

Skeleton, Joints & Muscles

Introduction

The act of changing place or position by the entire body or by one or more of its parts is called **movement**. Movement may occur at the cellular level, for instance cytoplasmic streaming and swimming of gametes; at the organ level, such as heartbeat and rotation of eyeball etc.

9.1 Human skeleton

The total number of bones in adult human is 206. The axial skeleton of adult man consists of 80 bones. The appendicular skeleton of adult man consists of 126 bones. The number of bones in the skull of man is 28 (cranium bones 8, facial bones 14 and ear ossicles ($3 \times 2 = 6$). The bone common to cranium and face is frontal. Number of bones present in the human cranium is 8. Human skeleton is divided into two parts.

(i) **Axial skeleton** : It includes skull, vertebral column, sternum and ribs which lie along the axis of the body.

(ii) **Appendicular skeleton** : Appendicular skeleton includes girdles and limb bones which lie on both the sides of the axis. Osteology is the study of bones and chondrology is the study of cartilages.

Axial Skeleton			Appendicular Skeleton		
Bones			Bones		
Cranium		8	Pectoral girdle Clavicle Scapula		
Face		14			2
Hyoid		1			2
Ear ossicles	3×2	6			
Vertebral column		26			
Sternum		1			
Ribs	12×2	24			
		80			
Cranial Bones			Forelimbs Humerus Ulna Radius Carpals Metacarpals Phalanges		
Frontal		1			2
Parietals		2			2
Temporals		2			2
Occipital		1			8×2 16
Sphenoid		1			5×2 10
Ethmoid		1			14×2 28
		8		60	
Facial Bones			Pelvic girdle Coxal, hip or pelvic		
Nasals		2			2
Maxillae		2			
Zygomatic bones		2			
Mandible		1			
Lacrimal bones		2			
Palatines		2			
Inferior nasals		2			
Vomer		1			
		14			

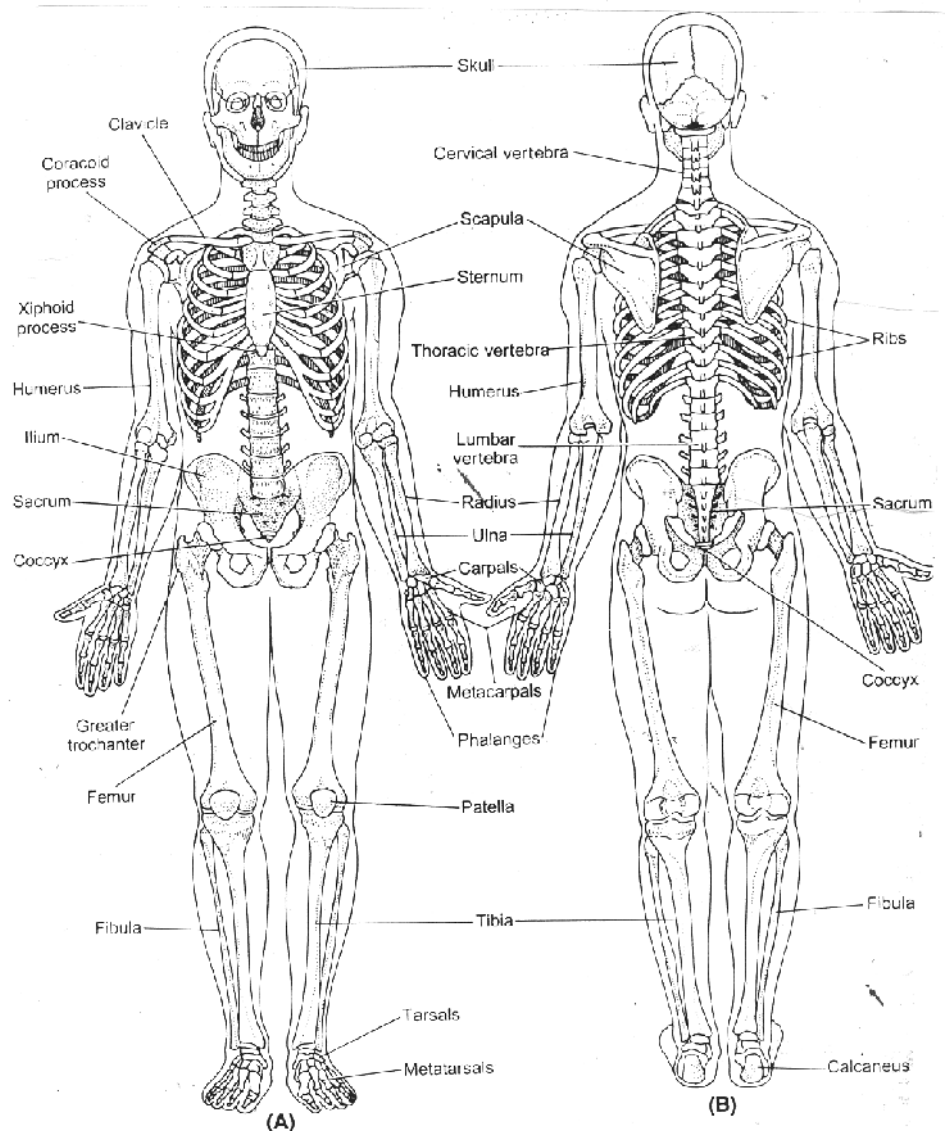
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Vertebral Column			Hindlimbs		
Cervical	7		Femur		2
Thoracic	12		Tibia		2
Lumbar	5		Fibula		2
Sacrum	1	(5)	Patella		2
Coccyx	1	(4)	Tarsals	7×2	14
	26	33	Metatarsals	5×2	10
			Phalanges	14×2	28
					60
Total number of bones in adult human					
80+2+2+60+2+60= 206					
Digital formula of both limbs 2, 3, 3, 3, 3					

The skeleton of a vertebrate is divided into two types: exoskeleton and endoskeleton. Exoskeleton is non-living derived either from epidermis or dermis of skin, e.g., Scales. Endoskeleton in vertebrates includes elements made of living skeletal connective tissues called cartilages and bones. A cartilaginous endoskeleton is found in elasmobranch fishes like *Scoliodon* (Shark). All other vertebrates have bony endoskeleton. Three types of bones in vertebrates are: cartilaginous bones or replacing bones, membrane bones (investing bones or dermal bones) and sesamoid bones formed by ossification of tendons.

The skull bones fit together by sutures. Temporary holes in the cranium are fontanelles. Sinuses are air spaces within skull bones. Cheek bones are called zygomatics. The only movable bone in the skull of man is mandible. The vertebral column of man consists of 33 vertebrae. Human vertebral formula is $C_7T_{12}L_5S_{(5)}Cd_{(4)}$. The number of bones in the vertebral column is 26. Vertebral column gives support to the trunk, provides places for the attachment of the ribs and bones of pelvis. Vertebral column permits movements and protects the spinal cord. Usually, there are 12 pairs of ribs, but occasionally, there may be 11, 13 or even 14 pairs.

The first seven pairs of ribs are known as "true ribs", the only one reach the sternum directly. Pairs 8, 9 and 10 are 'false ribs', they are attached indirectly to sternum by means of cartilages. Last two pairs



The human skeleton
A. Anterior view, B. Posterior view

(11 and 12) fall far short of the sternum and are known as 'floating ribs'. 'Gorilla ribs' are the extra floating ribs, if any. Sternum or breast bone of man consists of three portions: manubrium, body and xiphoid process. Clavicles or collar bones articulate with the manubrium of the sternum. The sternum is a favoured site for obtaining samples of haemopoietic (blood forming) tissue during diagnosis of suspected blood diseases.

9.2 Skeleton of frog

The skull of frog consists of cranium, sense capsules and, jaws.

(i) **Cranium** : The roof of cranium is constituted by two frontoparietals fusing in the middle line forming compound bones. The floor of cranium is covered by a median parasphenoid, dagger or inverted 'T' shaped. Cranium consists of two exoccipitals surrounding the foramen magnum through which brain joins the spinal cord. Both exoccipitals bear occipital condyles, so frog's skull is dicondylic. Mammalian skull (Rabbit) is also dicondylic. Monocondylic skull is found in reptiles and birds.

(ii) **Auditory capsule** : It consists of pro-otic bone in anterior face, columella auris and stapedial plate (cartilage) in the middle ear. Auditory capsule communicates by fenestra ovalis.

(iii) **Olfactory capsule** : Olfactory capsule consists of ethmoidal portion of sphenethmoid, paired nasals, vomers and septomaxillaries.

(a) **Nasals** are large triangular bones covering the roof of olfactory capsules.

(b) **Vomers** form the floor of the olfactory capsules, bearing about seven vomerine teeth in the posterior margin of each bone.

(c) **Septomaxillaries** are a pair of small irregular bones bounding external nares. Each consists of a basal plate, small limb and a large limb.

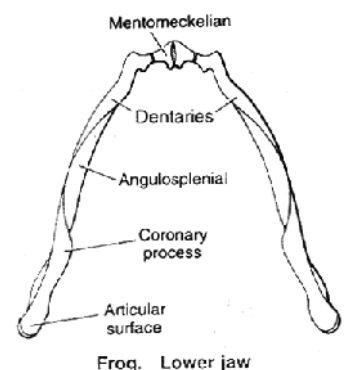
(iv) **Upper jaw** : Upper jaw consists of premaxilla, maxilla and quadratojugals. Premaxilla : anterior most bone of upper jaw with four to five teeth. Maxilla : Side bone of upper jaw with numerous minute teeth. Quadrato-jugal : comma-shaped, small, slender bone of posterior outer margin of upper jaw. Quadrate cartilage is found at the angle of jaw. It is attached to lower jaw through autostylic suspensorium. Three pairs of suspensoria bones connecting upper jaw with cranium are: palatines, pterygoids and squamosals.

(a) **Palatine** : Rod-like, ventral, anterior bone connecting maxilla with sphenethmoid.

(b) **Pterygoid** : Triradiate, Y-shaped bone lying ventral, posterior part

(c) **Squamosal** : Hammer-shaped or 'T' shaped or Y-shaped bone, dorsolateral, posterior part of skull.

(v) **Lower jaw** : Lower jaw consists of **Mento-meckelian**, dentary, angulosplenic (3 pairs of bones) and Meckel's cartilage. Mento-meckelian is found at the tip of the lower jaw. Dentary is at the outer surface of anterior half of jaw. Angulosplenic is at the inner surface and lower edge of the jaw. **Meckel's cartilage** is found at the articular surface. The lower jaw of frog is composed of two halves or rami. As each ramus has three bones and a cartilage, the number of the skeletal elements in the lower jaw of frog is eight. Teeth are entirely absent in the lower jaw of frog.



(vi) **Hyoid apparatus** : Hyoid apparatus lies in the floor of buccopharyngeal cavity and provides attachment and support to the tongue. Hyoid apparatus consists of:

Body : A cartilaginous plate

Alary processes : Also called anterior processes 'wing-like'

Posterior processes : Present in posterior-lateral margin

Anterior cornua : Two long processes articulating with auditory capsule

Posterior cornua : Two short processes (replacing bones)

(vii) **Vertebral column** : Vertebral column develops from notochord. It consists of vertebrae 8th vertebra is amphicoelous as the centrum is biconcave. 9th vertebra is acelous as the centrum is convex on both the sides. 9th vertebra is also called sacral, its transverse processes are backwardly directed and articulated with ilium of pelvic girdle (sacroiliac joint). Urostyle is the 10th vertebra, as long as remaining vertebral column. Urostyle has a dorsal keel or crest or ridge. Spinal cord in frog extends upto the anterior part of urostyle (Urostyle = coccyx). Frog has total ten vertebrae including urostyle. First vertebra is called atlas with reduced centrum and without prezygapophyses and transverse processes. 2nd to 7th vertebrae have same structure, called typical vertebrae, characterized by procoelous condition, centrum concave in front and convex behind.

(viii) **Sternum** : Sternum of frog has four parts

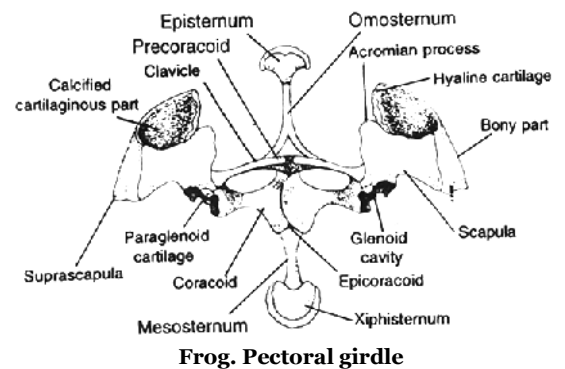
Episternum : Anterior flattened circular cartilage

Omosternum : Inverted 'Y' shaped cartilage bone articulated with clavicles

Mesosternum : Rod-like cartilage bone articulated with epicoracoids

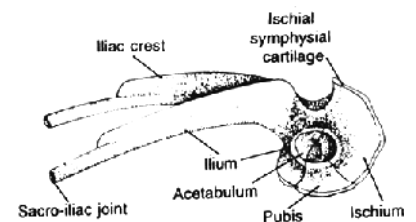
Xiphisternum : Terminal circular cartilage

(ix) **Pectoral girdle** : Each half consists of suprascapula (a calcified cartilage), scapula, coracoid, precoracoid, epicoracoid and paraglenoid cartilage. Clavicle is a slender rod, separated from the coracoid by a wide gap called coracoid foramen. Posteriorly, scapula forms the upper half of a deep cup-like depression, the glenoid cavity for articulation with humerus bone of forelimb. Sternum lies in the mid-ventral line intimately connected between the two halves of pectoral girdle. Pectoral girdle is also known as shoulder girdle. It is composed of two halves united along the mid-ventral line forming a C-shaped structure.



Frog. Pectoral girdle

(x) **Pelvic girdle** : Pelvic girdle is also known as hip girdle. Pelvic girdle is 'V' shaped. Each half is composed of ilium, ischium and pubis called os innominate. Ilium is greatly elongated, antero-dorsal, forms sacroiliac joint. It also possesses iliac crest. Ischium is intermediate in size, postero-dorsal, slightly oval bone. Pubis is the smallest, triangular calcified cartilage, antero-ventral in position. All the skeletal elements contribute in the formation of a cup-shaped cavity called acetabulum for the articulation of head of femur of hindlimb.



Frog. Pelvic girdle in lateral view

(xi) **Digital formula of frog** :

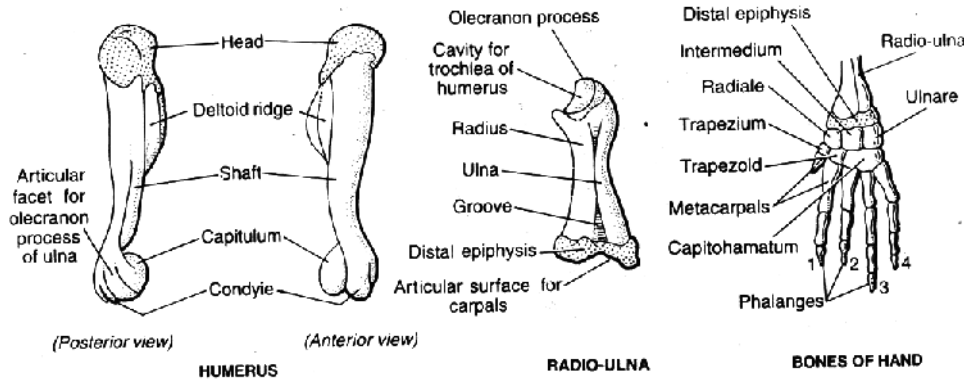
(a) Digital formula of forelimb 0, 2, 2, 3, 3

(b) Digital formula of hindlimb 2, 2, 3, 4, 3.

(xii) **Forelimb** :

(a) **Humerus** : It consists of head, shaft, capitulum and condyle. The shaft possesses a 'deltoid ridge' below the head. Distal end forms a rounded capitulum.

(b) **Radio-ulna** : It is a compound bone formed by the fusion of radius and ulna. Ulna projects into an olecranon process at the proximal end. There is also a cavity for trochlea of humerus.



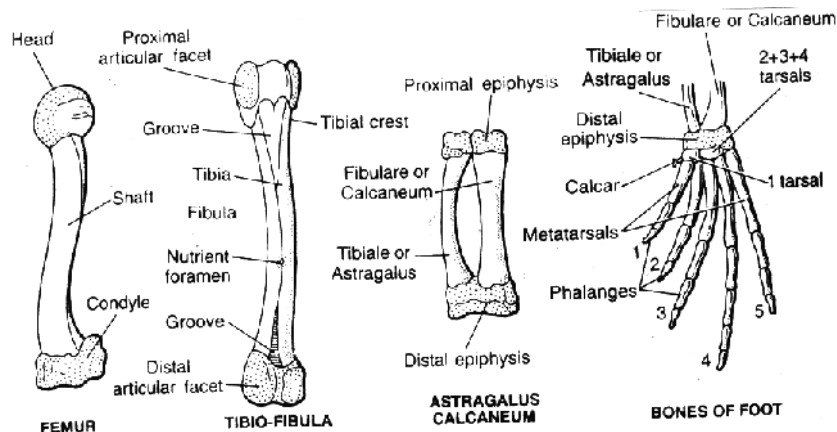
Frog. Forelimb bones

(xiii) **Hindlimb** :

(a) **Femur** : It is long and slender having a slightly curved shaft. Proximal swollen end of femur is called head articulated to acetabulum of pelvic girdle. The distal end forms the condyle.

(b) **Tibio-fibula** : It is a compound bone formed by the fusion of tibia and fibula. Near the proximal end, tibia bears a cnemial crest or tibial crest. A nutrient foramen for anterior tibial artery is present in the middle of the shaft. Tibio-fibula is the longest bone in frog.

(c) **Astragalus and Calcaneum** : The first two tarsals present in the ankle are astragalus and calcaneum, a compound bone. Inner bone is thinner and slightly curved astragalus or tibiale. Outer bone is thicker and straight calcaneum or fibulare.



Frog. Hindlimb bones

9.3 Skeleton of rabbit

There are four bones surrounding foramen magnum supraoccipital, (one) exoccipitals (two) and basioccipital (one). The skull of rabbit is dicondylic with two occipital condyles. A depression called 'sella turcica' is on the basisphenoid to lodge pituitary gland. Tympanic bulla encloses tympanic cavity or middle ear containing tympanic membrane and a chain of three ear ossicles, which from out side are malleus, incus and stapes.

(i) **Upper jaw of rabbit** : The upper jaw consists of following bones

(a) Premaxilla : Anteriormost with two incisor teeth.

(b) Maxilla : Middle region, bears cheek teeth (three premolars and three molars and a long zygomatic process).

(c) Palatine : Located behind maxilla, a secondary palate is formed from processes of premaxilla, maxilla and palatines.

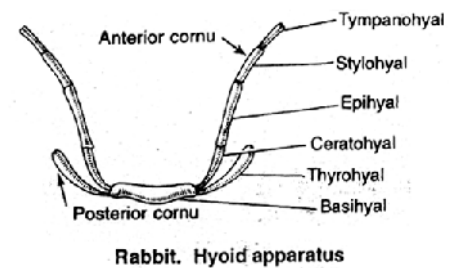
(d) Pterygoid : A small bone articulated with palatine.

(e) Squamosal : Located between parietal and frontal dorsally, periotic and tympanic bulla posteriorly. It also bears zygomatic process.

(f) Jugal : It is a narrow wavy bone. It connects zygomatic processes of squamosal and maxilla forming 'zygomatic arch' Zygomatic arch surrounds the eye orbit from outer side.

(ii) **Lower jaw** : Each ramus of lower jaw is made up of a single dentary. Dentary has a conspicuous condyle, coronoid process and angular process. Teeth in each dentary are incisor (one), premolars (two) and molars (three). Diastema is found between incisor and premolar. The bony sockets of the jaws in which teeth are implanted are alveoli. The jaw suspensorium in rabbit is craniostylic, i.e., lower jaw articulates with upper jaw by squamosal.

(iii) **Hyoid apparatus** : Hyoid apparatus is mainly formed of bones. Its main part or body, located beneath and supporting root of tongue is called basihyal. Anterior cornu is long and 4-segmented. The segments from base to tip are ceratohyal, epihyal, stylohyal and tympanohyal. Posterior cornu consists of a single thyrohyal bone.



(iv) **Vertebral column** : Long neck in camel and giraffe is due to length of vertebrae. The first cervical vertebra is atlas. Centrum is absent. It is articulated to skull through occipital condyles. Zygapophyses are absent. Odontoid fossa present. Second cervical vertebra is the axis. It has odontoid process. Vertebrae of mammals are acelous or amphiplatyan. Total number of vertebrae in rabbit varies from 45 to 47. The vertebral column is divisible into five regions namely cervical, thoracic, lumbar, sacral and caudal. Vertebral formula of rabbit is $C_7T_{12-13}L_{6-7}S_4Cd_{16}$. Cervical vertebrae seven in number constant in all mammals except four species given below :

Manatus oustralis – 6, Chloaeopus hofmani – 6 ; Bradypus tridactylus – 9, Bradypus torquates – 8

(v) **Sternum** : Sternum is composed of six rod-like pieces, the sternebrae arranged in a straight line. The first piece is called presternum or manubrium. Remaining five sternebrae constitute mesosternum (Gladiolus). This is followed by rod-like metasternum (Xiphisternum). Metasternum terminates in an expanded plate of cartilage, the xiphisternal cartilage or xiphoid cartilage. Sternum of rabbit consists of six sternebrae, a xiphisternum and a xiphoid cartilage.

(vi) **Ribs** : There are 12 or 13 pairs of thoracic ribs present in a rabbit. Three types of ribs in rabbit are:

(a) True ribs : 1st to 6th pair

(b) False ribs : 7, 8 and 9th pair (3 pairs)

(c) Floating ribs : 10, 11 and 12th pairs (3 pairs) (not attached to sternum)

A thoracic rib is divisible into a longer, dorsal bony vertebral rib and a smaller, ventral cartilaginous sternal rib.

Vertebral rib is bicephalous (with two heads). It is articulated to a thoracic vertebra by tuberculum to transverse process and by capitulum to centrum.

(vii) **Pectoral girdle** : Pectoral girdle of rabbit consists of two bones, a membranous bone called clavicle and a large replacing bone called shoulder blade or scapulacoracoid. Dorsal or vertebral edge of scapula is made of a thin strip of cartilage, the suprascapula. A bone universally present in mammalian pectoral girdle is scapula. Coracoid is fused with scapula forming a small coracoid process. An acromian spine is present on the dorsal surface of scapula. Acromian spine continues ventrally into a free downwardly directed acromian process and a long backwardly projecting metacromian process. A glenoid cavity for articulation of head of humerus, is present at the tip of scapula and coracoid process. Clavicle is a rod-like bone articulated with acromian process.

(viii) **Pelvic girdle** : Pelvic girdle of rabbit is W-shaped. Each half consists of four bones namely ilium, ischium, pubis and cotyloid. Ilium is elongated bone running parallel to the vertebral column with articular facet for sacral vertebra; sacroiliac joint. Ischium is stout and straight bone, found on dorsal and outer side. Pubis is the smaller bone, found on ventral and inner side. Pubis does not take part in the formation of acetabula. Between the pubis and ischium is present a cavity known as obturator foramen. A small cotyloid bone is present on the inner side of acetabulum between ilium and ischium. Cotyloid bone (acetabular bone) is not found in the pelvic girdle of frog. Pubis of both sides articulate in the middle by pubic symphysis. Pubic symphysis is provided with fibrocartilage.

(ix) **Digital formula of rabbit** :

(a) Digital formula of forelimb 2, 3, 3, 3, 3

(b) Digital formula of hindlimb 0, 3, 3, 3, 3

(x) **Forelimb** :

(a) Humerus : Proximally it bears a large head, greater tuberosity and lesser tuberosity. Between the two tuberosities is a bicipital groove. Proximal part bears a slight deltoid ridge. Distally humerus bears a pulley-like trochlea. Above trochlea are present supratrochlear foramen and olecranon fossa.

(b) Radio-ulna : Proximal end of ulna bears olecranon process. A sigmoid notch is present fitting trochlea of humerus.

(xi) **Hindlimb** :

(a) Femur: Femur is the longest and stoutest bone of the body in a mammal. Proximally, it bears a head, greater trochanter, lesser trochanter and third trochanter. Distally, it bears intercondylar groove (back) and patellar groove (front).

(b) Tibio-fibula: Tibia is large, stout and straight. Fibula is small and slender. Tibia and fibula are free proximally but fused distally, hence the name tibio-fibula. The proximal end of tibia bears a small sharp ridge called cnemial or tibiale crest.

9.4 Joints

There are many articulations or joints present in the skeleton. Joints are classified based upon their structure and the kinds of movements which they permit. Three main types of joints are : Immobile joints (Synarthroses), Imperfect movable joints (Amphiarthroses) and Perfect movable joints (Diarthroses).

(i) **Immovable joints** : No joint cavity, no movement possible. These joints include

(a) **Sutures**: Found between skull bones, Sutures are fixed or fibrous joints, articulating bones are held together by white fibrous tissue.

(b) **Gomphoses**: Teeth in mandibles, present in premaxillary and maxillary bones.

(c) **Shindylases**: Ethmoid bone in vomer (one bone fits into slit of another).

(ii) **Imperfect movable joints** : With or without joint cavities, permit a small amount of movement. Fibrocartilage is placed between the bones. These joints are also called cartilaginous joints. e.g., Between bodies of the vertebrae,

Between the manubrium and body of the sternum, Between bones of the pubic symphysis, Sacroiliac joint in frog.

(iii) **Perfect movable joints** :

(a) Movable joints are called synovial joints.

(b) Synovial joint has a synovial or joint cavity, a space between articulating bones.

(c) Articular cartilage covers the surface of articulating bones.

(d) Articular cartilage of synovial joint is hyaline cartilage.

(e) Synovial joints are surrounded by a tubular articular capsule.

(f) The articular capsule consists of two layers, outer fibrous capsule and inner synovial membrane.

(g) The synovial membrane secretes synovial fluid which lubricates and provides nourishment to articular cartilage.

(h) In old age, stiffness of joints is due to the decrease in synovial fluid.

(iv) **Types of Synovial Joints** :

(a) **Ball and Socket Joints** : Humerus in glenoid cavity. Femur in acetabulum.

(b) **Hinge Joints** : Knee Joint, between phalanges.

(c) **Gliding Joints** : (Angular joints) Between zygapophyses. Between carpals and tarsals.

(d) **Pivot or Trochoid or Rotatory joints** : Between atlas and axis of mammals, head of radius and capitulum of humerus.

(e) **Saddle Joints** : (Biaxial joints) Between carpals and radius, permit movements in two planes at right angles to each other.

9.5 Muscles

(i) **Movement of skeletal muscles**

(a) **Flexor and Extensor** : Muscles that bend one part over another joint is called flexor. Extensor muscle is antagonist of flexor muscle. The contraction of an extensor extends a joint by pulling one of the articulating bone apart from another.

(b) **Pronator and Supinator** : The contraction of a pronator rotates the forearm to turn the palm downward or backward. Supinator is antagonist of pronator. A supinator contracts to rotate the forearm and thus to make palm face upward or forward.

(c) **Abductor and adductor** : An abductor contracts to draw a bone away from the body midline. Muscle that brings the limb away from midline is called abductor. An adductor draws a bone towards the body midline. Muscle that brings the limb towards midline is called adductor. Abductor muscle is antagonist of adductor muscle. Abduction is elevation and adduction is depression.

(d) **Protractor and Retractor** : Protractor muscle pulls the lower jaw, tongue and the head forward. Retraction is opposite to protraction. Retractor muscle draws the lower jaw, tongue and the head backward.

(e) **Inversion and Eversion** : Turning of feet so that the soles face one another is inversion. Eversion is the opposite of inversion. In this movement, the soles of the feet face laterally.

(f) **Rotation and Circumduction** : Rotation is term that indicates the partial revolving of a body part on that part's long axis. Circumduction is a composite movement that involves successive flexion, extension and medial and lateral rotation.

(ii) **Characters of Red Muscles :**

(a) Red muscle fibres are thinner.

(b) Darker in colour.

(c) Slower in contraction rate.

(d) Rich in mitochondria.

(e) Rich in red heme-protein myoglobin.

(f) Depend mainly on aerobic metabolism.

(g) Perform slow and sustained contractions for long periods without fatigue.

(h) Carry out aerobic contraction without accumulating much lactic acid. e.g., Extensor muscles on back of the body. Avian flight muscles used for prolonged slow flying, kite.

(iii) **Characters of White Muscles :**

(a) White muscle fibres are thicker.

(b) Lighter in colour.

(c) Faster in contraction rate.

(d) Poor in mitochondria.

(e) Myoglobin absent.

(f) Depend mainly on anaerobic glycolysis.

(g) Perform fast and strenuous work for short periods with fatigue.

(h) Carry out anaerobic contraction with accumulation of much lactic acid. e.g., Muscles of eyeball. Avian flight muscles used in short fast flying, sparrow.

(iv) **Composition of Muscle** : Muscle tissue is about 75% water, 20% protein and 5% nonprotein organics and minerals Important nonprotein organics include ATP, phosphocreatine, creatine, urea and glycogen. Potassium is the most abundant mineral element in muscle. The oxygen carrying iron-protein pigment of muscle is called myoglobin.

(v) **Muscle Protein (Myoglobin) :**

(a) Myoglobin is an important heme containing globular protein; it is an oxygen storing protein in red muscle fibres of vertebrate muscles.

(b) Myoglobin is especially abundant in the muscles of diving mammals such as whales, porpoises, dolphins and seals and in diving birds like penguins.

(c) Myoglobin stores oxygen as oxymyoglobin.

(d) Oxymyoglobin releases oxygen for utilization during muscle contraction.

(e) Myoglobin has only one heme group.

(f) The oxygen dissociation curve of myoglobin is a simple hyperbola (sigmoid for oxyhaemoglobin).

(vi) **Important Fractures :**

(a) **Comminuted:** The bone is splintered at the site of impact and smaller fragments of bone are found between the two main fragments.

(b) **Greenstick:** A partial fracture in which one side of the bone is broken and the other side bends; it occurs only in children.

(c) **Spiral:** The bone is usually twisted apart.

(d) **Transverse:** A fracture at right angles to the long axis of the bone.

(e) **Impacted:** A fracture in which one fragment is firmly driven into the other.

(f) **Pott's:** A fracture of the distal end of the fibula, with serious injury of the distal tibial articulation.

(g) **Colles:** A fracture of the distal end of radius in which the distal fragment is displaced posteriorly.