Myosin filament (thick)
Actin filament (thin)
Meromyosin (Monomers)
F-Actin (Polymer of G-Actin)
Tropomyosin (two filaments)
Troponin (three unit protein)
Components
Parts
TpI (Attaches to Actin)
TpT (Attaches to tropomyosin)
TpC (Attaches to Ca2+ ions)
Two heavy chains (Heavy meromyosin) (HMM)
Four light chains (Light meromyosin) (LMM)
Head
Tail
Four light chains + Two heavy chains (Globular folded end)
Two heavy chains (spirally coiled)
Functional sites on globular end of heavy chains
Actin binding site
ATP binding site
ATPase enzyme

Summary

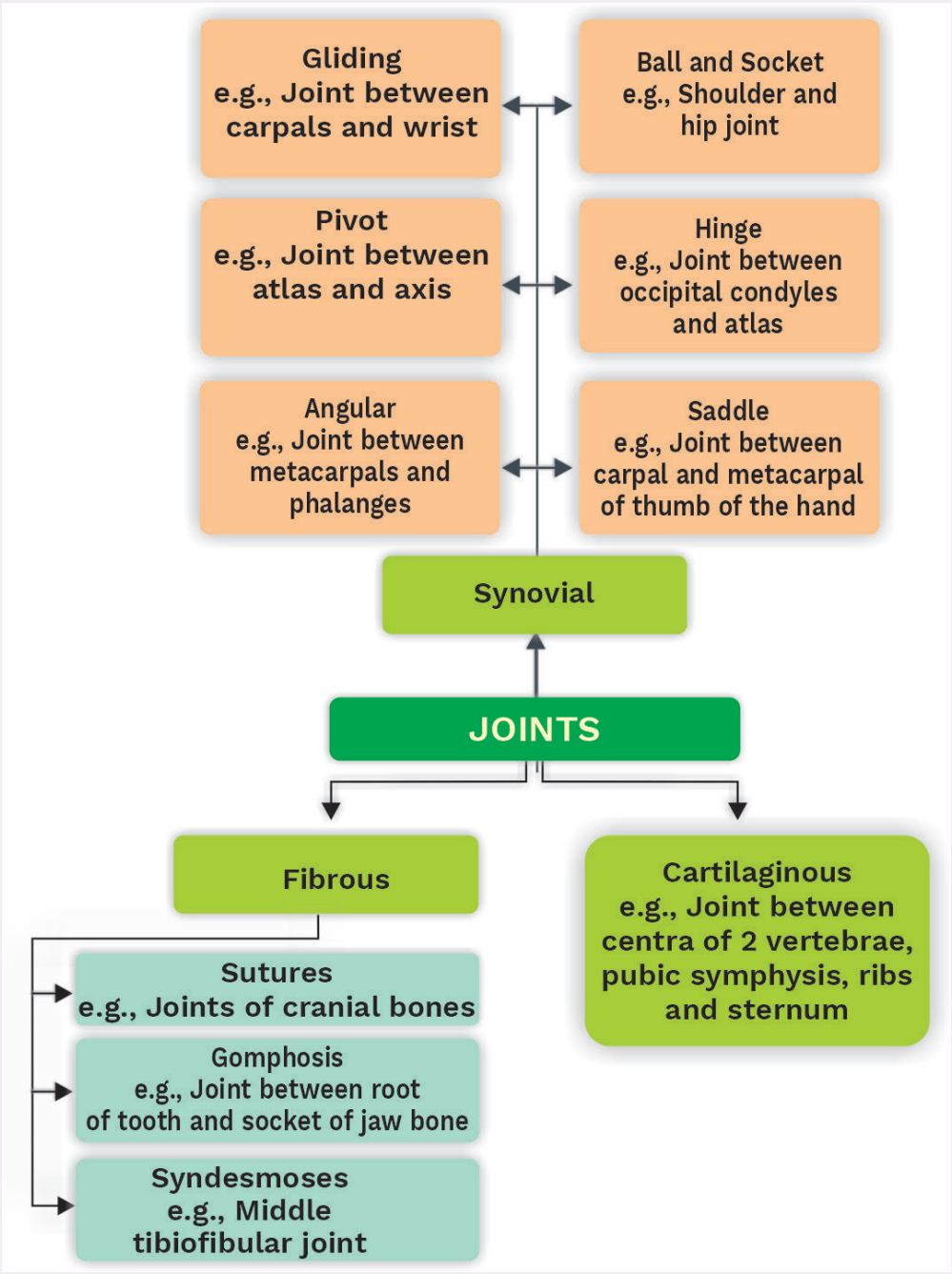

HUMAN SKELETON SYSTEM
Axial Skeleton (80 Bones)
Skull (29 Bones)
Vertebral Column (33/26 Bones)
Thoracic cage (25 Bones)
Ribs (12 pairs)
Sternum (1 Bone)
Cervical vertebrae (7 Bones)
Thoracic vertebrae (12 Bones)
Lumbar vertebrae (5 Bones)
Sacrum [1 (5 vertebrae fused)]
Coccyx [1 (4 vertebrae fused)]
True ribs (1st - 7th)
False ribs 8th, 9th, 10th,
Floating ribs 11th and 12th
Cranial bones (8 Bones)
Facial bones (14 Bones)
Ear Ossicles (6 Bones)
Hyoid Bone (1 Bone)
Paired
Unpaired
Paired
Unpaired
Parietal (2 Bones)
Temporal (2 Bones)
Frontal (1 Bone)
Occipital (1 Bone)
Sphenoid (1 Bone)
Ethmoid (1 Bone)
Nasal (2 Bones)
Zygomatic (2 Bones)
Lacrimal (2 Bones)
Maxilla (2 Bones)
Palatines (2 Bones)
Inferior nasal conchae (2 Bones)
Mandible (1 Bone)
Vomer (1 Bone)
Malleus (2 Bones)
Incus (2 Bones)
Stapes (2 Bones)

Summary


HUMAN SKELETON SYSTEM
APPENDICULAR SKELETONS (126 BONES)
Limbs
Girdles
Forelimbs (1 pair) (30 + 30 = 60 Bones)
Hindlimbs (1 pair) (30 + 30= 60 Bones)
Pectoral or Shoulder girdle (4 Bones)
Pelvic or Hip girdle (2 Bones)
Upper arm- Humerus (1 + 1)
Forearm-Radius (1+1) and Ulna (1+1)
Hand
Wrist bones (Carpals) (8+8)
Palm bones (Metacarpals) (5+5)
Finger bones (Phalanges) (14+14)
Thigh bone - Femur (1 + 1)
Shank - Tibia (1 + 1) and Fibula (1 + 1)
Over Knee - Patella (1 + 1)
Foot - Ankle bones (Tarsals) (7 + 7)
Sole bones (Metatarsals) (5 + 5)
Phalanges (14 + 14)
Scapula or Shoulder blade (1 + 1)
Clavicle or collar bone (1 + 1)
Innominates or Coxal or hip bones (1 + 1)
Ilium
Pubis
Ischium


TYPES OF BONES
Based of Shape
Based on Texture
Based on Origin
Long Bone e.g., Femur, Ulna
Short Bone e.g., Carpals, Tarsals
Flat Bone e.g., Scapula, Sternum
Irregular Bone e.g., Hip bone
Spongy Bone e.g., Epiphysis of long bones
Compact Bone e.g., Shaft of long bones
Cartilage Bone e.g., Long bones like humerus, femur
Investing Bone e.g., Frontal, Parietal, Nasal, Vomer Bones
Sesamoid Bone e.g., Patella

Summary


Gliding
e.g., Joint between carpals and wrist
Ball and Socket
e.g., Shoulder and hip joint
Pivot
e.g., Joint between atlas and axis
Hinge
e.g., Joint between occipital condyles and atlas
Angular
e.g., Joint between metacarpals and phalanges
Saddle
e.g., Joint between carpal and metacarpal of thumb of the hand
Synovial
JOINTS
Fibrous
Cartilaginous
e.g., Joint between centra of 2 vertebrae, pubic symphysis, ribs and sternum
Sutures
e.g., Joints of cranial bones
Gomphosis
e.g., Joint between root of tooth and socket of jaw bone
Syndesmoses
e.g., Middle tibiofibular joint

SOLVED EXERCISE

Q1 **Which of the following stores calcium ions (Ca^{2+}) in a muscle fibre?**
(1) Sarcoplasm **(2) Sarcoplasmic reticulum**
(3) Mitochondria **(4) Sarcolemma**

A1 **(2)**
Sarcoplasmic reticulum stores calcium ions in a muscle fibre.

Q2 **Deltoid (shoulder) muscle functions as a/an**
(1) Flexor **(2) Supinator** **(3) Abductor** **(4) Rotator**

A2 **(3)**
Deltoid muscle functions as an abductor as it pulls the forelimb away from the axis of the body.

Q3 **Which of the following is correct regarding muscle contraction?**
(1) There is no change in the size of I-band.
(2) Myosin filaments are attached at their one end to Z-disc.
(3) Calcium ions bind with troponin protein to initiate muscle contraction.
(4) Length of a sarcomere is about 2 mm.

A3 **(3)**
- During muscle contraction, there is no change in the size of A-band.
- Actin filaments are attached at their one end to Z-disc.
- Length of a sarcomere is about 2 μm.

Q4 **Which of the following is not correct about red muscle fibres?**
(1) Red muscle fibres contain a large amount of myoglobin.
(2) Slow muscle fibres have increased number of mitochondria.
(3) Tonic muscle fibres have an extensive blood vessel system.
(4) Sarcoplasmic reticulum present in red muscle fibres is comparatively more developed.

A4 **(4)**
Sarcoplasmic reticulum present in red muscle fibres is comparatively less developed.

Q5 **A motor unit consists of**
(1) A single motor nerve innervating a single muscle fibre.
(2) Many motor nerves innervating a single muscle fibre.
(3) A single motor nerve innervating a group of muscle fibres.
(4) Many motor nerves innervating a group of muscle fibres.

A5 **(3)**
A motor unit consists of a motor neuron and a group of skeletal muscle fibres it innervates.

Q6 **Select the incorrect pair of skull bones from the following options.**

(1) Ear Ossicle	**-**	**6 bones**
(2) Facial Bones	**-**	**14 bones**
(3) Cranium	**-**	**6 bones**
(4) Hyoid Bone	**-**	**1 bone**

A6 **(3)**
There are 8 bones in the cranium.

Q7 **How many cervical vertebrae are present in the vertebral column?**
(1) 5 **(2) 7** **(3) 12** **(4) 4**

A7 **(2)**
There are seven cervical vertebrae in the vertebral column.

Q8 **Glenoid cavity is related to**
(1) Pectoral girdle **(2) Sternum**
(3) True ribs **(4) Pelvic girdle**

A8 **(1)**
Scapula of the pectoral girdle contains glenoid cavity for attachment with the head of humerus.

Q9 **Which of the following is an example of a hinge joint?**
(1) Hip joint **(2) Ankle joint**
(3) Metacarpophalangeal joints **(4) Joint of skull**

A9 **(2)**
Ankle joint, knee joint, elbow joint are examples of hinge joint.

Q10 **Deficiency of dystrophin causes**
(1) Myasthenia gravis **(2) Rheumatoid arthritis**
(3) Bursitis **(4) Muscular dystrophy**

A10 **(4)**
Muscular dystrophy is a genetic disorder involving degeneration of muscles due to deficiency of dystrophin protein.