UNIT 2

# Skeletal System

## Structure



## 2.1 INTRODUCTION

In the previous unit you have studied about the integumentary system which forms the outer most protective covering of the body. In the present unit we shall discuss the skeletal system which provides strength and definite shape to the body of the vertebrates. You have already studied about soft-bodied animals in the core course BZYCT-131 (Animal Diversity). As you will recall the soft bodied animals can bend and twist their bodies as they like it. They can wriggle through burrows and crevices to avoid obstacles. At the beginning of evolution of life this ability appeared to be an advantage. But it is not always so. It puts a restriction on size because large soft bodies are difficult to manage. A large body needs support to prevent it from collapsing. The supporting structure needs to be hard, as only then can it provide a definite shape to the animal and also help protect the soft vital parts of the body. The supporting structure should also be helpful in locomotion. Locomotion as you know is brought about by the movement of the body due to contractions and

expansions of muscles, the contractile tissue. Muscles need to be attached to hard surfaces to assist in contractions. In nonchordate animal as you will recall all these needs were fulfilled by the development of an external covering in the form of a chitinous hard structure as seen in arthropods or formation of a calcareous shell as in molluscs. In vertebrates, the bone or cartilage or both are present within the body in order to provide protection, support and locomotion to the body. Both the bone and cartilage are formed of connective tissue. This supporting structure of shell or chitin or cartilage or bone is called skeleton.

Generally there are two types of skeletons in animals; (a) the **exoskeleton** found on the outside of the body and (b) the **endoskeleton** found within the body of the animal. Vertebrates possess an endoskeleton which is formed of connective, living tissue that is mesodermal in origin and grows with the animal. It helps to hold the soft parts of the animal together and serves as a mechanical framework for the animal body giving it distinct shape and rigidity. It also provides a hard surface for the attachment of muscles and protects the vital internal organs of the body. In this unit we will study the composition and general structure of endoskeleton of vertebrates which in them is formed of connective tissue. We will also compare the skeleton of two vertebrates, an amphibian (an anamniote) and a mammal (amniote) which will help us understand the changes that have occurred in the skeleton of vertebrates during the course of evolution.

## Objectives

After studying this unit, you should be able to:

- explain the advantages of endoskeleton of vertebrates,
- give the differences between the cartilage and the bone,
- describe the typical skeleton of a vertebrate, and
- describe the differences between the skeleton of frog and rabbit.

## 2.2 CARTILAGE AND BONE

The vertebrate endoskeleton is composed of two different types of supportive connective tissue, the **cartilage** and the **bone**. Cartilage is a relatively soft elastic connective tissue, whereas bone is a more ossified hard rigid connective tissue. Both the cartilage and the bone consist of non-living, ground substance, called matrix in which living cells are present.

Cartilage which is believed to have appearded first during embryonic development in vertebrates is later replaced by bone. However, in elasmobranch fishes and cyclostomes the complete skeleton is made only of cartilage, though the skeleton of a majority of vertebrates is bony. The matrix

of cartilage contains elastic or tough white fibres. The protein found in cartilage is **chondrin** and the living cartilage cells are called **chondrioblasts.** There are no blood vessels or nerves in cartilage. Nutrients are diffused within the matrix and therefore, the cartilage is seldom thick (Fig. 2.1).

The matrix of the bones contains a protein called **collagen** that provides the surface on which the inorganic salts can adhere. These inorganic salts are formed when **calcium phosphate and calcium carbonates** combine to form **calcium hypoxyapatite** that gives the bone its hardness. The collagen on the other hand gives flexibility so that the bones are not brittle. Compact bone is composed of calcified bone matrix, arranged in concentric rings. The rings contain cavities (lacunae) filled with bone cells (**osteocytes**) which are interconnected by many minute passages called **canaliculi**. The **canaliculi** serve to distribute nutrients throughout the bone. This entire organisation of lacunae and canaliculi is arranged into an elongated cylinder called an **osteon** and also called the **Haversian system** (Fig. 2.2).

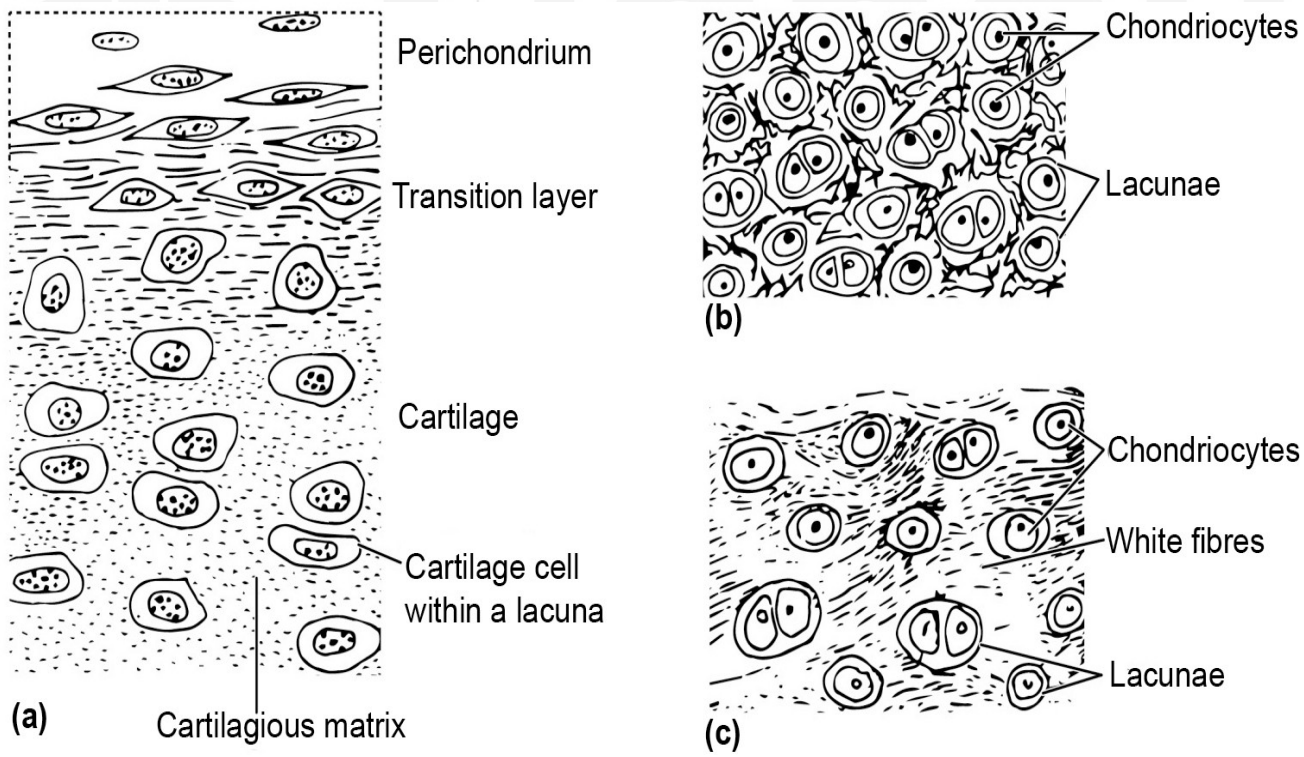



**Fig. 2.1: (a) Section through a piece of hyaline cartilage, adjacent to the connective tissue perichondrium. Cartilage of this type would be found in joints and the rings of the trachea; (b) elastic cartilage; (c) Fibro cartilage which is found in the pubic symphysis.**

The bone secreting cells are called **osteoblasts**. These do not divide but secrete collagen and calcium salts, and as the secreted matrix surrounds the cells, they get entrapped into it and the nature of the cells changes. They are then called **osteocytes** (see Fig. 2.2c).

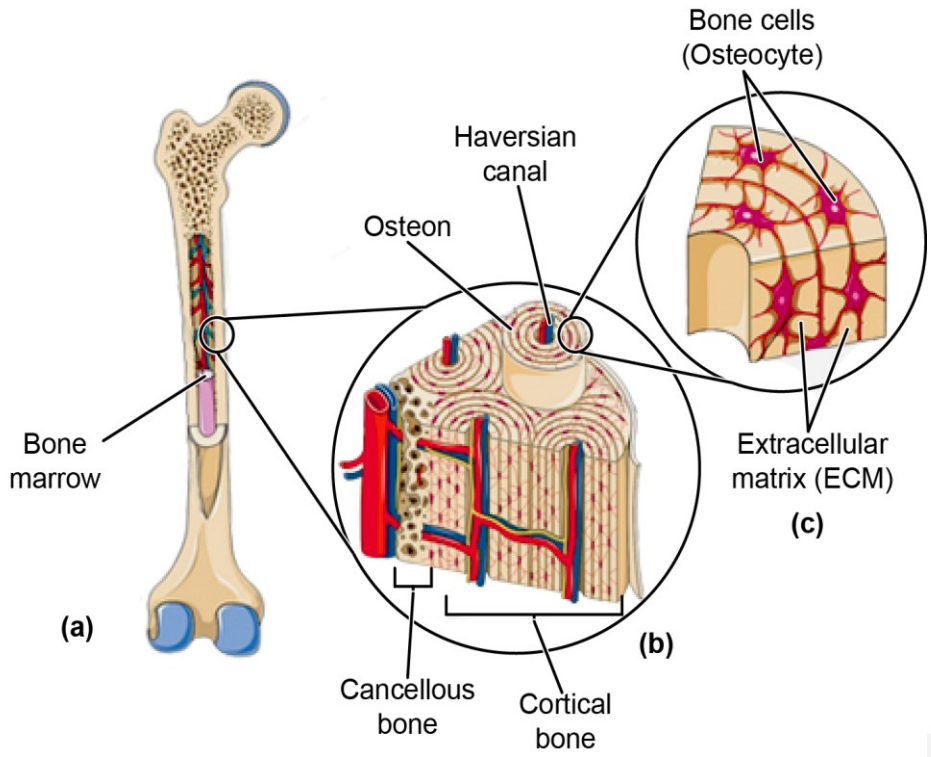



**Fig. 2.2: Bone structure. (A) Adult long bone. (B) Enlarged section showing how bone cells and the dense calcified matrix are arranged in units called osteons.**

There are two types of bones based on the manner of their formation during embryonic development. (i) Bones may be formed by ossification of the pre-existing cartilage which are then called **cartilage bones or replacment bones** because they replace the pre-existing cartilages. This type of ossification is known as **endochondral ossification** because the cartilage itself does not become a bone but serves as a template to be completely replaced by bone. The long bones (vertebrae, ribs and limb) and the bones at the base of the skull are formed by endochondral ossification. (ii) In the second type of formation of bones, the bones are formed afresh at places from membranes coverings. They are called **membrane bones** as they develop directly from sheets of mesenchymal tissue. They are also called **investing bones** because they form as an investment over the membranes. The flat bones of the face, most of the cranial bones and the collar bone (clavicle) are formed by this intramembranous ossification.

## *SAQ 1*

Give one word answer for each:

i) Name the protein found in the matrix of the bone and in cartilage.

ii) Which type of cells do the osteoblasts cells change into when they are trapped in the bone matrix?

iii) What is the principal structure of compact bone known as?

iv) The long bones of the body are formed by which kind of ossification?

# 2.3 CLASSIFICATION OF SKELETON

The endoskeleton of vertebrates is divided into two main parts based on their position in the body.

a) **The Axial Skeleton:** is arranged along the anteroposterior axis of the body. It consists of the skull (head skeleton) and the vertebral column. The sternum, called the breast bone is also included in the axial skeleton.

b) **The Appendicular Skeleton:** is located on the sides of the body as appendages of the axial skeleton. It includes the skeleton of the limbs and the limb girdles.

## 2.3.1 Axial Skeleton

The skeletal elements of the axial skeleton consist of skull and the vertebral column. They surround and protect the structures of the central nervous system, the brain and the spinal cord. The skull is enlarged and specialised to enclose the brain and the sense organs present in the head. The vertebral column forms the longitudinal skeletal axis of the body behind the head. It encloses the spinal cord and blood vessels of the trunk and the tail that go through it.

**The Skull**

The skull also called cephalic skeleton or head skeleton forms the skeletal framework of the head of craniate vertebrates. Vertebrates are divided, on the basis of presence or absence of head skeleton into two sub-divisions. Those vertebrates in which head skeleton is absent are called **Acraniata** and those in which head skeleton is present are called as **Craniata**. Urochordates and cephalochordates belong to Acraniata and the rest of the vertebrates are grouped under **Craniata**.

The skull of craniate (with skull) vertebrates consists of different parts which enclose the brain, cranial nerves and other sense organs present in the head. The part of the skull, enclosing the brain is called the **cranium** and is composed of several bones. The parts of the skull enclosing the sense organs are called **sensory capsules**. Thus the **paired auditory capsules** enclose the hearing apparatus, the paired **olfactory capsules** enclose the apparatus of smell and the paired bony, cup-like structures the **orbits** contain the eye balls.

The cranium or the brain box is oriented anteroposteriorly. The olfactory capsules are present on the anterior end and the auditory capsules are present on the posterolateral sides of the cranium. The head skeleton provides passages for blood vessels serving various parts of the brain.

In living fishes of modern times gill slits are present on the pharyngeal wall and are supported by a skeletal structure called **visceral skeleton**. During the course of evolution of vertebrates, the visceral skeleton lost its importance when in terrestrial vertebrates gills were replaced by lungs. However, the structure which constituted visceral skeleton has been retained and has been incorporated in the formation of jaws, providing skeletal elements to the middle

ear which have assumed the function of transmitting sound waves to the internal ear and forming the skeletal support for the floor of the buccal (mouth) cavity.

The skull of cyclostomes does not contain jaws and so they are jawless and are thus, included under the group **Agnatha** (meaning without jaws). The rest of the vertebrates have jaws and are included in the group **Gnathostomata** (meaning mouth bound by jaws).

In vertebrates, during the early stages of development of brain and sensory capsules, the brain and sensory capsules are surrounded by a tough membranous skull called the **membranocranium**. Later the membranous skull is strengthened by the development of cartilage. This cartilaginous skull is called the **chondrocranium**. The brain-case or chondrocranium of cartilage or its replacement bone, forms the anterior end of the axial skeletal system. Chondrocranium is modified in relation to the brain and specialised sense organs of the head appears as a stage in the development of head skeleton of various group of vertebrates. In most vertebrates, the brain case is fused with dermal and visceral skeletal materials to form a definitive and complex skull which is later replaced by a bony skull by ossification or by replacement of cartilages by bones and/or formation of fresh bones at places covered by membranes.

**Visceral Arches**

In addition to the cranium and the sensory capsules, the skull contains other structures which are derived from the visceral skeleton. The visceral skeleton when modified to form part of the cranium derived is referred to as **splanchocranium**. The visceral skeleton consists of a series of cartilaginous rods forming dermal support of the pharyngeal wall between gill slits in fishes. The number of **visceral arches** (Fig. 2.3) correspond to the number of gill slits which is assumed to be seven in the hypothetical vertebrate ancestor. These are modified in different groups of vertebrates depending on the presence or absence of gills and type of jaw suspension. The anterior most or the first visceral arch is called the **mandibular arch**. Each mandibular arch consists of a dorsal **palatoquadrate** (forms upper jaw) and a ventral **Meckel's cartilage** (forms lower jaw). It lies just behind the oral aperture (the mouth).The second arch is called the **hyoid arch and** consists of a **hyomandibular** and **ceratohyal cartilages**. Subsequent arches are called **branchial arches**. The skeleton of the branchial arches support gill slits in the aquatic vertebrates. Each visceral arch, consists of a series of cartilaginous rods encircling the pharynx forming paired half loops on the side wall. The left and the right bars of the corresponding arches are united on the floor of the pharynx by an unpaired midventral cartilage.

In cyclostomes there are innumerable number of gill slits and the visceral skeleton forms a structure called **branchial basket.** During the evolution of vertebrates there was a backward shift of the mouth thus establishing contact with the first gill slit. In the first jawed fishes the skeletal support of the first gill slit became the supporting structure of the mouth giving rise to jaws.

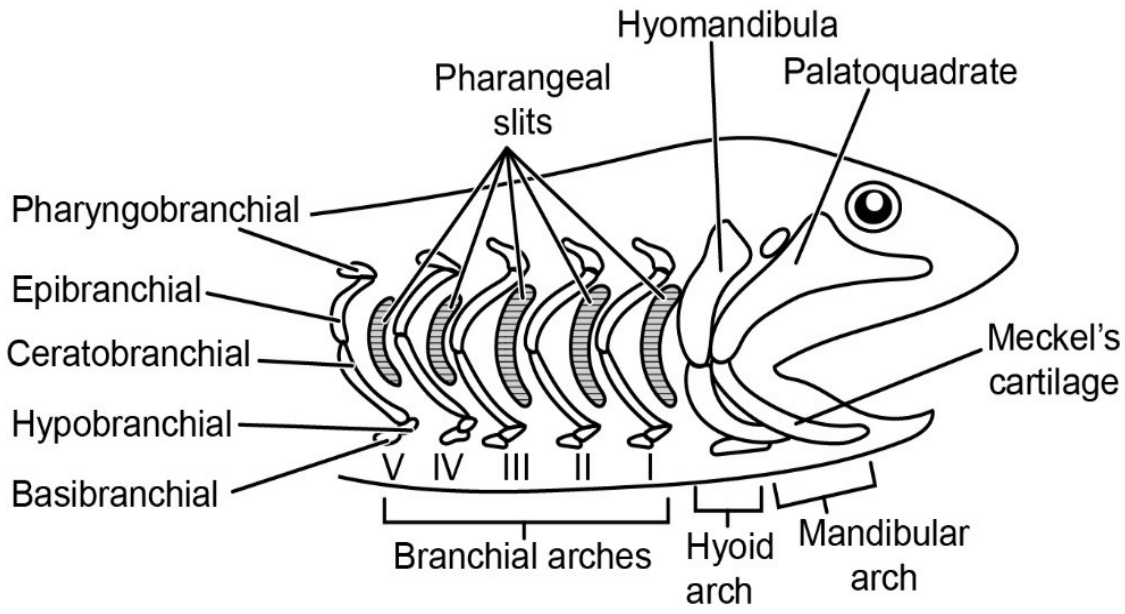



**Fig. 2.3: The visceral skeleton showing the full complement of 7 visceral arches as seen in cartilaginous fish. The first arch is modified to form the jaws.**

**Jaw Suspensorium**

The two palatoquadrates of the mandibular arch (dorsal part of first visceral) grow along the anterior or the upper margin of the mouth and unite with one another in the midline to form the upper jaw. Similarly the Meckel's cartilages of the mandibular arch (ventral part of first visceral) extend along the lower or posterior margin of the mouth and unite anteriorly in the midline to form the lower jaw. The quadrate portion of the palatoquadrate helps in the suspension of the jaws to the skull and so is called **suspensorium** (Fig. 2.4). In the earlier stages of evolution of gnathostomes, jaws were attached to the skull by means of ligaments. This condition is called **autodiastylic** type of suspensorium. In some sharks the upper jaw is braced against the skull and attached to the hyomandibula at the posterior end which is also braced against the cranium, this is known as **amphistylic** suspensorium (Fig. 2.4 a). In most living fishes the upper jaw is not directly attached to the anterior part of the cranium but by ligaments and the back portion is attached to the hyomandibula of the hyoid arch to which the lower jaw also attaches. This condition is called **hyostylic suspensorium** (Fig.2.4b). In tetrapods, chimeras and lungfishes the upper jaw is directly fused with the skull, the hyomandibula is not involved in the suspension of the jaws. This 'self bracing' condition is called **autostylic suspensorium** (Fig.2.4c). The elements of the hyoid arch are thus, released from participating in providing the suspensorium are incorporated into the middle ear as **ear ossicles**.

The branchial arches allow dilation and contraction of the pharynx in fishes. This enables, swallowing and expulsion of water during respiration. These elements of the branchial arches were lost in tetrapods with the loss of branchial respiration which was replaced by pulmonary respiration.

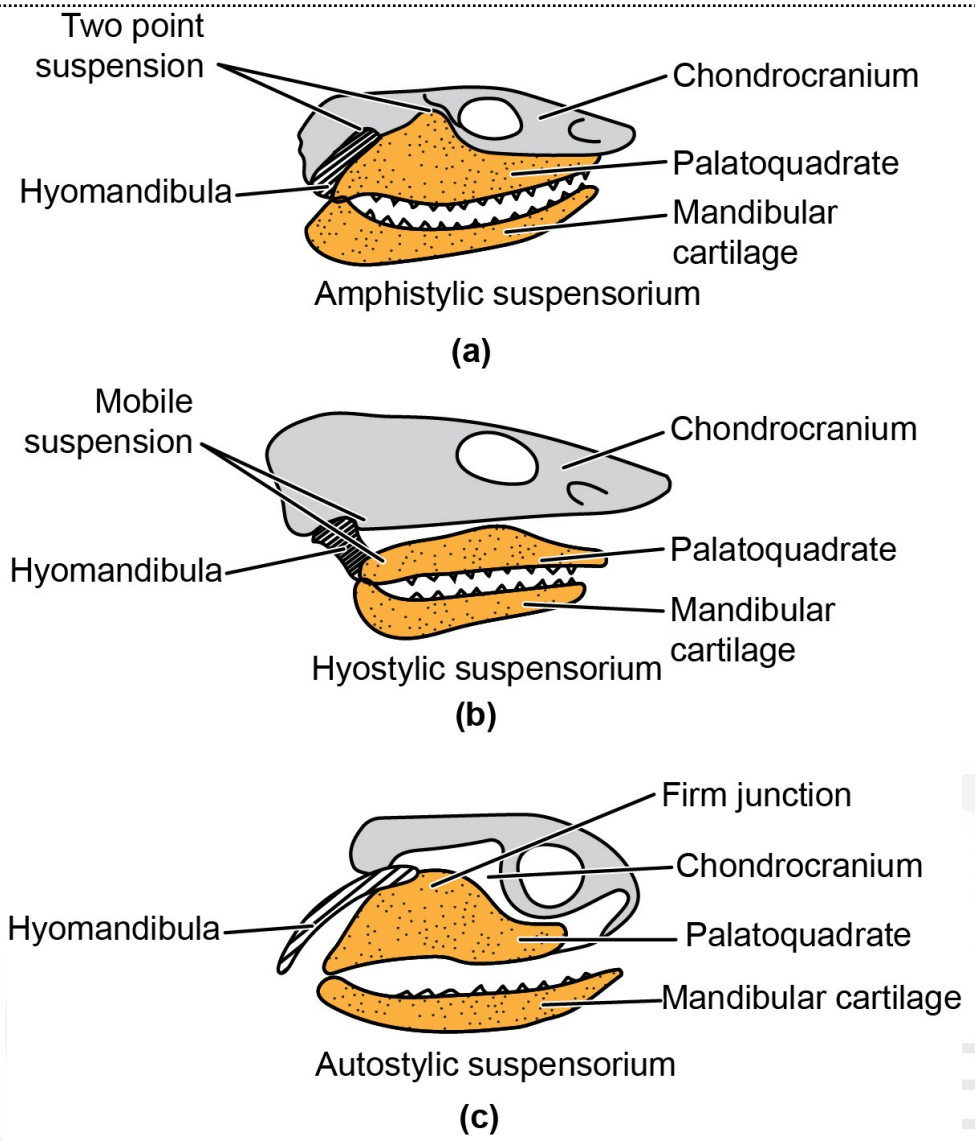



**Fig. 2.4: Jaw suspensorium in vertebrates. a) Amphistylic Jaw Suspensorium (presumed primitive condition found in some sharks). b) Hyostylic Jaw Suspensorium (most modern cartilaginous and bony fishes). c) Autostylic Jaw Suspensorium (lung fishes, chimeras and tetrapods).**

### The Vertebral Column

The vertebral column is a chain of segmented structures called **vertebrae** (vertebra - singular). It begins anteriorly from behind the skull and extends posteriorly to the tip of the tail. It forms the longitudinal axis of the animal and provides both stability and mobility to the animal. Vertebrae have specific structures which allow them to be joined to each other firmly and also allow some amount of movement. Articulation of vertebrae is achieved by the presence of bulges (convexities) and depression (concavities) in the vertebrae (Fig. 2.5). The bulge present at one end of a vertebra fits into the depression present on the adjacent vertebra. Furthermore, additional structures are also present which strengthen the articulation between vertebrae and also keep the mobility in check to the required extent. This helps to prevent dissociation and dislocation of the vertebrae of the vertebral column. The series of vertebrae form a tube-like structure which is located dorsally in the body and encloses and protect the spinal cord. Similarly, the vertebrae of the tail region of some animals form a ventral tube to enclose blood vessels.

A typical vertebra consists of the following parts (see Fig. 2.5):

a) A central body in line with the notochord of early developmental stage, the **centrum**. The centrum bears depressions and bulges on its anterior and posterior ends for articulation with the vertebra in front of it and behind it.

b) A dorsal arch-like structure called the neural **arch** (Fig. 2.5) which encloses the spinal cord. The neural arches of all vertebrae together form the **neural** tube or the neural canal which encloses the spinal cord. Neural arches are formed by vertical neural plates that arise from the dorsolateral sides of the centrum. The two neural plates of either side meet above the spinal cord. There is usually a backwardly directed neural spine present dorsally, above the neural arch.

c) There is a pair of lateral processes known as the transverse processes. These extend outwards from the centrum. The transverse processes provide the attachment sites for muscles.

d) In fishes, salamanders, most reptiles and many long tailed mammals the caudal vertebrae usually have a **haemal arch** which is present ventrally. The **haemal arch** is formed by a pair of plates (**haemapophyses**) and contains a haemal canal which encloses the blood vessels. The **haemal arch** may also have a ventrally projected **haemal spine**.

e) The centrum bears a couple of plate-like projections both in front and behind (Fig. 2.5) which are called **prezygapophyses** and **postzygapophyses** respectively. These help in articulating the vertebrae firmly and the limit of movement between the vertebrae to the necessary amount.

f) In higher vertebrates a pair of lateral processes are also present which arise on each side, from the base of the neural arch. These are known as **diapophyses**. Usually there is another pair of processes that arise from the centrum and are known as **parapophyses**. These articulate with the ribs as the bifurcated heads of the ribs are attached to these processes on each side.

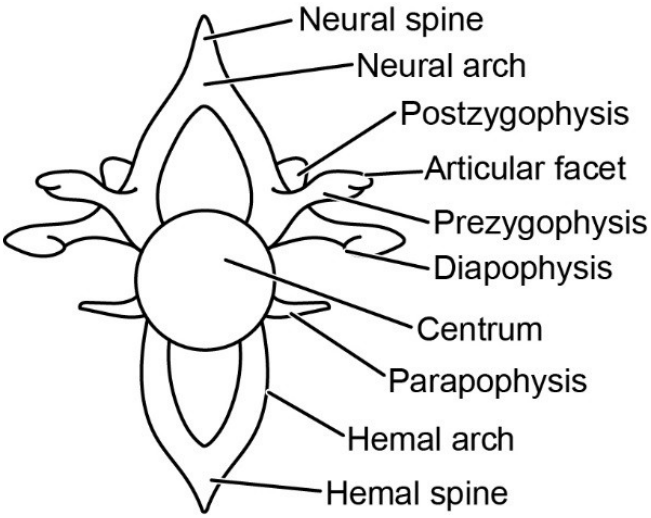



**Fig. 2.5: Front view of a generalised vertebra.**

**Types of Vertebrae**

The vertebrae are of different types depending on the structure of the centrum (see Fig. 2.6):

i) **Procoelous:** The centrum of the vertebra bears concavity in front (anterior) and a convexity behind (posterior) (Fig 2.6a). The convexity of the vertebra in front fits into the concavity of the vertebra behind, eg., typical vertebra of frog and lizards and other living reptiles

ii) **Opisthocoelous:** It is the opposite of procoelous vertebra as it has a convexity in front and a concavity behind (Fig 2.6b), as seen in most salamanders.

iii) **Amphicoelous:** The vertebral centrum has concavities both in front and behind (Fig 2.6c). The vertebra appears dumbbell shaped in lateral view and is found in most fishes, a few salamanders and caecilians.

iv) **Heterocoelous:** The centrum of this vertebra appears concave when seen from side to side and convex from above downwards and opisthocoelous in sagittal view. They are also described as saddle shaped. These saddle shaped vertebrae articulate together allowing extensive lateral and dorsoventral rotation and are characteristic of birds (Fig 2.6d).

v) **Acoelous or Amphiplatyan:** The centrum of this vertebra is usually flat on both sides,without any bulging or depressions (Fig 2.6e). These vertebrae are found in mammals.

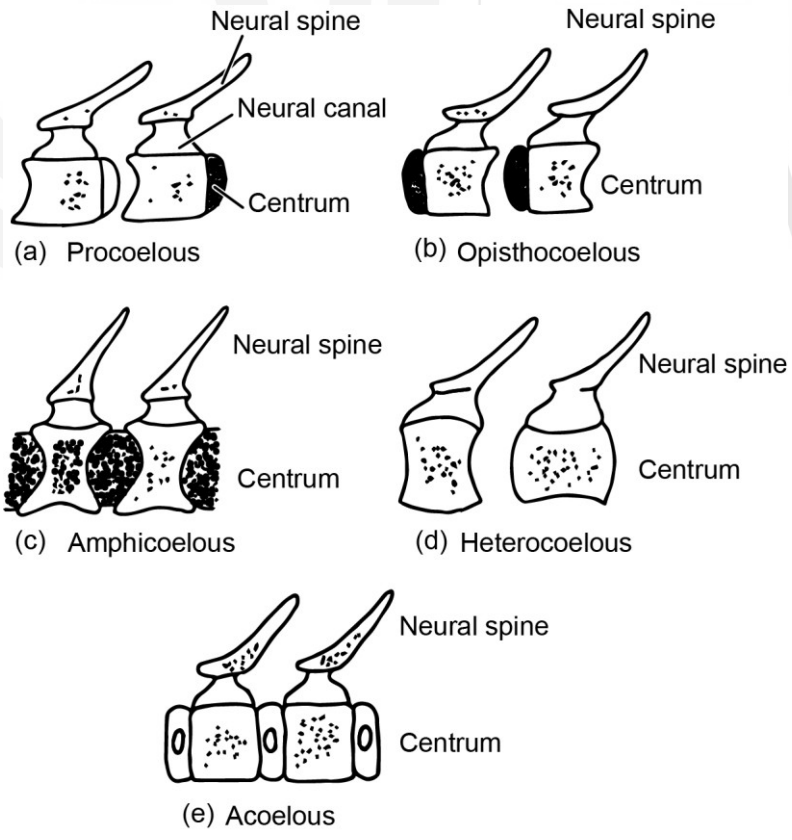



**Fig. 2.6: Different types of vertebrae distinguished by their centra: (a) procoelous; (b) ophisthocoelous; (c) amphicoelous; (d) heterocoelous; (e) acoelous.**

**Vertebral column of vertebrates**

The notochord is present in the embryonic stages of all vertebrates. Hagfish and lamprey retain the notochord, throughout their life which in other vertebrates is present only in the embryo. In cyclostomes (lampreys), the persistent notochord is supported by the lateral neural cartilages.

Teleost fishes have well ossified amphicoelous vertebrae. The vertebral column and vertebrae of teleosts can be divided on basis of their location in the body as the trunk vertebrae and the tail vertebrae. In tetrapods the vertebral column is divided into the following regions:1) the cervical region, 2) thoracic region, 3) lumbar region, 4) sacral region and 5) the caudal or tail region and shows regional specialisation. The number of vertebrae in each of these regions is variable depending on the animal group.

In tetrapods, such as amphibians only a single cervical vertebra is present amphibians which restrict their neck movement. Reptiles and most mammals as you have read earlier have 7 cervical vertebrae which give them increased flexibility. The first cervical vertebra in them is known as atlas and it articulates with the back of the skull which allows the head to move in all directions. The 2$^{nd}$ vertebra is known as axis which has an anteriorly projecting process the **odontoid process** that fits into the cavity of the atlas vertebra and acts as a pivot for the movement of the head; the other 5 are similar cervical vertebrae (Figs.2.7 and 2.9). Birds however, have a variable number of cervical vertebrae depending on the length of the neck (swans have 25 cervical vertebrae).

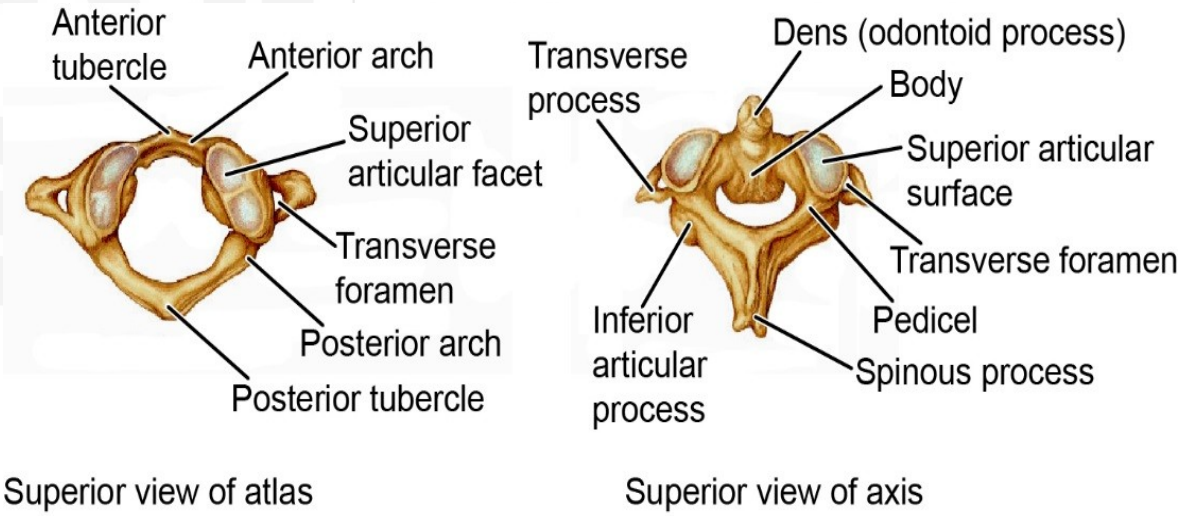



**Fig. 2.7: First and second cervical vertebrae in mammals. Note the ring like centrum in atlas and the transverse foramen (TR) in both vertebrae that forms the passage for the blood vessels.**

The thoracic region has the thoracic vertebrae. These articulate with the ribs. The lumbar vertebrae are present in the lumbar region and are more robust than the vertebrae of other regions. Sacral vertebrae are often fused to form a **sacrum** that is also fused with the pelvic girdle. In birds a structure known as **synsacrum** is present (Fig. 2.8) and is formed by the fusion of the last thoracic vertebrae and all lumber, sacral and a few caudal vertebrae. The synsacrum in turn is fused with the pelvic girdle in order to provide support for bipedal locomotion.

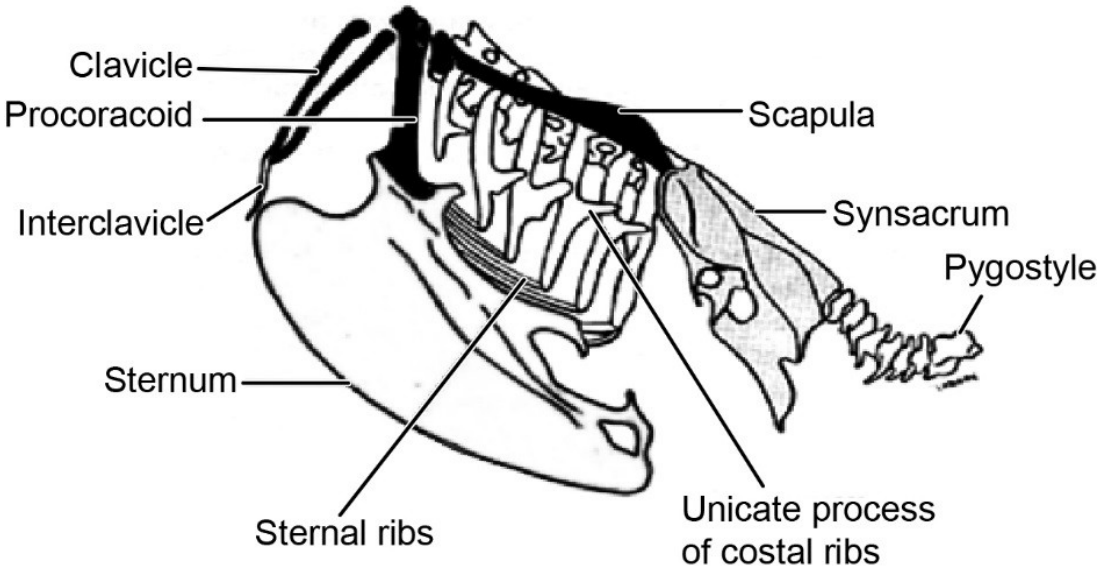



**Fig. 2.8: Skeleton of bird showing the sternum, synsacrum, ribs, and free and fused vertebrae of the caudal region.**

The caudal vertebrae form the tail region and may be fused in the tailless animals. The arches and spines of the vertebrae get progressively shorter in this region. In frogs and toads the terminal vertebrae form the **urostyle** and in birds the last 4-5 vertebrae fuse to form the **pygostyle** (see Fig. 2.8). In apes and humans the last 3-5 caudal vertebrae fuse to form the **coccygeal** or tail bone. The regions of the vertebral column and their specialised vertebrae in mammals, are shown in Figure 2.9. In the figure you can see the intervertebral cartilage disc made of fibrous tissue and remnants of notochord.

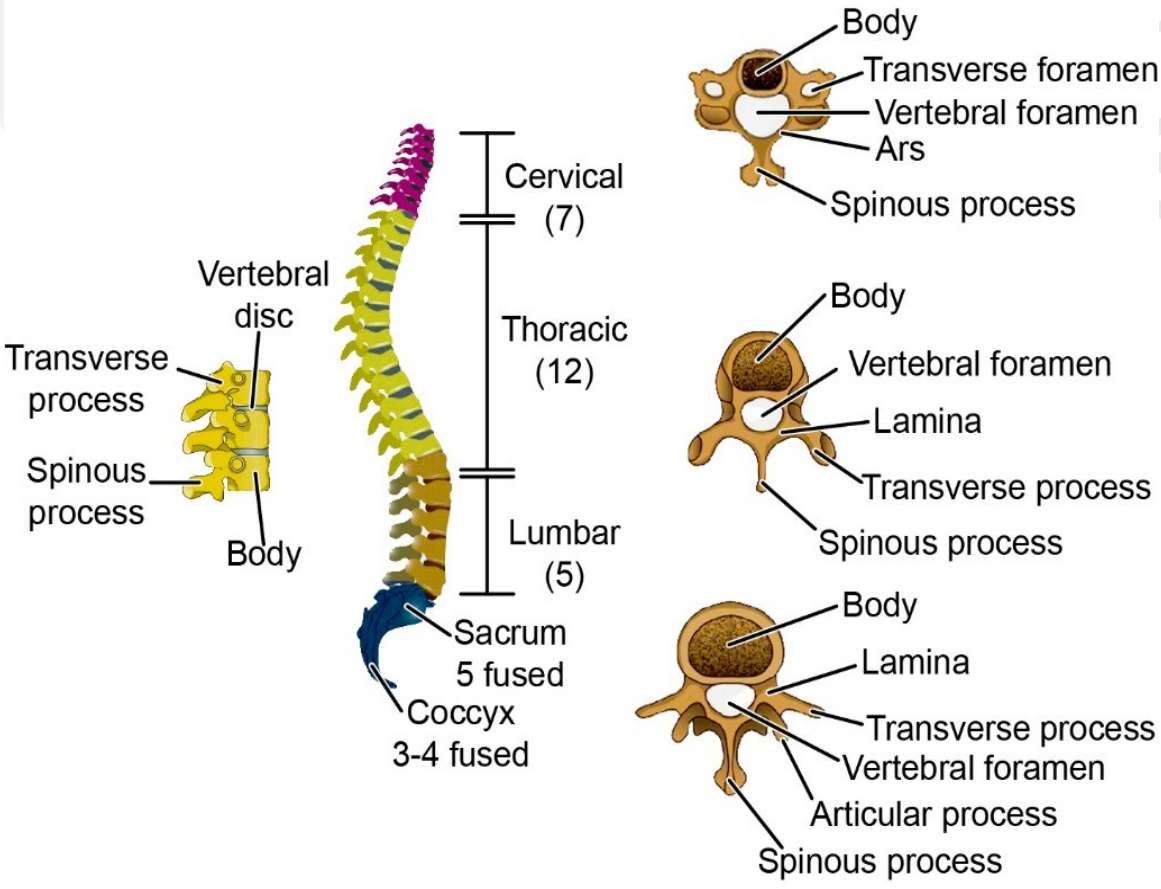



**Fig. 2.9: Structure of the segments of vertebrae.**

## *SAQ 2*

A) Fill in the blanks:

i) Procoelous centrum of a vertebra bears a concavity in …… and a convexity …… .

ii) …… centra appear dumb bell shaped in the lateral view.

iii) …… centra are described as saddle shaped.

iv) Acoelous centra are usually …….. without any bulging or ……... .

B) Choose the correct alternative:

i) The visceral skeleton is also referred to as (chondrocranium/ splanchocranium).

ii) Jaws arose from the (mandibular/hyoid) arch.

iii) The upper jaw is made up of the (palatoquadrate/meckel's cartilage).

iv) Branchial basket formed of the visceral arches is found in (teleosts/cyclostomes).

v) If the jaw is attached to the skull and not suspended by the hyomandibula, the suspensorium is (autodiastylic/autostylic).

## 2.3.2 Appendicular Skeleton

Most vertebrates have two pairs of appendages, an anterior (pectoral) and a posterior (pelvic) pair. Fishes have paired fins (pterygia) and other vertebrates with have jointed limbs (podia). During embryonic development the paired appendages of fishes appear as horizontal folds and the limbs of vertebrates appear as buds. The skeleton of paired appendages namely, forelimbs and hind limbs articulate and are supported by the anteriorly located pectoral girdle and the posteriorly located pelvic girdle respectively. Both the pectoral and pelvic girdles and skeleton of the forelimbs and hind limbs collectively constitute the **appendicular skeleton**.

The pectoral girdle is made up of both dermal and endochondral (replacement) bones. The pectoral girdle consists of two identical parts. In some vertebrate species each part of the pectoral girdle has three components which consist of the clavicle, scapula, and coracoid. In humans each part consists of the clavicle and scapula. Some mammalian species (such as the dog and the horse) have only the scapula. Each part of the pectoral girdle also has an **acetabular** cavity for the articulation of the head of the humerus bone of the forelimb.

The pelvic girdle is made up of 2 dermal bones, a dorsal **iliac** and a ventral **ischio-pubic** part. It is composed of two identical appendicular hip **bones.** Each part is formed of **ilium**, **ischium**, and **pubis**. The two parts are joined and oriented together to form a ring. Each part of the pelvic girdle contains a **glenoid** cavity which articulates with the head of the femur bone of the hind limb. The pelvic girdle also has the pelvic spine which consists of the sacrum and coccyx. The extremities of the vertebrate limbs are typically pentadactyl, being provided with five digits each. The vertebrate fore and hind limbs have similar joints and similar number of skeletal elements. The general pattern of the parts and skeleton can be listed as follows (Table2.1):

**Table 2.1: Similarity of Plan between Anterior and Posterior Part of the Appendicular Skeleton.**

| | | | | | |
|---|---|---|---|---|---|
| 1. | **Anterior part of the Appendicular Skeleton** | Shoulder Joint | 1. | **Posterior part of the Appendicular Skeleton** | Hip joint |
| 2. | **Point of attachment of the pectoral girdle with the fore limbs** | Head of the anterior bone (humerus) of the forelimb | 2. | **Point of attachment of the pelvic girdle with the hind limbs** | Head of the anterior bone (femur) of the hind limb |
| 3. | **Upper arm bone of forelimb** | Single bone: Humerus | 3. | **Upper bone (thigh) of hind limb** | Femur |
| 4. | **Lower bone(radio-ulna) of forelimb** | Two bones: Radius and Ulna | 4. | **Lower bone (tibio-fibula) of hind limb** | Two bones: Tibia and Fibula |
| 5. | **Point of attachment between the upper arm bone(humerus) and lower arm bone(radio- ulna)** | Elbow joint | 5. | **Point of attachment of between the upper bone(femur) and the lower bone (shank/tibio-fibula) of the hind limb** | Knee joint |
| 6. | **Wrist** | Carpal bones | 6. | **Ankle** | Tarsals |
| 7. | **Palm** | Metacarpal bones | 7. | **Sole** | Metatarsal bones |
| 8. | **Fingers** | Phalanges | 8. | **Toes** | Phalanges |

### Ribs and Sternum

Ribs are found in the thoracic region of most vertebrates. They are sets of paired slender curved bones and are attached to vertebrae at one end and to the sternum (breast bone) at the other end. Ribs have a bony vertebral part and attach to the breast bone or sternum by a ventral cartilaginous or bony sternal portion (Fig. 2.10c).The ribs together with the vertebral column and the sternum form a skeletal cage that encloses and protects the organs of the thorax. During the course of vertebrate evolution ribs first appear in

Gnathostomes. There are two types of ribs (Fig. 2.10 a & b) : (1) the **dorsal** or **intramuscular ribs** and the (2) **ventral** or **haemal ribs**. The dorsal ribs grow as extensions of the vertebrae and extend into the horizontal septa. Dorsal ribs that occur in elasmobranchs and amphibians are short and incompletely developed. However, they are well developed in amniotes. The dorsal ribs establish contact with vertebral column and sternum and surround the body. A typical dorsal ribs has two heads (i) the **capitulum** which is the rib head that attaches at the centrum of the vertebrae and the (ii) the **tuberculum head** which attaches to the transverse processes of the vertebrae. The two heads of the ribs enclose a space between them known as the **vertebro-arterial or vertebrarterial canal** or foramen through which the vertebral artery passes. The ventral or haemal ribs seem to have arisen from the haemal arches. They also encircle the body but are located inside the peritoneal cavity. Ventral ribs are present in most teleost fishes, ganoid fishes and Dipnoi. Both dorsal and ventral ribs are found in most teleost fishes (Fig.2.10). In most reptiles, birds and mammals the ribs are attached by movable joints only to the thoracic vertebrae (snakes have ribs articulating with all the vertebrae). In birds the entire rib is ossified and firmly attached to the sternum, while in mammals the sternal part is cartilaginous. The ribs which are short and not directly attached to the sternum but to the other ribs are called **false ribs** (number 8 to 10 in humans). False ribs are also found in crocodiles. The ribs that are not attached to sternum but are free are known as floating ribs (numbers 11 and 12 in humans).

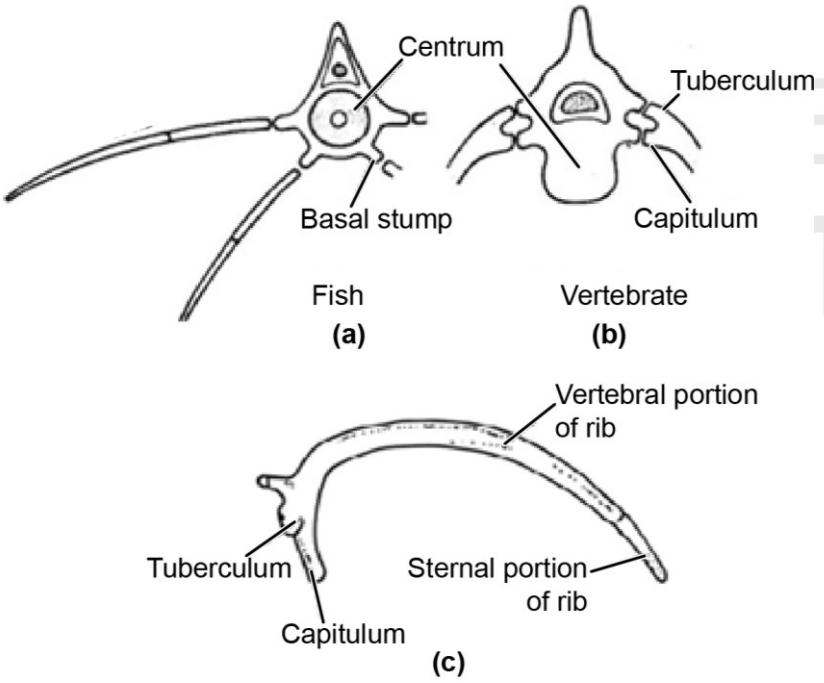



**Fig. 2.10: Attachment of dorsal and ventral rib to the vertebrae in: (a) Fish and (b) Terrestrial vertebrates (c) Structure of a double headed rib of a vertebrate**.

**Sternum** is a shield or rod shaped bone or group of bones found in the mid-ventral side of the thorax of vertebrates. Sternum is also commonly called the breast bone. In amniotes, the ventral ends of the ribs are attached to the sternum. The sternum of birds as you have read in the previous course is broad and develops a ventral keel-like projection and provides a surface for

the attachment of wing muscles (see Fig. 2.8 again). Sternum is also usually present in vertebrates and is adapted according to the type of locomotion. Snakes which have lost limbs also have lost the sternum.

In the present section we have discussed the general features of the skeletal system in vertebrates. In the next two sections we will compare the salient features of the axial and appendicular skeletons of two vertebrate tetrapods namely, frog and rabbit. The frog shows the adaptations for terrestrial life while still maintaining a partly aquatic life, while rabbit a mammal, is fully terrestrial. The skeletons of both these vertebrates are suitably adapted to their life styles

## *SAQ 3*

Match the statement given in column 'B' with the caption of the column 'A'.

| | A | | B |
|---|---|---|---|
| a) | Cartilage and bone | i) | The haemal arch contains the haemal canal which encloses the blood vessels. |
| b) | The skull | ii) | The tetrapod limbs are typically pentadactyl being provided with five digits each. |
| c) | The vertebral column | iii) | The matrix is composed mainly of mineral salts mostly of calcium combined with phosphates and carbonates. |
| d) | Appendicular skeleton | iv) | The olfactory capsules are present on the anterior end and the auditory capsule are present on the posterolateral sides of the cranium. |

# 2.4 AXIAL SKELETON OF FROG AND RABBIT

In the earlier section you studied the general features of the axial and appendicular skeletons of vertebrates. In this section we go into greater details of the axial skeleton of frog and rabbit by comparing the structures of their skull and vertebral column. Let us first examine the features of the skull.

## 2.4.1 Skull of Frog and Rabbit

### The Skull of Frog

The skull of frog is interesting for several reasons. It is simple in structure with fewer number of bones and areas of ossification compared to other vertebrates. It is broad and flat, consisting of the cranium, sense capsules, large eye orbits, jaws, **hyoid apparatus** and cartilages of the larynx. Figure 2.11 shows the dorsal and ventral view of the frog's skull. Refer to both these figures while studying this subsection.

The **cranium** of frog is anterio-posteriorly elongated and is formed of just six bones. The posterior end of the cranium is called the occipital end and

consists of a large aperture the **foramen magnum**. It is surrounded by a pair of bones the **exoccipitals** that bear two bulges, the **occipital condyles**, for articulation with the atlas, the cervical vertebra. The roof and sides of the cranium are covered by a pair of composite of bones called **frontoparietals.**

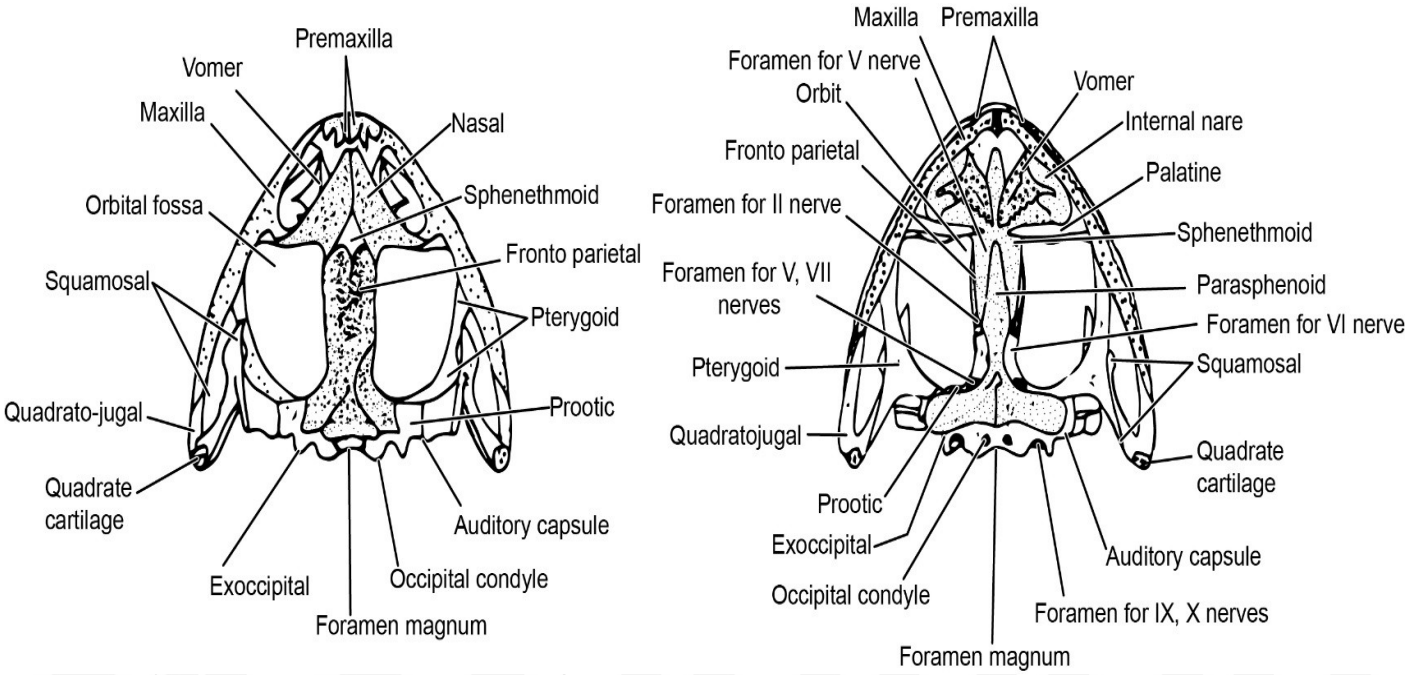



**Fig. 2.11: Frog skull. a) Dorsal view; b) Ventral view.**

At the front end of the skull, there is a single ring shaped bone, the **sphenethmoid** which almost covered on the dorsal side by the **nasal bones** and is only visible as a triangular bone on the dorsal side. On the ventral side the **sphenethmoid** bone is covered by the dagger- shaped **parasphenoid** bone, which forms the floor of the cranium.

Each of the paired auditory capsules of the frog skull is situated at the posterolateral side of the cranium. Each auditory capsule consists of only one bone, the **pro-otic bone**. The rest of the auditory capsule is covered by membranes. The middle ear has a cartilaginous extra stapes and a bony stapes that transmits the sound waves to the internal ear. The olfactory capsules are found anterior to the cranium. Each olfactory capsule is covered by the **nasal** bone above and a **vomer bone** below. The two bones are bound by membranes to the cranium and to each other. A space located anterolaterally on each sides, of the cranium forms the eye **orbit** which contains the eye ball. The eye socket is bound on the outer border by bones of the upper jaw, by bones of the olfactory capsule, the cranium on the inner margin and the bone of the auditory capsule behind. The floor is covered by tough membranes which bulge into the buccal cavity.

**The upper jaw** of frog is horse shoe shaped. It forms the outer margin of the skull anteriorly and laterally. The upper jaw is made up of two halves united in front and free behind. Each half of the upper jaw consists of an anterior **premaxilla**, a middle **maxilla** and a posterior **quadratojugal**. The two halves of the upper jaw are united at the premaxillar end. The upper jaw is immovably fixed to the skull on each side by means of three bones. These 3 bones consist of i) a bar-like **palatine** (Fig. 2.11) which connects the maxilla to

**sphenethmoid** of the cranium and ii) two other bones which are present at the posterior end on each side of the upper jaw and connect the auditory capsule of the respective side. A **'T' shaped squamosal bone** is present dorsally. The long limb of this bone is attached posteriorly to the quadratojugal. The inner tip of the horizontal limb of the **'T' shaped squamosal bone** is attached to the pro-otic and the other end is free. A tri-radiate bone, the **pterygoid** is present ventrally is on each side of the jaw. The three ends of this bone are attached to the maxilla anteriorly, the pro-otic on the mid posterior side and the quadratojugal posteriorly.

**The lower jaw** is complementary in shape to the upper jaw and so is also horse shoe shaped (Fig. 2.12). Each part of the lower jaw articulates posteriorly with the quadratojugal bone of the upper jaw and is free rest of the way. The two halves of the lower jaw are also united at the anterior end. Each half of the lower jaw consists of 3 bones: i) an anterior **mentomeckelian bone**; ii) the **dentary bone** behind the mentomeckelian bone and the; iii) posterior most **angulosplenial bone** present behind the dentary bone. The two mentomeckelian bones of the two halves of the lower jaw are united anteriorly. The angulosplenial bone of each side articulates with the quadratojugal bone of each side of the upper jaw. The quadratojugal bone of each side of the upper jaw, fits into a concavity present at the terminal end of each of the angulosplenial bone. A small ridge-like process is present in front of the concavity on the angulosplenial bone of each side which is called the **coronary process** (Fig. 2.12).

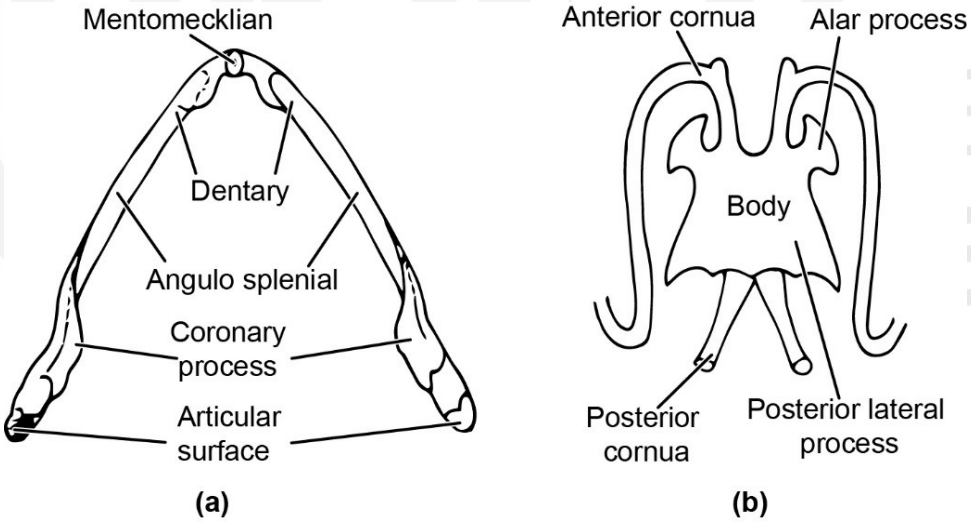



**Fig. 2.12: a) Lower jaw of frog; b) hyoid bone of frog.**

Teeth in frogs are found on the premaxilla and maxilla of the upper jaw and also on the vomers of the olfactory capsule (vomerine teeth). Teeth project into the buccal cavity. Teeth are curved, fused to the bones on which they are found and are arranged in a single row along the edges of the premaxilla and maxilla. They do not help in mastication but help to prevent the prey from escaping from the buccal cavity. A hyoid apparatus is present which forms the support for the floor of the buccal cavity, (Fig. 2.12 b). It is derived from the visceral skeleton and consists of a central plate-like body lying on the floor of the buccal cavity. The hyoid apparatus provides a surface for the attachment of the tongue. The central plate has two pairs of processes, one pair at the anterior end and another at the posterior end. They are called **anterior** and

**posterior hyoid cornua** respectively. The anterior hyoid cornua are long slender cartilaginous processes that curve back to extend into the auditory region of the skull where they are attached to the **collumella auris** of the middle ear. The posterior hyoid cornua are stout rod-like bones projecting backwards on either side of the glottis, which is the opening of the trachea on the floor of the buccal cavity.

### The Skull of Rabbit

**The skull of rabbit** is thick and is elongated anteroposteriorly when compared to the skull of frog. The elongation of the skull is due to the prolongation of the jaws for forming a snout. The snout is required in order to provide more space for the attachment of the jaw muscles. The skull of rabbit (Fig. 2.13) can also be studied under the same divisions like that of the frog: i) the cranium enclosing the brain; ii) the sensory capsules enclosing the sense organs; iii) the two jaws and iv) the hyoid apparatus. The different parts of the skull of the rabbit in comparison to the frog are more complicated in structure due to addition of more bones either by ossification of pre-existing cartilages or by addition of a few investing bones where only membranes existed earlier. At present mammals represent the final stage of vertebrate evolution. The complexities of the mammalian skull and skeleton are due to adaptations in order to accommodate evolutionary features that have made survival on land possible.

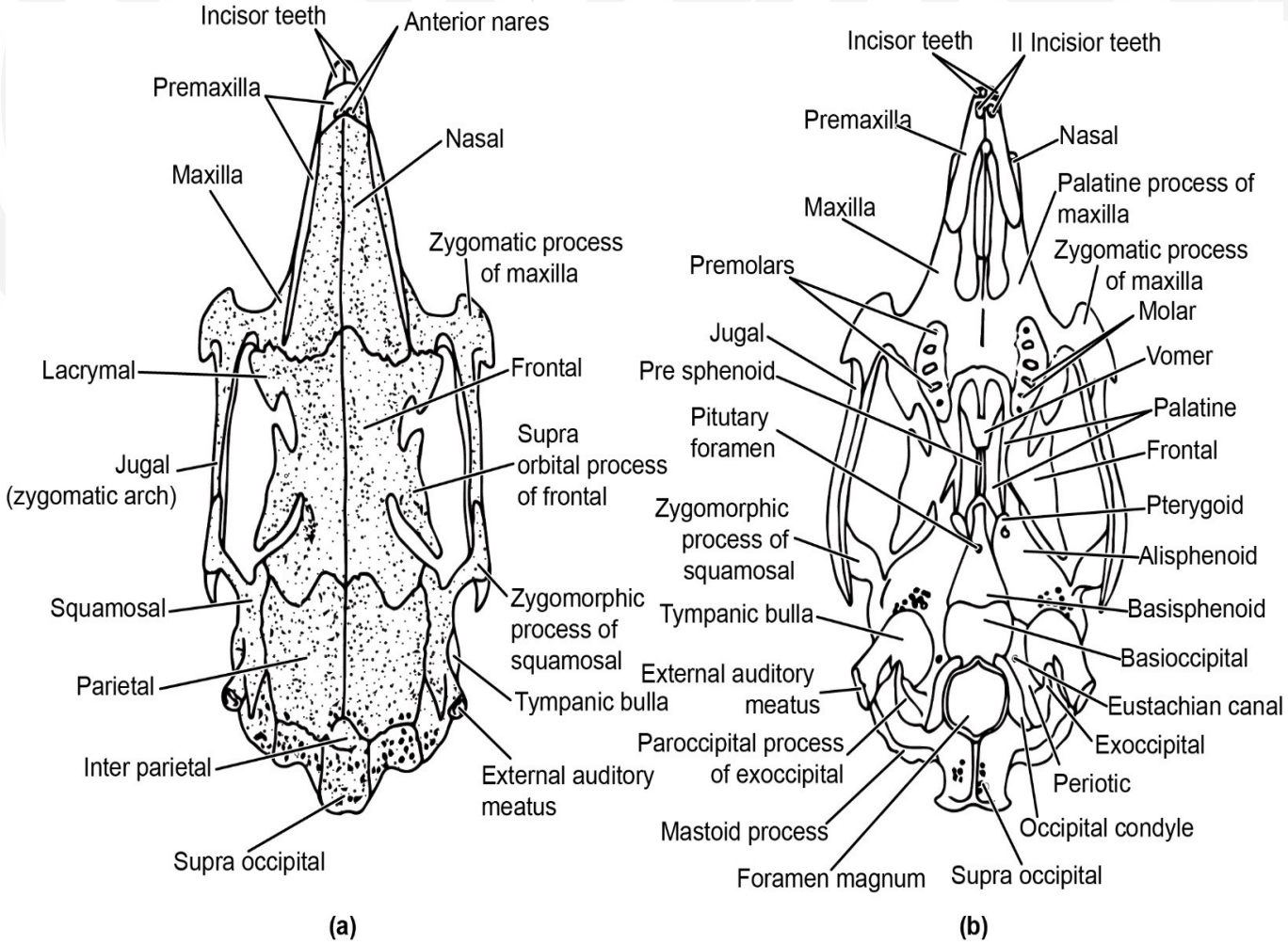



**Fig. 2.13: a) Dorsal view of rabbit skull; b) ventral view of rabbit skull.**

## Cranium

**The cranium** is short compared to the length of the skull as a whole. The cranium is found behind the eye orbits. The cranium can be divided anteroposteriorly into three segments. The segments are in the form of rings which are placed one behind the other and they all collectively surround the brain. The posterior segment is the **occipital segment**. It consists of four bones as compared to only two bones in the frog. The four bones of the **occipital segment** surround the **foramen magnum** which is large and directed downwards and not backwards as in frog. The foramen magnum is surrounded at the top by the single **supraoccipital** bone, a pair of **exoccipital bones** on the lateral sides and a single plate-like **basioccipital** bone, on the lower side, (Fig. 2.13). The posterior end of the rabbit skull,similar to the frog skull rabbit has two **occipital** condyles for the articulation of the skull with the first vertebra. So the skulls of both frog and rabbit are **bicondylar**. The **occipital** condyles of rabbit project from the lower part of the exoccipitals. Both the exoccipitals and the basioccipitals contribute in the formation of condyles which are smooth and round, and articulate with the concavities on anterior face of the first vertebra (atlas).

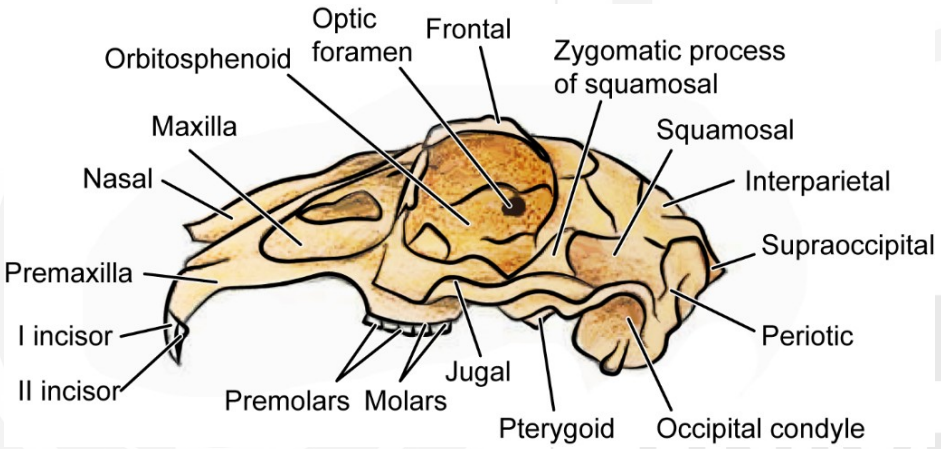



**Fig. 2.14: Lateral view of rabbit skull showing its various bones.**

The part of the cranium in front of the occipital region is the **parietal segment** and consists of six bones- i) A single, flat, triangular **basisphenoid** bone forms the floor in front of the basioccipital. A depression is present on the dorsal surface of basisphenoid in which the body of pituitary lodges (not visible in the figure). ii) A pair of **parietal** bones is present which, form the roof of the parietal segment. The two parietals bones are united in the mid-dorsal line. The sides of the **parietal** segment are formed by a pair of wing shaped **alisphenoid** bones that are present one on each side, (Fig. 2.13 b).The parietal bones are separated on each side from the alisphenoid bone by a rectangular bone known as **squamosal bone** which connects dorsally to the parietal and ventrally to basisphenoid. A projection from the squamosal called **zygomatic process** unites with the **jugal** bone on each side to form the **zygomatic arch.** Below the zygomatic process is a depression with which the lower jaw articulates. Dorsally between the two parietal bones and the supraoccipital bones located behind is a single wedge shaped bone called **interparietal bone**. The anterior part of the cranium is the **frontal segment**. The roof of the frontal segment is covered by a pair of **frontal bones** which have prominent ridges on each of them called **supraorbital** process. These

processes project over the eye orbit on each side. There is a median **presphenoid** bone which forms the floor of the **frontal** segment. It is present in front of the basisphenoid. There is a pair of **orbitosphenoid bones**, which extend vertically on either side to form the inner boundary of the eye orbit. There is a vertical plate-like bone which forms the anterior boundary of the cranium called **cribriform plate**. This cribriform plate bears an aperture for the passage of the olfactory nerves.

### 1. Sensory Capsules

**The auditory capsules** are situated on the posterolateral sides of the cranium on each side, between the squamosal and exoccipital bones, (Fig. 2.14). Each auditory capsule in the adult, is represented by a complex of bones called the the **periotic**, which is made up by fusion of 3 embryonic bones **prootic**, **epiotic** and the **opisthotic**. In addition to this the auditory capsule consists of two other structures, the **tympanic bone** and the **auditory ossicles**. The periotic bone is divisible into two parts, the **petrous** which forms the internal ear and encloses the membranous labyrinth and the **mastoid process** which projects outside, between the periotic process and the exoccipital bone. The petrous bears two openings on its outer surface, the **fenestra ovalis** and the **fenestra rotundum**. The tympanic bone lies across the auditory meatus between the basisphenoid bone and the squamosal bone and is closely attached to the periodic bone on its outer surface. The tympanic bone is flask shaped (Fig. 2.14) consisting of an outer tubular part and a lower smaller part forming the **tympanic bulla** which contains the tympanic cavity enclosing the auditory ossicles. The tubular part encloses the auditory meatus. A tympanic membrane is stretched across the tympanic cavity at the inner end of the tube. The tympanic membrane separates the tympanic cavity from the tube of the tympanic bone. The auditory ossicles consist of three small bones the **malleus**, the **incus** and the **stapes**, (Fig. 2.15). They extend between the tympanic membrane and the periotic bone. An eustachian aperture is present anteriorly on the tympanic bone and opens into the eustachian canal which communicates with the pharynx.

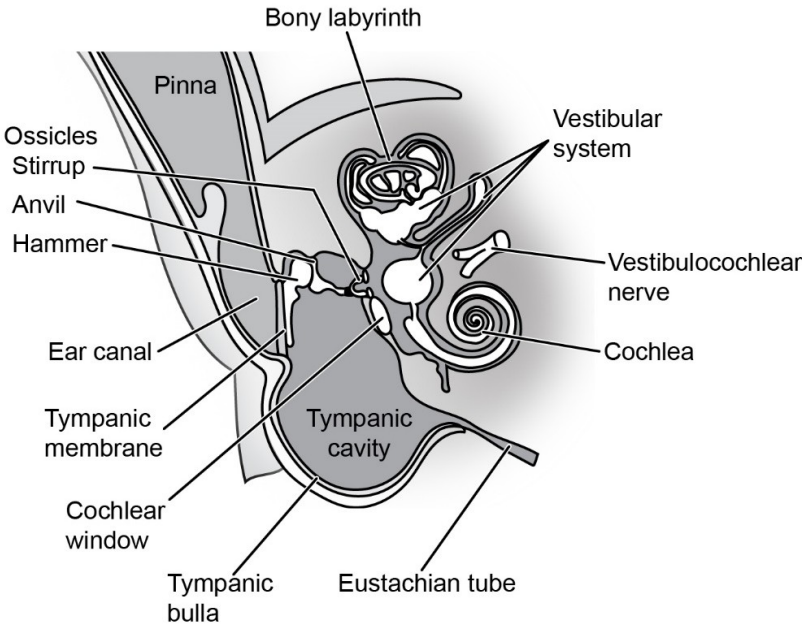



**Fig. 2.15: Inside the rabbit ear.**

**The olfactory capsules** are present in front of the cranium. They are roofed over by two flat nasal bones. These bones extend from the tip of the external **nasal** openings in front upto the frontal bones behind. The nasal cavity is separated into two separate cavities by a vertical plate-like **mesethmoid** bone, which lies in front of the cribriform plate. Each nasal cavity contains a scroll-like **turbinal** bone. The paired nasal cavity opens to the outside through the external nares and internally open into the buccal cavity far behind through the internal nares also called the posterior nares.

**The paired eyes orbits** are hollow spaces and each contains an eye balls. Each **eyes orbit is located** on the anterolateral sides of the cranium between the upper jaw and the olfactory capsule. A small **lachrymal** or lacrymal bone is present, on each side of the anterior wall of the orbit. It contains a lacrymal aperture, through which the **lachrymal glands (tear glands)** open into the orbit.

## 2. Jaws

**The upper jaw of the rabbit** consists of two halves that are united in front. Each half of the upper jaw consists of a **premaxilla (plural:** premaxillae**) bone**, anteriorly, and **a maxilla** bone behind (see Fig. 2.14 again). The two halves of the upper jaw are united in the front at the premaxillae end. The premaxillae are large bones and form anterior part of the snout. The premaxillae bones, bear incisor teeth on their ventral surface. The maxilla bone, which is present behind the premaxilla forms the major part of the upper jaw and bears premolar and molar teeth. A horizontal palatine process originates from the inner margin of each of the maxilla and both meet in the centre to form the anterior part of the palate. The anterior part of the palate forms the horizontal partition that separates the nasal cavity from the buccal cavity and also forms the roof of the buccal cavity. A zygomatic process projects outwards from the outer margin of each of the maxilla bone and forms the anterior border of the eye orbit. Each maxilla bone extends externally behind the nasal cavity. On each side of the upper jaw, between the palatine and the alisphenoid bones an irregular- shaped, **pterygoid** bone is present. A laterally compressed **jugal** bone with the zygomatic process and the squamosal bone is present on each side. The **jugal** bone, along with the squamosal and maxilla bones is involved in the formation of the zygomatic arch.

**Each half of the lower jaw of the rabbit** is similar to all mammal**,** instead of being composed of three bones as present in each half of the lower jaw of frogs, **is made up of a single bone known as dentary** (Fig. 2.16). The two dentaries are joined together in front in the midline by a symphysis. Each dentary consists of an anterior horizontal part which bears the incisors and premolars and molars. A **gap known** as the **diastema** is present in each half of the lower jaw, between the incisors and the rest of the teeth. The posterior ascending process of the dentary ends in a condyle at the upper tip. The condyle helps in articulating with the glenoid fossa on each side. The glenoid fossa is formed by the squamosal and the zygomatic process.

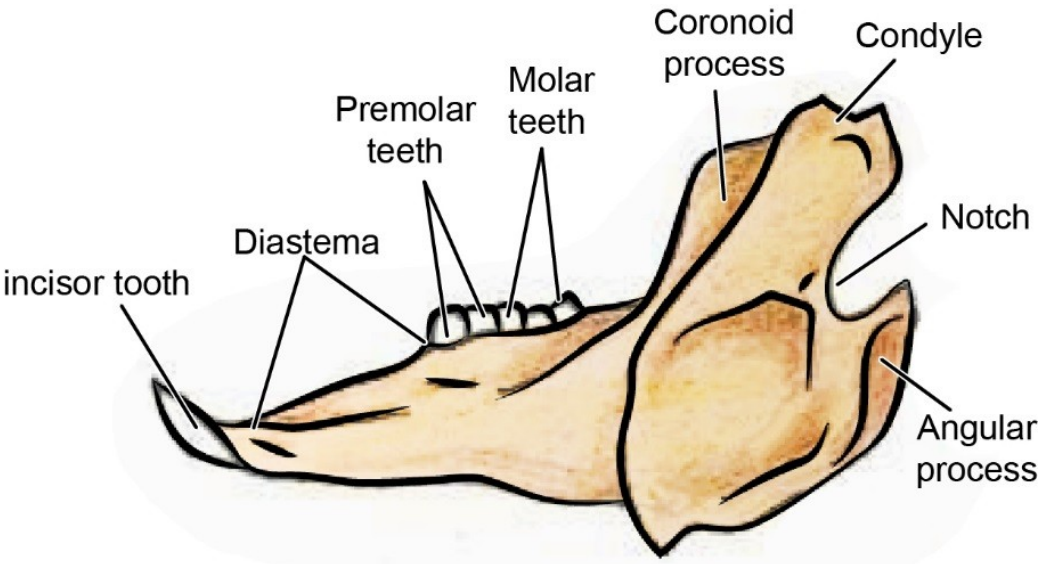



**Fig. 2.16: Lower jaw (Mandible) of rabbit.**

The hyoid apparatus is represented by a central plate, the **basihyal** (Fig. 2.17) which has two pairs of processes projecting backwards. The anterior cornua are connected to the periotic and consists of three bones. The posterior cornua are connected to the larynx.

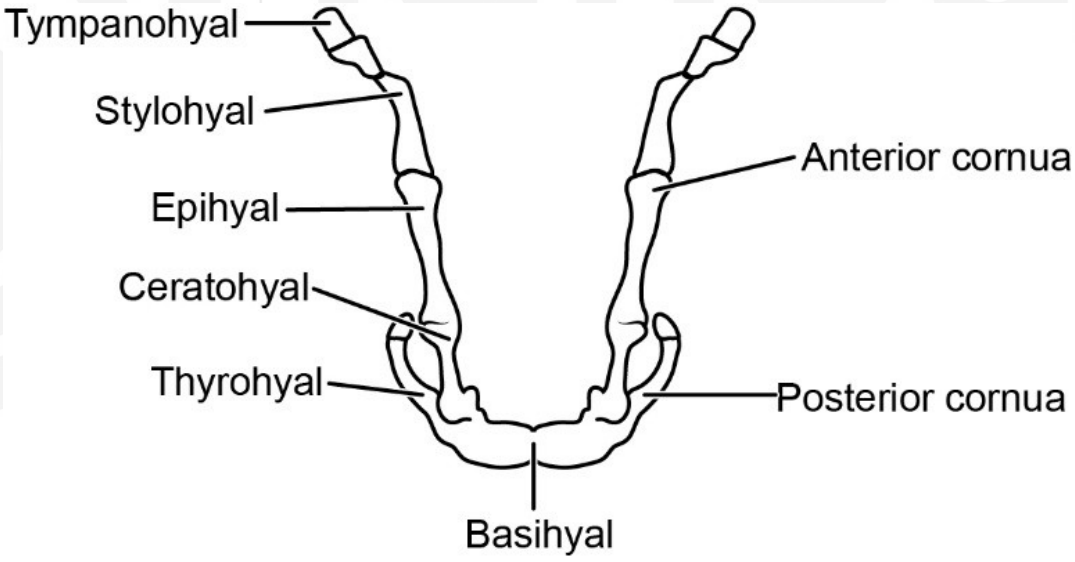



**Fig. 2.17: Hyoid apparatus of rabbit.**

**Some of the key features of mammals as seen in the rabbit skull**

- A true palate, which is only found in mammals is present. The true palate separates the respiratory passage from the buccal cavity.
- The bones of the skull are united or joined with each other by zig-zag lines called **sutures** which is characteristic of mammals.
- Teeth are accommodated in holes called sockets which are present on the jaw bones. The condition when teeth are present in sockets is called **thecodont** dentition. The teeth of most vertebrates including frog are all of the same type, and such a condition is known as **homodont** dentition.

In mammals however, teeth in each half of the jaw may be of different types -differing in shape and structure for performing different functions. The dentition in which the jaw has different types of teeth adapted for different functions as cutting, tearing and chewing food is called **heterodont** dentition. Mammals also have two sets of teeth during their life time. The dentition in which two sets of teeth are formed during the life term is termed as **diphyodont** type of dentition. In this condition one set of teeth appears early in life and such teeth are called **milk teeth.** Another set of relatively permanent teeth appears later in life which lasts for the rest of the adult life. This set is called **permanent set of teeth**.

## *SAQ 4*

Match the following statements to the skulls of frog and rabbit by indicating **R** for **rabbit** and **F** for **frog**.

i) The foramen magnum is enclosed in 4 bones and directed downwards.

ii) The skull is flattened with few bones.

iii) The upper jaw has similar teeth

iv) A diastema is seen in the jaws

v) The true palate seperates the buccal cavity from the nasal cavity.

vi) Two occipital condyles articulate with the concavities on the atlas vertebra.

vii) The roof and sides are made up of 2 frontoparietal bones and the floor is made up of parasphenoid.

viii) The auditory capsule is made up of 2 bones periodic and tympanic.

ix) Middle ear has 3 ossicles malleus and incus and stapes

x) Each half of the upper jaw is made up of premaxilla, maxilla and quadratojugal bones.

## 2.4.2 Vertebral Column of Frog and Rabbit

### Frog

The vertebral column of frog is simple and short (Fig. 2.18). It consists of a total of nine vertebrae with a rod-like urostyle at the posterior end. The first vertebra is called the **atlas** vertebra. It is ring shaped with a small centrum and two concavities on its front surface for articulation with two condyles of the skull. Transverse processes and the pre-zygapophyses are absent in atlas vertebra of frogs. The second vertebra in the vertebral column of frog is called the **axis** vertebra as in all other vertebrates.

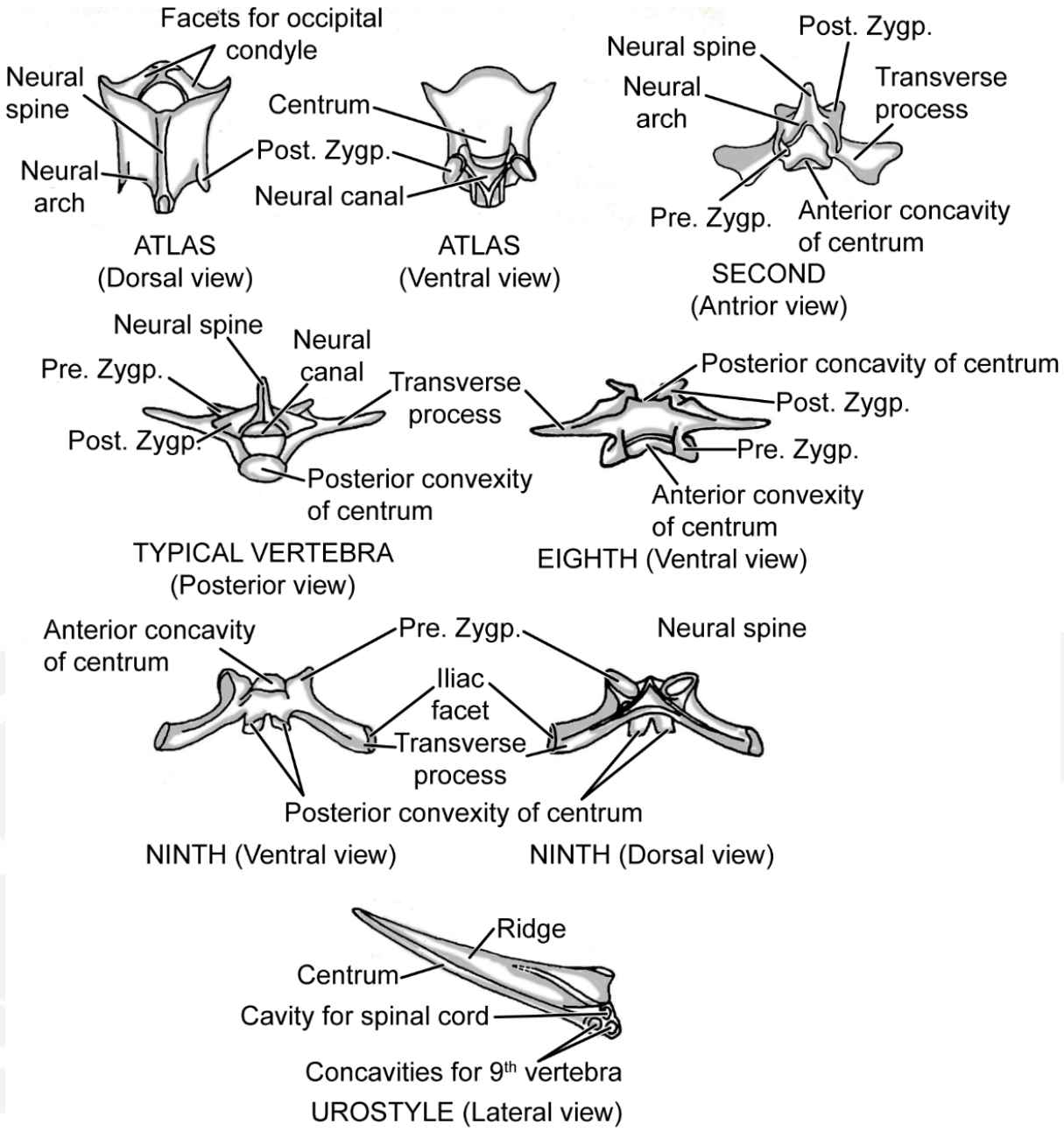



**Fig. 2.18: Vertebrae of Frog.**

The vertebrae from 3 to 7 of the vertebral column of frogs are typically procoelous. They possess a pair of transverse processes, a pair each of pre- and post- zygapophyses and a neural arch dorsally enclosing the neural canal.These vertebrae also have dorsally, a backwardly directed neural spine. The prezygapophyses of the vertebra lie behind the postzygapophyses which is present in front of the vertebra. The eighth vertebra is biconcave with concavities both in front and behind. The ninth vertebra has a convexity in front and two knob-like bulgings behind for articulation with the two depressions present on the anterior end of the urostyle. The ninth vertebra has transeverse processes which are directed backwards. However, the postzygapophyses are absent in the ninth vertebra.

The urostyle is a long, slender and rod-like in structure. In fact it is as long as the length of the whole vertebral column. The anterior end of the urostyle has two concavities in front for articulation with the two convexities present on the posterior end of the ninth vertebra. A longitudinal ridge is present along the dorsal surface of the urostyle and encloses the terminal part of the spinal cord. Urostyle is a composite structure which represents the fused caudal vertebrae of the tadpole, as a result of the loss of the tail of the tadpole during metamorphosis. In between the vertebrae, **paired apertures** called **intervertebral foramina** are present on either side for the passage of the spinal nerves. The vertebrae are also bound together by ligaments which permit limited movement.

**Rabbit**

The vertebral column of rabbit is long when compared to that of frog. The vertebral column of rabbit is divisible into five regions: i) the **cervical**, ii) the **thoracic**, iii) the **lumbar**, iv) the **sacral** and the v) **caudal** regions, (Fig. 2.19). There are a total of 45 vertebrae in the vertebral column of rabbits and include- 7 cervical vertebrae in the cervical region, 12 thoracic vertebrae in the thoracic region, 7 lumbar vertebrae in the lumbar region, 4 sacral vertebrae in the sacral region and 15 caudal vertebrae in the caudal region. The vertebrae are separated from each other by plates of fibrous cartilage known as **intervertebral discs**. The central part of the disc is known as nucleus pulpous which is a remnant of the notochord.

The number of vertebrae in the cervical region of mammals is constant irrespective of the neck being long as in giraffe (only the length of each cervical vertebra is larger) or short as in elephant. The exception in the number of seven cervical vertebrae are seen in mammals sloth and manatee about which you have read earlier in the theory course BZYCT-131. The centra of the cervical vertebra are short, the neural spine is small and the vertebral arterial foramina, through which the vertebral arteries come out are present at the base of the transverse processes of all cervical vertebrae except the 7th vertebra. The transverse processes of the cervical vertebrae are fused with the ribs to form a composite structure called the **cervical** rib.

**The atlas,** the first cervical vertebra has no distinct centrum. It is ring shaped. The neural spine is small and inconspicuous. Transverse processes are large, flattened and perforated. A pair of concavities is present on the anterior surface of the atlas vertebra for articulation with the two condyles of the skull. Small facets are on the posterior surface of the atlas vertebra for articulation with the second vertebra called the axis vertebra. The axis vertebra has a large neural arch which encloses a large neural canal which is divided into an upper part and a lower part by ligament. The spinal cord passes through the

upper part and the lower part accommodates the anteriorly directed **odontoid** process of the axis vertebra.

**The axis vertebra** has a broad centrum which has an anteriorly directed plough-like process called the odontoid process that fits into the lower part of the neural canal of the atlas vertebra. The neural spine of the axis vertebra is long and compressed and the transverse processes are long. The anterior zygapophyses are absent in the axis vertebra

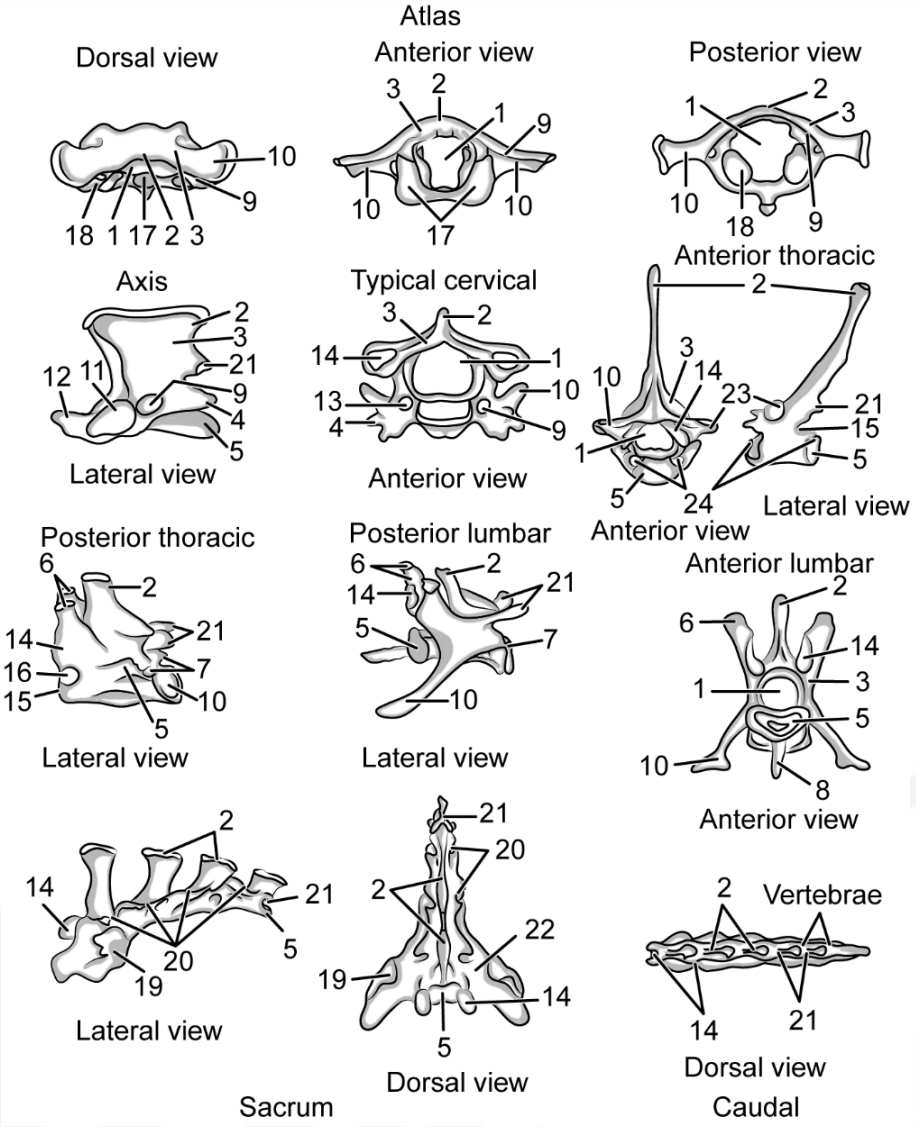
**The cervical vertebrae** from third to seventh are typical cervical vertebrae of the rabbit and are broad with a small flattened centrum. The typical cervical vertebra has a large neural arch but a small neural spine. A long neural spine is however, present in the 7$^{th}$ vertebra. The transverse processes of all cervical vertebrae except the 7th are bifurcated into a dorsal and a ventral branch. The transverse processes are simple however, and do not possess the intervertebral foramen.

**The thoracic vertebrae** have a centrum, a neural arch with a backwardly directed neural spine, a pair of short and stout transverse processes, a pair each of the pre- and post-zygapophyses. The thoracic vertebrae are movably connected with ribs through their processes. In the 9th to 12th thoracic vertebrae a pair of **metapophyses** are present above the anterior **zygapophyses**.

The lumbar vertebrae also exhibit typical mammalian vertebrae structure. They are comparatively large with shorter neural spines and longer transverse processes. There is a median ventral process called **hypapophyses** in each of the first two lumbar vertebrae. **Metapophyses** and **anapophyses** are well developed. All the lumbar vertebrae bear short lumbar ribs at the tip of the transverse processes.

**The sacral vertebrae** are fused together to form a composite structure called sacrum which is wedged between the two halves of the pelvic girdle. The neural spines of the **sacral vertebrae** are large. Hypapophyses and anapophyses are absent in the sacral vertebrae while small metapophyses are present.

**The anterior caudal vertebrae** exhibit typical mammalian **vertebrae** structure. The **caudal vertebrae** gradually decrease in size posteriorly and the more posterior **caudal** vertebrae are represented only by centra.




| | | |
|---|---|---|
| 1 - Neural canal | 9 - Vertebraterial canal | 17 - Facet for occipital condyle |
| 2 - Neural spine | 10 - Transverse process | 18 - Facet for articular surface on axis |
| 3 - Neural arch | 11 - Articular surface for atlas | 19 - Articular facet for ilium |
| 4 - Cervical rib | 12 - Odontoid process | 20 - Intervertebral foramina |
| 5 - Centrum | 13 - Epiphysis on centrum | 21 - Post zygapophyses |
| 6 - Metaphyses | 14 - Pre. Zygapophyses | 22 - 1st sacral vertebra |
| 7 - Anaphyses | 15 - Intervertebral notch | 23 - Facet for tuberculum of rib |
| 8 - Hypophysis | 16 - Facet for rib | 24 - Demifacets for capitulum of ribs |

**Fig. 2.19: Mammalian vertebrae of rabbit.**

## 2.4.3 Sternum and Ribs of Frog and Rabbit

The sternum is present in both in frogs and rabbits but the ribs are absent in frogs. Let us study in brief the main features of the sternum in frogs and the main features of the sternum and its attachment with the ribs in the rabbits.

**Sternum of Frog**

The sternum of frog is composed of cartilage and bone. It consists of four segments that are located in front and behind the epicoracoid of the pectoral girdle. Anteriorly the sternum has an omosternum which is connected to a cartilaginous episternum in front and to the epicoracoid of the pectoral girdle posteriorly. A mesosternum is present behind the epicoracoid and behind it a

cartilaginous plate-like xiphisternum is present. The sternum of the frog is joined with the pectoral girdle on the midventral line where the two halves of the pectoral girdle are joined. Ribs are absent in frogs. This is present at end of the pectoral girdle of frog.

**Sternum and Ribs of Rabbit**

The sternum of rabbit is attached to the pectoral girdle only on the ventral side and is not attached to the short ribs. Twelve pairs of ribs in the thoracic region are associated with the vertebrae of the thoracic region. The first 7 pairs of ribs in the thoracic region are called **true ribs** and are connected with the sternum on the ventromedian side. The other 5 pairs of ribs, posterior to the true ribs are called **false ribs** or floating ribs and are not connected to the sternum. In rabbit the sternum is made up of many segmental bones, a feature found only in mammals. The sternum consists of the anterior most bone which is the longest and is called the **manubrium** sterna **or presternum** and has a keel (Fig. 2.20). The last segment of the sternum is called xiphisternum and is in the form of a rounded cartilaginous plate which ends in a rounded xiphoid cartilage. Between these two parts of the sternum are five elongated bony pieces called the sternebrae that make up the body of the sternum called the **mesosternum**. The ribs are attached to the sternebrae by their costal part which is cartilaginous. The other ends of the ribs as you have learned in the earlier section are connected to the thoracic vertebrae and form a ribcage.

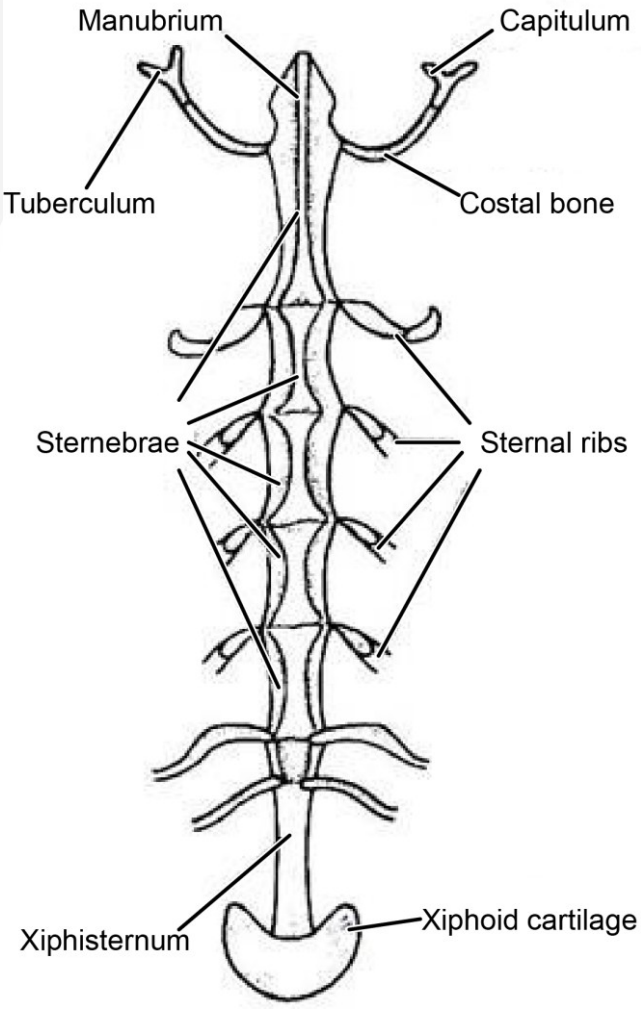



**Fig. 2.20: Rabbit sternum.**

*SAQ 5*

Identify the following statements as true or false. Write **T** for the correct statement and **F** for the wrong statement.

a) The first cervical vertebra of the rabbit, the atlas has a distinct centrum.

b) In both rabbit and frog the atlas articulates with the occipital condyles and axis.

c) All the vertebrae of rabbit are procoelous except the atlas.

d) Urostyle is typically found in frog not in rabbit.

e) The vertebral column in rabbit is divided into 5 regions in its entire length and vertebrae are separated from each other by intervertebral discs.

f) The cervical vertebrae in rabbit are connected to the ribs.

g) Lumbar vertebrae in rabbit have stout transverse processes and short spines.

h) The sacral vertebrae are loose and connected to the pelvic girdle in rabbit.

i) The caudal vertebrae decrease in size posteriorly in frog and rabbit.

j) The frog has only 9 vertebrae.

## 2.5 APPENDICULAR SKELETON OF FROG AND RABBIT

In this section, we will first compare the shoulder or pectoral girdle, of the frog and rabbit. After, which we will compare their pelvic girdle or hip. Finally, we will discuss the two sets of limbs attached to the girdles of the frog and rabbit.

### 2.5.1 Pectoral Girdle of Frog and Rabbit

The Pectoral Girdle is the anterior girdle found in the terrestrial vertebrates. The head of the humerus which is the anterior most bone of the upper arm of the forelimb articulates with the pectoral girdle of its side.

**Frog**

**The pectoral girdle of the frog** consists of two halves, which are united in the midventral line and are separate dorsally (Fig. 2.21 a).The outer ends of the two halves are bent upwards to form an arch-like structure for enclosing and protecting the organs of the thorax. The dorsally bent terminal parts of each half of the pectoral girdle, consists of a cartilaginous, triangular suprascapula, which is partially ossified. Attached to the inner end of the suprascapula on the ventral side, is a stout flat scapula bone. From each scapula two bones, i) the clavicle and the ii) coracoid, extend towards the midventral side. The clavicle of each side meet midventrally through a strip of cartilage called epicoracoid. Similarly, the coracoid of each side also meets the epicoracoid midventrally.

Each clavicle is a slender rod-like bone, located anterior to the coracoid of its side and separated from it by a wide space called coracoid fenestra. At the junction of the clavicle, the coracoid and scapula a depression called the glenoid cavity is present. The head of the humerus bone of the upper arm of the forelimb articulates with the glenoid cavity.

As discussed before, in subsection 2.4.3 the pectoral girdle of frog is joined with the sternum on the mid-ventral line where the two halves of the girdle are joined. We have already described the structure and details of the frog sternum in subsection 2.4.3.

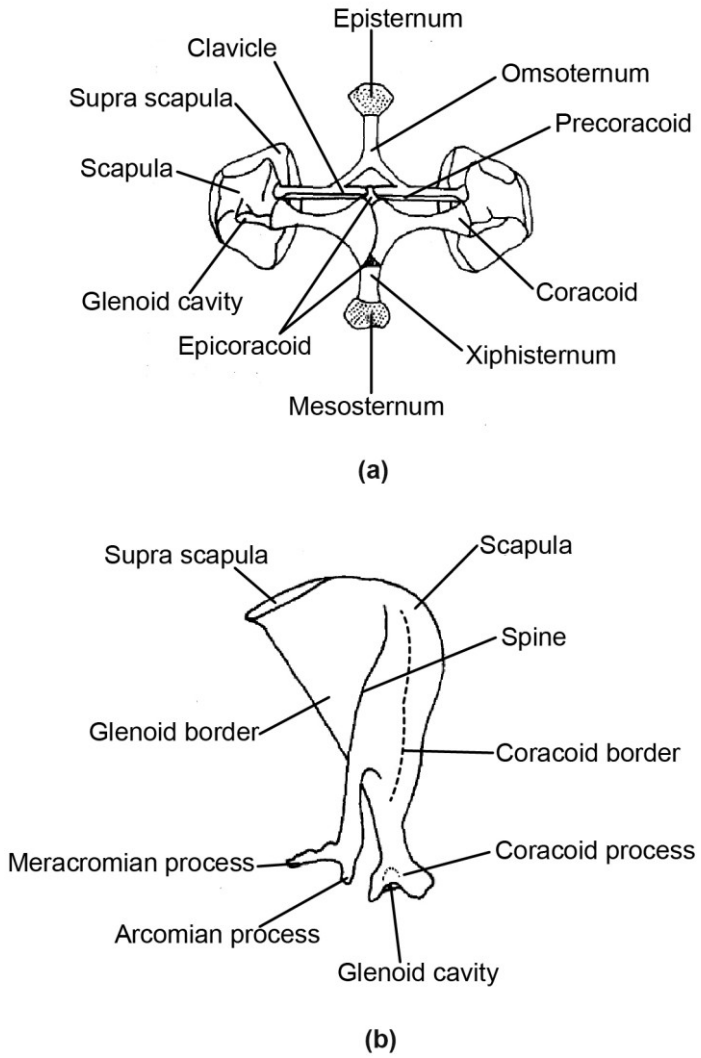



**Fig. 2.21: Pectoral girdle a) frog and b) rabbit.**

### Rabbit

**The pectoral girdle of rabbit** consists of fewer bones when compared to frog (Fig.2.21 b). The pectoral girdle consists of a flat thin triangular **scapula** and the rod like **clavicle**. The glenoid cavity is present at the narrow end of the scapula where it articulates with the head of the humerus bone of the forelimb. The narrow end also articulates with the clavicle. In the pectoral girdle of rabbits, the coracoid is present as a small curved process called the **coracoids process** (instead of the prominent coracoid as seen in the pectoral girdle of the frogs) and is fused to the scapula at the narrow end in front of the glenoid cavity.

A thin strip-like **suprascapula is present** at the dorsal edge of scapula and a ridge called the **spine** is present on the outer surface of the scapula. The scapula on its free ventral end terminates in a process called the **acromian** process. The scapula also gives out posteriorly a branch like process called the **metacromian**. The clavicle lies obliquely between the presternum and scapula.

## 2.5.2 Pelvic Girdle of Frog and Rabbit

**The pelvic girdle** is the posterior girdle found in the terrestrial vertebrates. The head of the femur which is the anterior most bone of the upper leg or thigh of the hind limb articulates with the pelvic girdle of its side.

**Frog**

**The pelvic girdle of the frog** is simpler with fewer bones in comparison to its pectoral girdle. The pelvic girdle of frog, consists of two halves joined at one end and free at the other to form a V shaped structure (see Figure 2.22 a). Each half is made up of three bones the **ilium, ischium and pubis.** The ilium is elongated and its bar- like free end articulates with the transverse process of the 9$^{th}$ vertebra. The other end of the ilium together with the pubis and ischuim symphysis( the place where two bones pubis and ischuim in this case are closely joined, forming an immovable joint) forms a disc like structure with a cavity in the center known as **acetabulum.** The proximal head of the thigh bone femur articulates with the **acetabulum** (Fig. 2.22 b). The disc like structure of each side is fused together. The three bones of the pelvic girdle namely, **ilium, ischium and pubis** are distinct and separate during early developmental stages and become fused in the adult. The fusion is assisted by cartilage or bone and this is known as symphysis. In the pelvic girdle of frog there is both pubic and ischiatic symphysis.

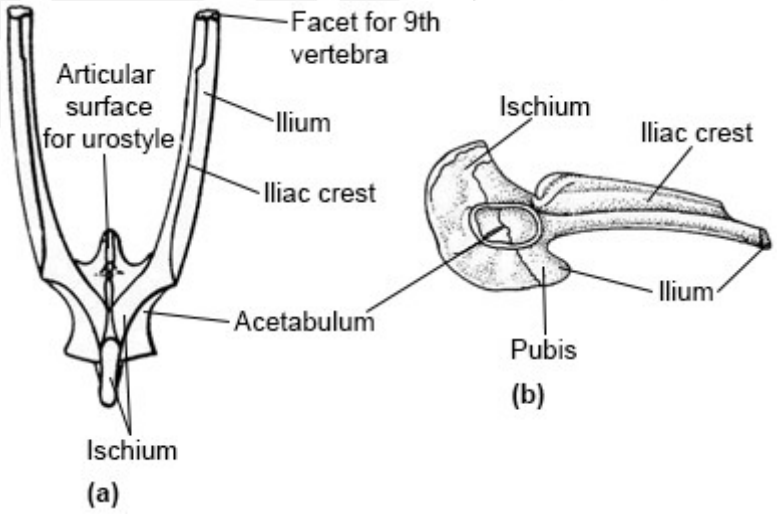



**Fig. 2.22: Pelvic girdle of frog. a) dorsal view of the V shaped girdle that supports the hind limbs. b) Lateral view of one half of the girdle.**

**Rabbit**

The pelvic girdle of rabbit also consists of two halves which are united together by symphysis. Each half is composed of the same three bones found in the pelvic girdle of frog, the **ischium**, the **pubis** and the **ilium**, (Fig. 2.23). Ischium

and the pubis are united ventrally in the midline by symphysis. The acetabular cavity is found on the outside at the union of **ischium** and **ilium**. The three bones are separate in young animal but become completely fused into a single bone in the adult. This united structure is called **innominatum**. The **Ilium** is dorsal in position and is found in front of the **acetabulum**. It has a rough inner surface which is expanded and wing-like to which the transverse processes of the 1st sacral vertebra are articulated. Each Ischium lies posteriorly and dorsally and continues downwards to form the ischial tuberosity at the **ischiatic symphysis**. Pubis is the smallest of the three bones. It lies anteriorly and is directed downwards. It is separated from the ischium by a wide foramen called **obturator foramen**. The two pubis (plural: pubes) unite midventrally at the **pubic symphysis**. The acetabulum is bound by a small bone called **cotyloid bone.**

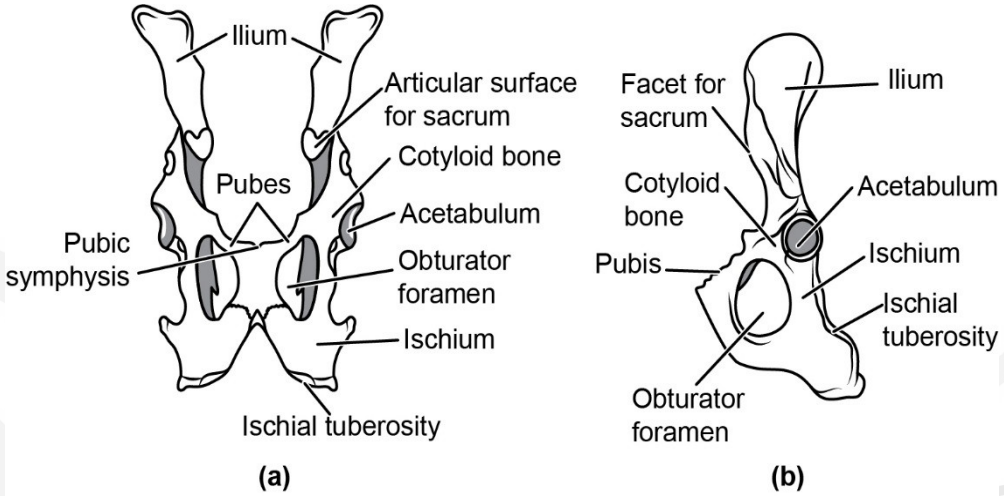



**Fig 2.23: Pelvic girdle of frog. a) ventral view of the complete girdle; b) lateral view of left half.**

## 2.5.3 Limbs of Frog and Rabbit

The pattern of the skeleton of the limbs is same in most vertebrates with very little variation. Thus, the pattern of the skeleton of the limbs in both frog and rabbit is similar. Recall the bones of the forelimbs and hindlimbs as given in Table 2.1.

**Forelimb of Frog**

A single bone called the **humerus** forms the upper arm of the forelimb of each side (Fig. 2.24). It is a stout, long and curved shaft- like bone, with swollen ends on each side. The head **of the humerus** at its proximal end fits into the glenoid cavity of the pectoral girdle. The distal end of the humerus is round with two projections side by side. A ridge known as the **deltoid ridge** extends from the proximal end of the **humerus** upto its middle on its inner side. **This is a characteristic of all vertebrates.** The humerus bone on its distal end articulates with the proximal end of the two bones radius and ulna of the lower arm of the forelimb. The radius and ulna bones are fused in the frog in order to form the **radio-ulna bone.**

The proximal end of the **radio-ulna bone** of the lower forelimb of each side contains a concavity. The distal rounded end of humerus articulate with this

cavity to form the elbow joint. A backwardly directed process the **olecranon process** is present at the elbow joint. The distal end of radio-ulna is expanded into two articular surfaces that connect with the 3 proximal carpel bones of the wrist. The other 3 distal carpal bones are arranged below the three proximal carpal bone in order to form the complete wrist. The proximal carpals that articulate with the radius bones are called **radiale**.The proximal carpels present in the middle are called the **central** carpals while the proximal carpels that articulate with the ulna bones are called **ulnare.** The carpals of the distal row are fused and articulate with the metacarpals of the hand. The innermost metacarpal is reduced and the other 4 are long. These metacarpals articulate with the phalanges and provide them support. The thumb which corresponds to the first finger as seen in other tetrapod and bipedal vertebrates is absent in frog. Two phalanges are present in fingers 2 and 3 while there are 3 phalanges in fingers 4 and 5.

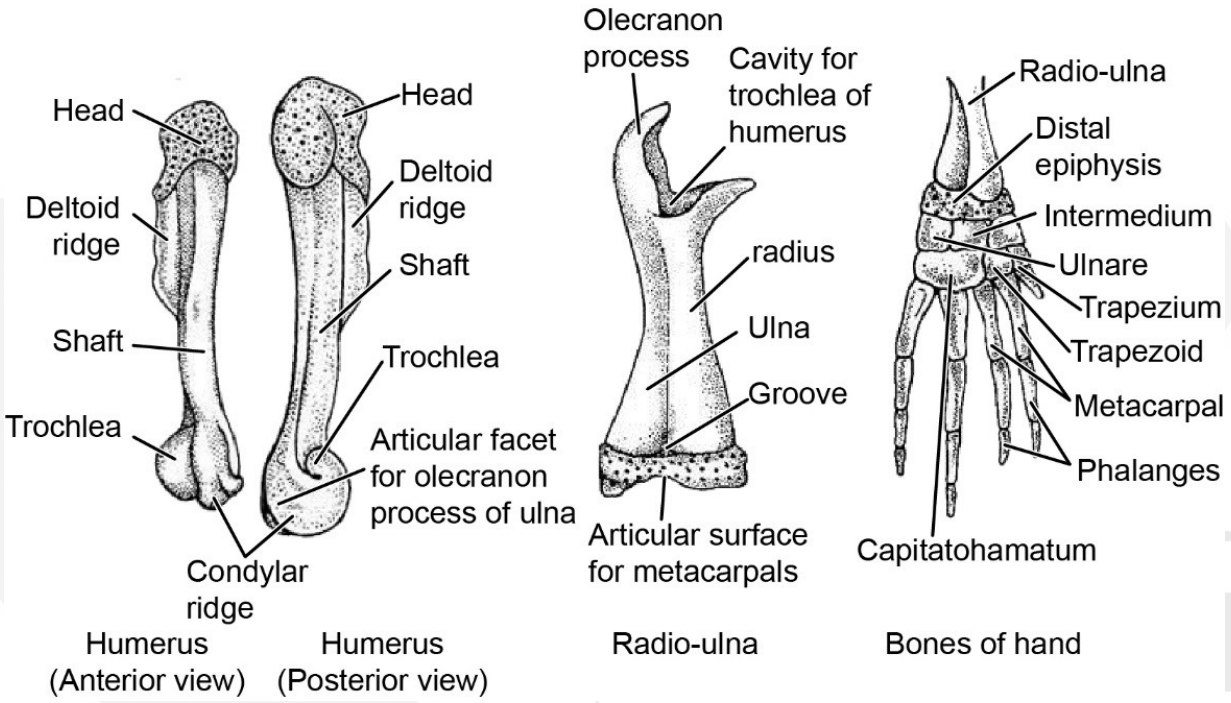



**Fig. 2.24: Forelimb of frog.**

**Forelimb of Rabbit**

The number and nature of bones in the rabbit are similar to the frog except for some differences. Look at figure 2.25.You will observe that the proximal end of humerus has two tuberosities at its outer border that provide attachment surface for the bicep muscles. The tendons of the muscles are inserted between the tuberosities in a **bicipital groove.** The deltoid ridge is present on the anterior surface of the proximal part of the shaft of the humerus. The distal end of the humerus also has two articular surfaces for articulation with the 2 bones radio-ulna of the lower arm of the forelimb. The part of the humerus bone that articulates with the ulna has a pulley like formation called **trochlea.** The part of the humerus called the **capitulum** articulates with the radius. Just above the trochlea are two fossae or depressions the anterior is coracoids and the posterior is the olecranon there is a **supratrochlear foramen** through these two depressions (see Fig 2.25 again). The bones of the lower arm, radius and ulna are connected to each other at the ends so that they do not

move over. The ulna is the longer of the two and articulates with the olecranon fossa of the humerus by its **sigmoid notch.** The radius is the smaller bone and on the inner side of the arm. The radius and ulna are provided with epiphysis on the distal end that articulates with the wrist. The wrist has 9 bones arranged in 2 rows, the proximal row is made up of 3 bones-**radiale** below the radius, **ulnare** below the ulna and **intermedium** between them. The distal row is made up of **trapezium, trapezoid** situated below the radius; **magnum** and **centrale** situated below the intermedium and the **unciform** situated below the ulna. The metacarpals are narrow and long except the first which is shorter than the others and there are 5 fingers as opposed to the 4 found in frog. All of them have 3 phalanges except the first which has only 2. The distal phalanges have grooves for insertion of claws.

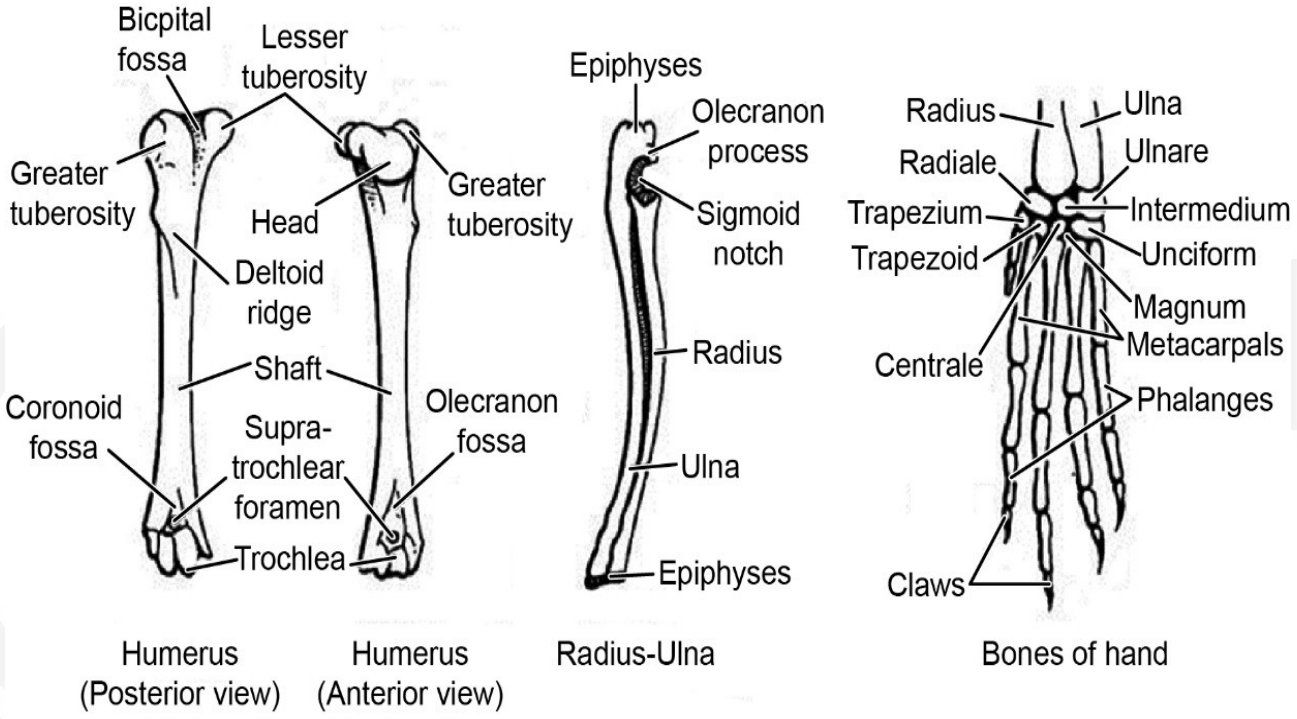



**Fig. 2.25: Bones of the forelimb of rabbit.**

**Hindlimb of frog**

As you can see, Figure 2.26, shows the single thigh bone called the femur which is long, slightly curved and swollen at both ends. The femur forms the upper bone of the hind limb and its proximal end fits into the acetabulum of the pelvic girdle. The distal end of the femur is flat and laterally expanded to articulate with the proximal end of the fused tibio-fibula bone (inner bone tibia and outer bone fibula) which forms the shank or lower bone of the hind limb. A median longitudinal groove is present in the tibio-fibula. Near the proximal end of the tibio-fibula a **tibial crest is present**. The distal end of the tibio-fibula bone articulates with the tarsal bones to form the ankle joint. The ankle consists of 4 tarsal bones that are arranged in two rows. The tarsals of the proximal row are longer and consists of two long bones the inner slender **tibale or astralagus** and the outer stout bone the **fibulare or calcaneum**. These two tarsals are united at their ends with a gap in between. These bones increase the length of the hind limbs and help in the jumping motion. The distal

row of tarsals are small and fused with the metatarsals. There are 5 elongated metatarsals as the foot has 5 toes with 2 phalanges in the 1st and 2nd and 3 phalanges in the 3rd, 4th and 5th. There is a supplementary 6th toe in the form of a calcar formed of 2 short bones.

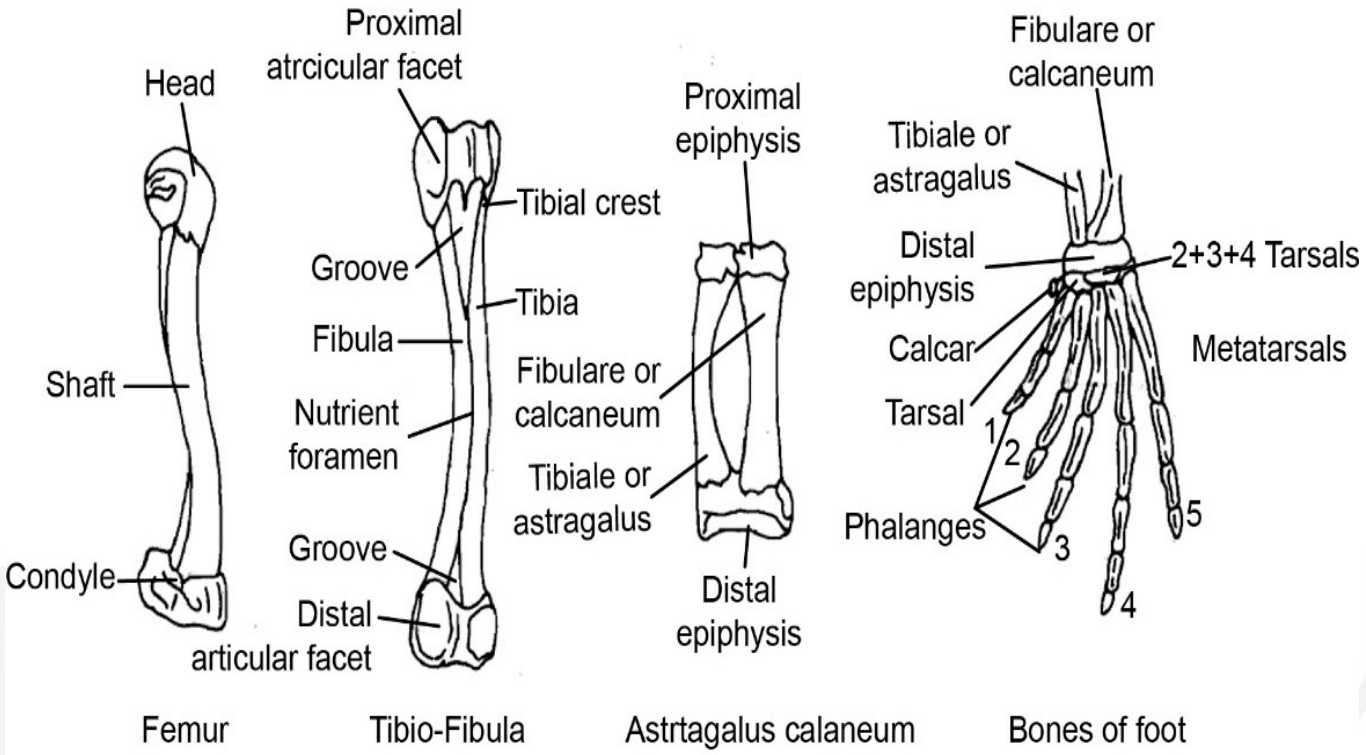



**Fig. 2.26: Bones of hindlimb of frog**.

**Hindlimb of Rabbit**

The femur of rabbit is long and stout with a prominent head at the proximal end for articulation with the acetabulum of the pelvic girdle. Three protuberances are present at the proximal head called of the femur which are termed as **greater trochanter, lesser trochanter** and **third trochanters** (Fig.2.27). The greater trochanter is situated above the head of the femur, the lesser trochanter is located below the head of the femur and the third trochanter is present below the greater trochanter. The shaft or main bone of the femur ends distally into a pair of expanded condyles enclosing the intercondylar groove for articulation with the proximal end of the tibia and fibula present below to form the knee joint. The tibia and fibula bones form the lower or shank bone of the hindlimb of the rabbit. The tibia and fibula bones are free above and fused below. The knee joint also has a large bone the patella or the knee cap. The fused distal end of the tibia and fibula articulate with the fused tarsal bones which are 6 in number as compared to 4 tarsal bones in frog. The tarsal bones are arranged in 2 rows with one tarsal in between. The astralagus and calcanium as you can see in Fig. 2.27 are larger than the rest and form the proximal row. The tarsals of the distal row are termed as the **mesocuneiform, ectocuneiform** and the **cuboid tarsals.** The bones of the sole of the foot are formed of 4 long metatarsal bones which articulate with 4 toes. Each toe has 3 phalanges.

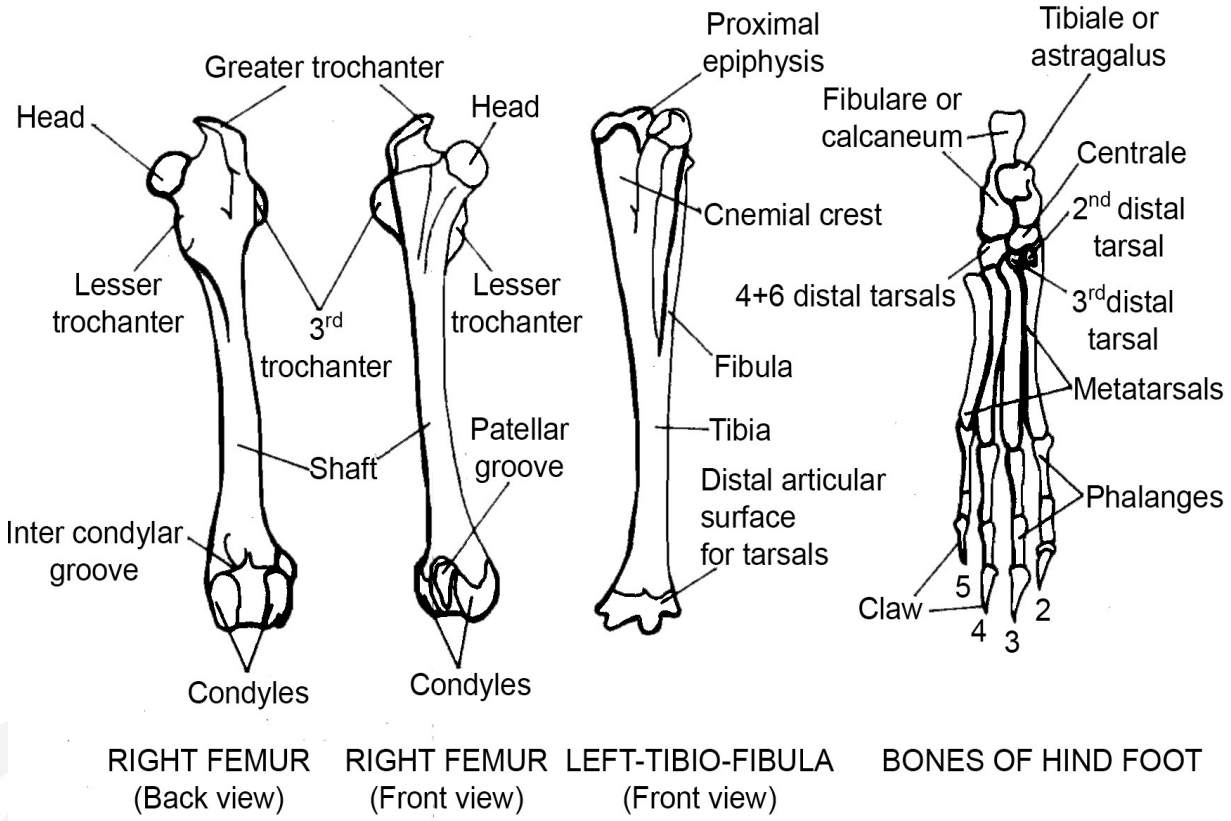



**Fig. 2.27: Bones of hindlimb of rabbit**.

## *SAQ 6*

Which of the following descriptions relate to rabbit and which to Frog?

i) Tibiofibula or the shank bone has two distal articular facets.

ii) Calcaneum and Astralagus are two tarsals that are fused at the ends but separated in the middle.

iii) The pectoral girdle is made up of only two bones clavicle and scapula.

iv) There are 5 metatarsals in the foot each with 3 phalanges except the first which has 2.

v) The ankle bones or tarsals are fused and foot has 4 metatarsals.

vi) The tibia and fibula are free anteriorly while they are fused posteriorly.

vii) Humerus has anterior deltoid ridge and three tuberosities, distally it has pulley like trochlea and capitulum.

viii) The two bones radius and ulna are immovably articulated along their length.

ix) Six carpal bones in the wrist.

x) Wrist made up of 9 carpals arranged in two rows with 4 bones in each row and one between the two rows.

## 2.6 SUMMARY

Let us sum up what we have learnt in this unit:

- The vertebrate endoskeleton is made up of living tissue of mesodermal origin and grows with the growth of the animal. It supports and protects the internal organs and gives shape and rigidity to the animal form. The endoskeleton is made up of cartilage and bone both composed of living tissue and consisting of a nonliving matrix secreted by its living cells. Cartilage has a matrix of chondrin and bone has a matrix of collagen which entraps inorganic calcium salts. Bones are of two types the replacing (cartilage) bones and investing bones.

- The skeleton can be divided into axial and appendicular skeleton. The axial skeleton consists of the skull and vertebral column. The skull forms the skeletal frame work for the head of craniate vertebrates and consists of different parts enclosing brain, cranial nerves and other sense organs found in the head. In addition to the cranium and the sensory capsules the skull contains other structures which are derived from the visceral skeleton also refered to as **splanchocranium.**

- The visceral arches support the gills in fish and the mandibular arch gave rise to the jaws, jaw suspensorium and later have been modified in terrestrial vertebrates to form the ear ossicles.

- The vertebral column is a chain of segmented structures called **vertebrae** (vertebra - singular). It extends from behind the skull anteriorly to the tip of the tail posteriorly. It supports and protects the spinal cord. The vertebrae have similar basic structure consisting of a central body, neural arch, transverse processes. They are classified into different categories on the basis of their structure and specialised according to their location in the body.

- The appendicular skeleton consists of the anterior and posterior girdles to which the fins in fishes and paired limbs of tetrapod and bipedal vertebrates are attached. The extremities of the limbs of tetrapod and bipedal vertebrates are pentadactyl being provided with five digits each. The limbs of tetrapod and bipedal vertebrates have similar joints and similar number of skeletal elements.

- Sets of paired slender curved bones called ribs are found in the thoracic region of most vertebrates. They are attached to vertebrae at the dorsal end and to the sternum at (breast bone) at the ventral end, Together with the vertebral column and the sternum the ribs form a skeletal cage enclosing and protecting the organs of the thorax.

- The salient features of the axial and appendicular skeletons of two tetrapods: frog and rabbit are described in detail and compared. The frog shows the first adaptations for amphibious life among vertebrates while the rabbit a mammal, is fully terrestrial in its habitat. The skeletons of both these vertebrates are suitably adapted for their life styles.

## 2.6 TERMINAL QUESTIONS

1. Mention the two types of endoskeletal structures found in vertebrates. What is the difference between their ground matrix?

2. Fill in the blanks in the following sentences by selecting an appropriate word from those given in the parenthesis after each sentence:

   a) The skeleton of the head is known as ……. (vertebral column, pelvic girdle, skull)

   b) Cranium encloses and protects the …… (eye, heart, brain)

   c) The brain within the cranium is in contact with the spinal cord through …… an aperture found at the hind end of the cranium (fenestra ovalis, foramen magnum, external nares).

   d) The vertebra with concavity infront and convexity behind is called …….. type (amphicoelous, procoelous, opisthocoelous).

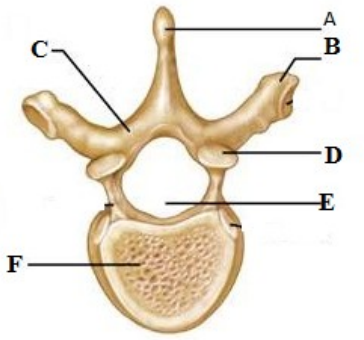
   e) The bone humerus of the upper arm articulates with the pectoral girdle at …… cavity (glenoid, acetabulum, zygapophysis).

   f) Radio-ulna a composite bone is found in ……..…….. (rabbit, bat, frog).

3. Names of some bones are given in column A and the part of the skeleton in which these bones occur in column B. Match them.

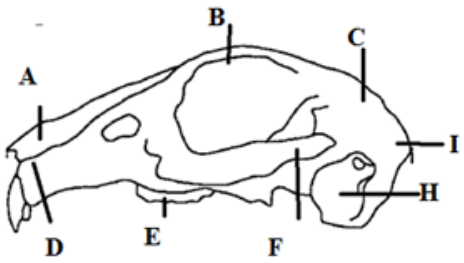
| | Column A | | Column B |
|---|---|---|---|
| a. | Parietal | A. | Pectoral girdle |
| b. | Vomer | B. | Cranium |
| c. | Maxilla | C. | Olfactory capsule |
| d. | Dentary | D. | Upper jaw |
| e. | Clavicle | E. | Pelvic girdle |
| f. | Pubis | F. | Lower jaw |

4. Label the parts of the vertebra given below:



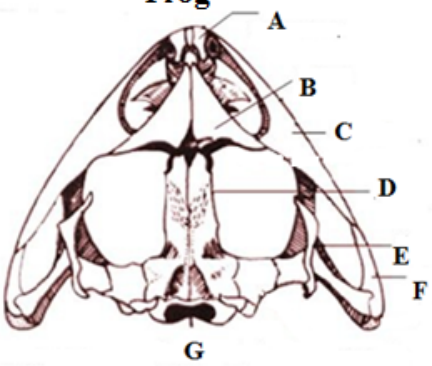
5. State whether the following sentences are true (T) or false (F).
   a. Cranium is a part of the vertebral column.
   b. Jaws are derived from the visceral skeleton.
   c. Axis is the name of the first vertebra.
   d. The bone in thigh segment of the hind limb is femur.
   e. Glenoid cavity is found in the pelvic girdle.
   f. Deltoid ridge is found on the humerus.
6. How many bones are found in the lower jaw of rabbit?
7. Mention the names of bones bearing teeth in the skull of frog.
8. Give five features that you can use to distinguish between the skulls of frog and rabbit.
9. Label the given diagrams:

**Rabbit**




**Skull lateral view**

**Frog**




**Skull dorsal view**

## 2.7 ANSWERS

## Self-Assessment Questions

1. i) Collagen in bone and chondrin in cartilage;
   ii) Osteocytes
   iii) Osteon
   iv) Endochondral ossification
2. (A). (i) front, behind; (ii) Amphicoelous; (iii) Heterocoelous;
   (iv) flat, depressions.
   (B) (i) Splachocranium; (ii) mandibular arch; (iii) Palatoquadrate;
   (iv) cyclostomes; (v) autostylic.
3. (a) iii (b) iv (c) i (d) ii.

4. i). R ii). F iii). F iv). R v). R vi). F & R vii). F viii). F ix). R x). F.

5. a) F b) T c) F d)T e) T f) F g) T h) F i) F j) T

6. (i) F (ii) F (iii) R (iv) F (v) R (vi) R (vii) R (viii) R (ix) F (x) R

## Terminal Questions

1. Cartilaginous and bony; cartilage has a matrix of chondrin, bone has a matrix of collagen and mostly inorganic calcium phosphate

2. a. skull; b. brain; c. foramen magnum; d. procoelous; e. glenoid; f. frog

3. a & B; b & C; c & D; d & F; e & A; f & E.

4. A=neural spine; B=transverse process; C=neural arch; D=articular facet; E=neural canal; F=centrum.

5. a. false b. true c. false d. true e. false f. true

6. One.

7. Premaxilla, Maxilla and Vomer.

8. i). Foramen magnum in frog is directed backwards and encircled by 2 exoccipitals while in rabbit it is directed downwards and encircled by 4 bones 2 exoccipitals, supraoccipital and basioccipital

   ii). Frog skull is broads and flattened while rabbit skull has a domed cranium and elongated frontal end

   iii). Teeth in frog present only in the upper jaw and vomer and attached to them while in rabbit teeth are present in both upper jaw and lower jaw placed in individual sockets, they are heterodont.

   iv). Large orbits placed on top of head in frog while in rabbit the orbits are lateral and there is an interorbital bone.

   v). Lower jaw in frog is made up of three bones while in rabbit there is a single bone that makes the lower jaw

9. Rabbit skull: A=Nasal; B=orbit; C=parietal; D= premaxilla; E=Maxilla; F=zygomatic arch; H = Tympanic bulla; I =supraorbital.

   Frog Skull dorsal side: A=premaxilla; B = Nasal; C= maxilla; D=frontoparietal; E =squamosal; F= quadratojugal; G= foramen magnum