CHORDATE DEVELOPMENT AND EVOLUTION 2

- ORGANOGENESIS IN AMPHIBIANS AND THE CHICK.
- MORPHOGENESIS AND COMPARATIVE ANATOMY OF SELECTED VERETEBRATE SYSTEMS(AT LEAST 4 SYSTEMS IN A YEAR).
- ORIGIN OF LIFE AND MODERN THEORY OF EVOLUTION.
- EVOLUTION OF MAN.
- THEORIES GOVERNING DEVELOPMENT-PRINCIPLES.

- Milton Hildebrand (1974) : Analysis of Vertebrate Structure.
- Kenneth V. Kardong(1998) : Vertebrates. Comparative anatomy, Function, Evolution. 2^{nd} Edition

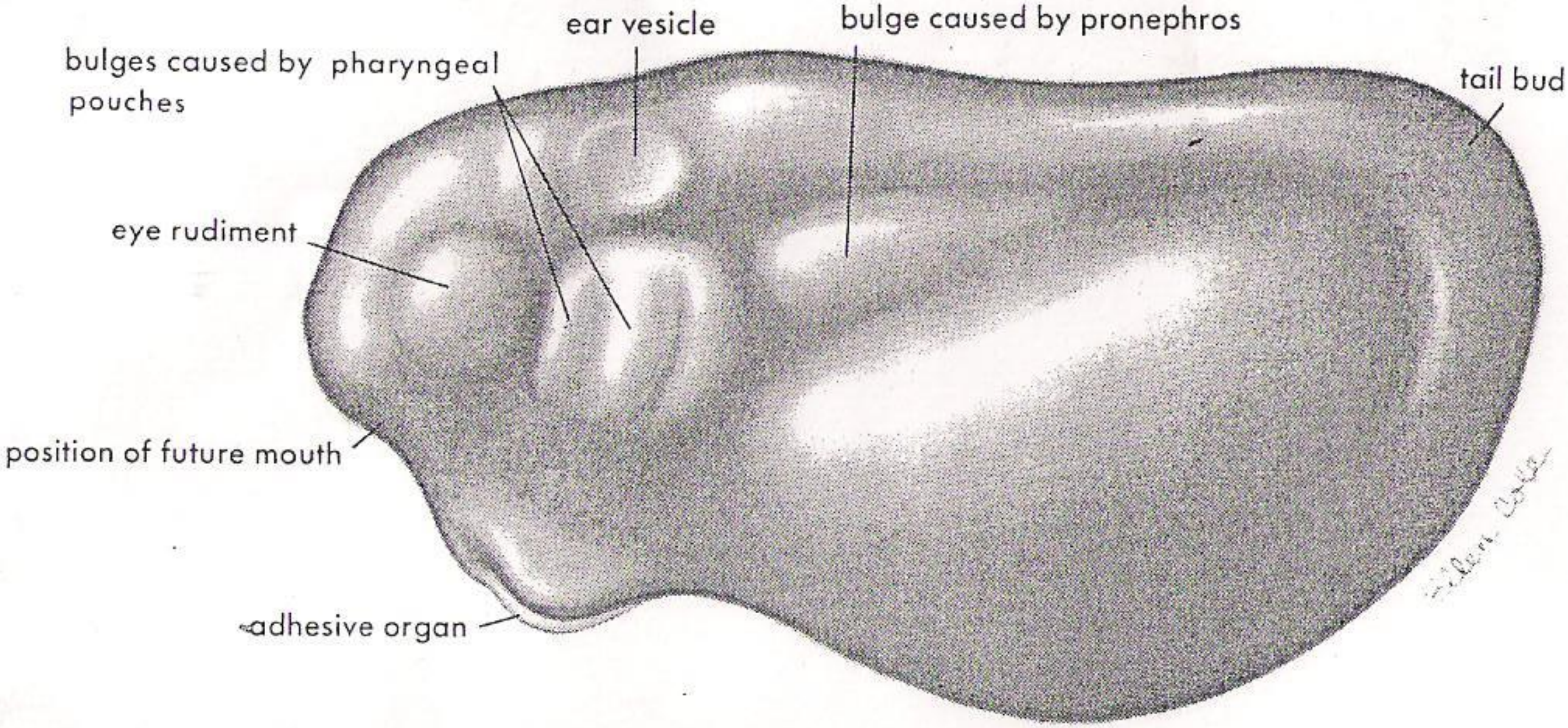
- <u>Organogenesis</u> is the development of primary organ rudiments.
- Neural tube and the alimentary tract are formed after gastrulation; then other organ rudiments develop later.
- Each organ rudiment consists of a group of cells with special properties.
- These groups of cells segregate from other cells and groups of cells in the embryo and are destined to develop into specific organs.

- An organ rudiment is often called an **anlage.**
- There are two major processes that are associated with organogenesis and these are ***morphogenesis*** and ***differentiation.***

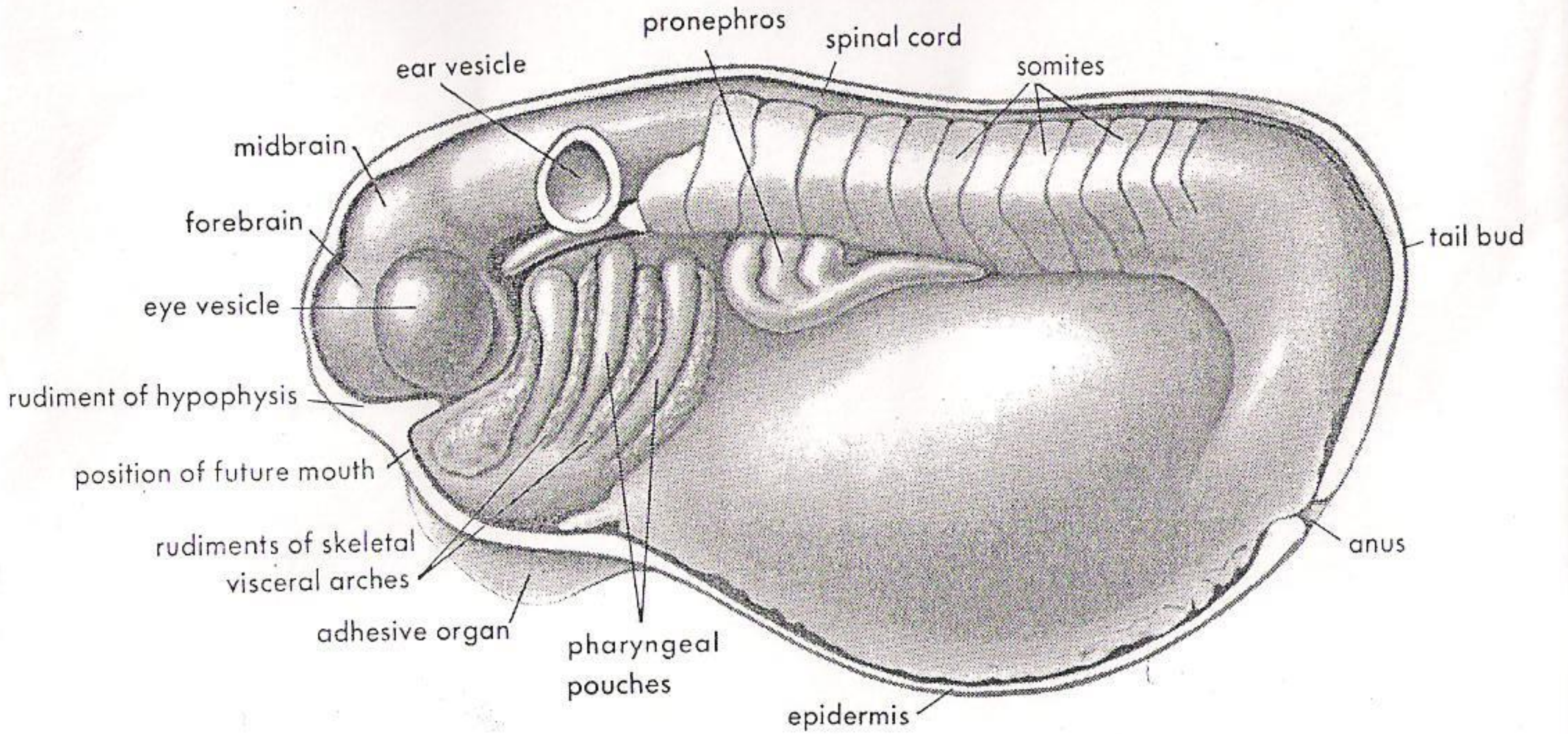
- **Morphogenesis** refers to the various processes by which the form of the embryo and its parts are acquired.
- **Differentiation** is the gradual changes in cells during development and their integration into structural and functional whole entity.
- The way in which sheets of epithelial cells give rise to the various organ rudiments is the same as that by which gastrulation is achieved i.e by means of morphogenetic movements.

The frog Embryo after Neurulation

- The neural system, at this stage is in the form of a closed tube which is broad at the anterior end where the brain will develop.
- The parts of the brain are indicated by thickenings and constrictions of anterior end of the neural tube.


ear vesicle
bulge caused by pronephros
bulges caused by pharyngeal pouches
tail bud
eye rudiment
position of future mouth
adhesive organ

A


pronephros
spinal cord
ear vesicle
somites
midbrain
forebrain
tail bud
eye vesicle
rudiment of hypophysis
position of future mouth
rudiments of skeletal
visceral arches
anus
adhesive organ
pharyngeal
pouches
epidermis

B

- The eye rudiments bulge laterally from the future forebrain.
- The notochord stretches underneath the neural tube from the midbrain to the posterior end of the body.
- At this point it fuses with other tissues which are in an undifferentiated state.
- Under the notochord, in the posterior part of the embryo lies a strand of endodermal cells called the subchorda.

- This structure exists for a short time and later on disappears.
- Lateral to the notochord, the mesoderm is subdivided into segments called **somites**.
- The **endoderm** surrounds the gut cavity, which is broad at the anterior end but narrow at the posterior part of the body.
- In the anterior part of the gut are lateral outpushings which represent the pharyngeal pouches.

- At the posterior end, an anal opening has been formed but the mouth is not yet perforated.
- Underneath the foregut are groups of mesodermal cells which represent the rudiments of the heart.
- The posterior end of the body, above the anus is elongated to form a tail bud.

Frog embryo (Stage 19) about 4mm long

- Elongated tail bud developed into a recognizable tail.
- The embryo has a long axis which consists of a neural tube, the notochord, segmented mesoderm and fin fold all round its edge.
- The neural system has developed further; the eye vesicles have constricted and separated from the forebrain.

- The ear vesicles have been formed to the right and left sides of the hindbrain.
- The nose rudiments are in the form of (placodes) thickenings of the epidermis.
- Ventral to the position of the future mouth, the adhesive organs become well developed.
- The foregut becomes subdivided into an anterior part, the pharynx and a posterior part forming the gastric and duodenal portions.

- The pharynx has developed into pharyngeal pouches on the lateral sides of the embryo.
- Underneath the pharynx the heart rudiment is developing.

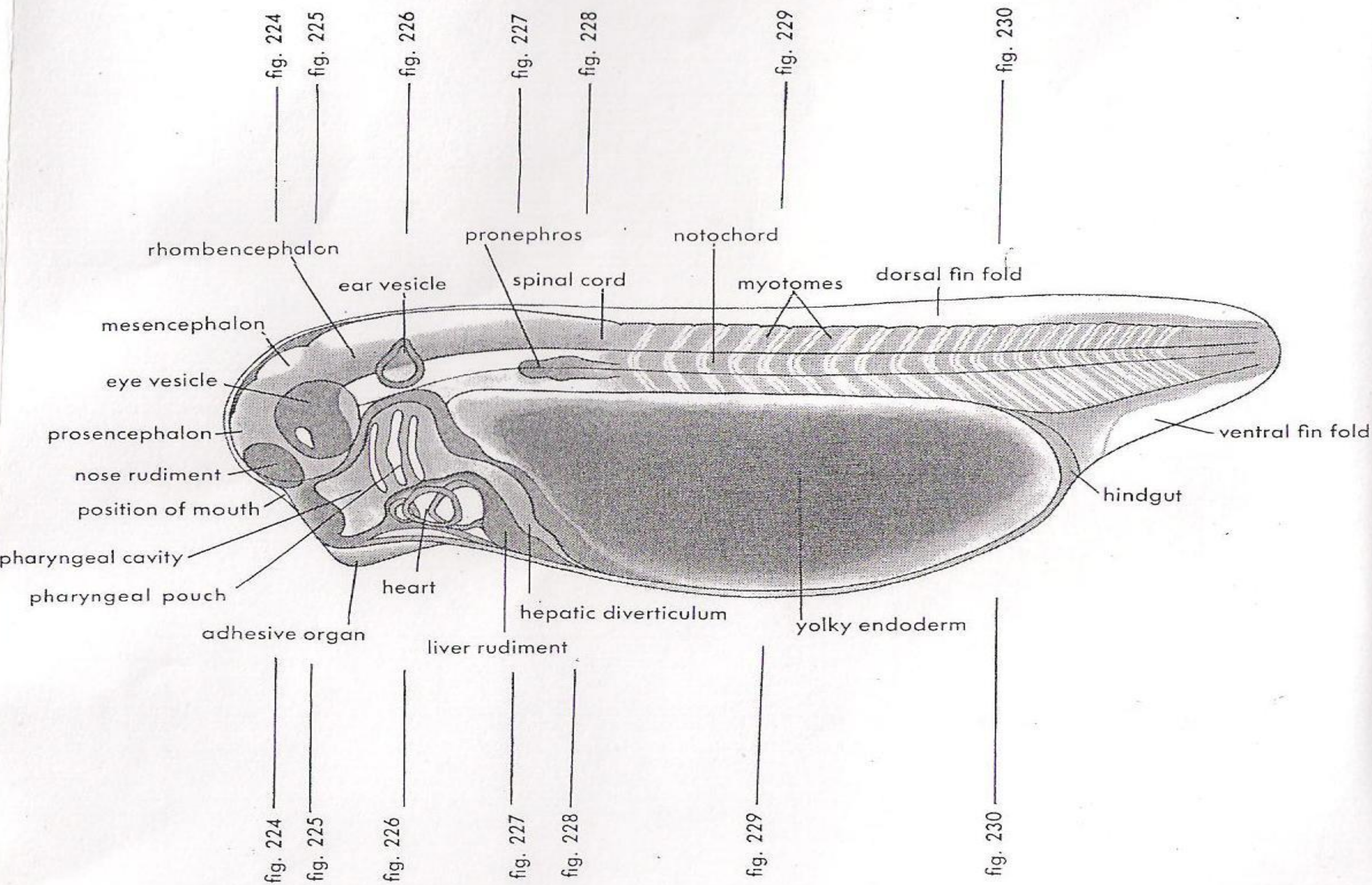


Figure 223. 4 mm. frog embryo (drawing made from a specimen cleared and mounted in Clarite). The vertical lines indicate the levels represented by photographs of transverse sections (Figs. 224 to 230). The sections used for the photographs are from different embryos; this accounts for some slight discrepancies between the drawing and the photographs.

Frog embryo (10mm in length)

- The embryo has changed its shape and has become a tadpole.
- The head and trunk become bloated and has egg-shaped body.
- The tail has elongated and has become a powerful swimming organ with segmented muscles laterally.
- The tail has fin fold dorsally and ventrally.

- The brain is rapidly differentiating and the forebrain has produced two hemispheres.
- The nose rudiments have invaginated and are in the form of sacs which are connected to the outside by nares.
- The eye vesicle has differentiated into a retina and pigmented layer and a lens has been formed.

- The mouth is opened and is surrounded by horny jaws and teeth.
- The branchial clefts are perforated and the external gills project from the sides of the head.
- The gut is now differentiated into the various parts.
- One can distinguish the pharynx, oesophagus, gall bladder pancreas and the intestine.

Organogenesis of the chick embryo (27-28 hrs)

- The head has elongated and projects from the blastoderm.
- The neural folds in the cephalic region meet in the dorsal midline and their edges become fused.

- By 27hrs of incubation the cephalic part of the neural tube which will form the brain enlarges compared to the caudal part which will form the spinal cord.
- Three primary brain vesicles can be distinguished in the cephalic region of the neural tube: the most anterior vesicle is the **forebrain** (**prosencephalon**). Separated from this by a constriction is the **midbrain** or **mesencephalon.**

- A very slight constriction marks the boundary between the mesencephalon and the **rhombencephalon** or **hindbrain.**
- The hindbrain is continuous with the spinal cord without any transition. The lateral wall of the prosencephalon become bulged out to form a pair of primary optic vesicles. At the ventral part of brain, the notochord extends forward into a depression in the floor of the prosencephalon known as the

infundibulum.

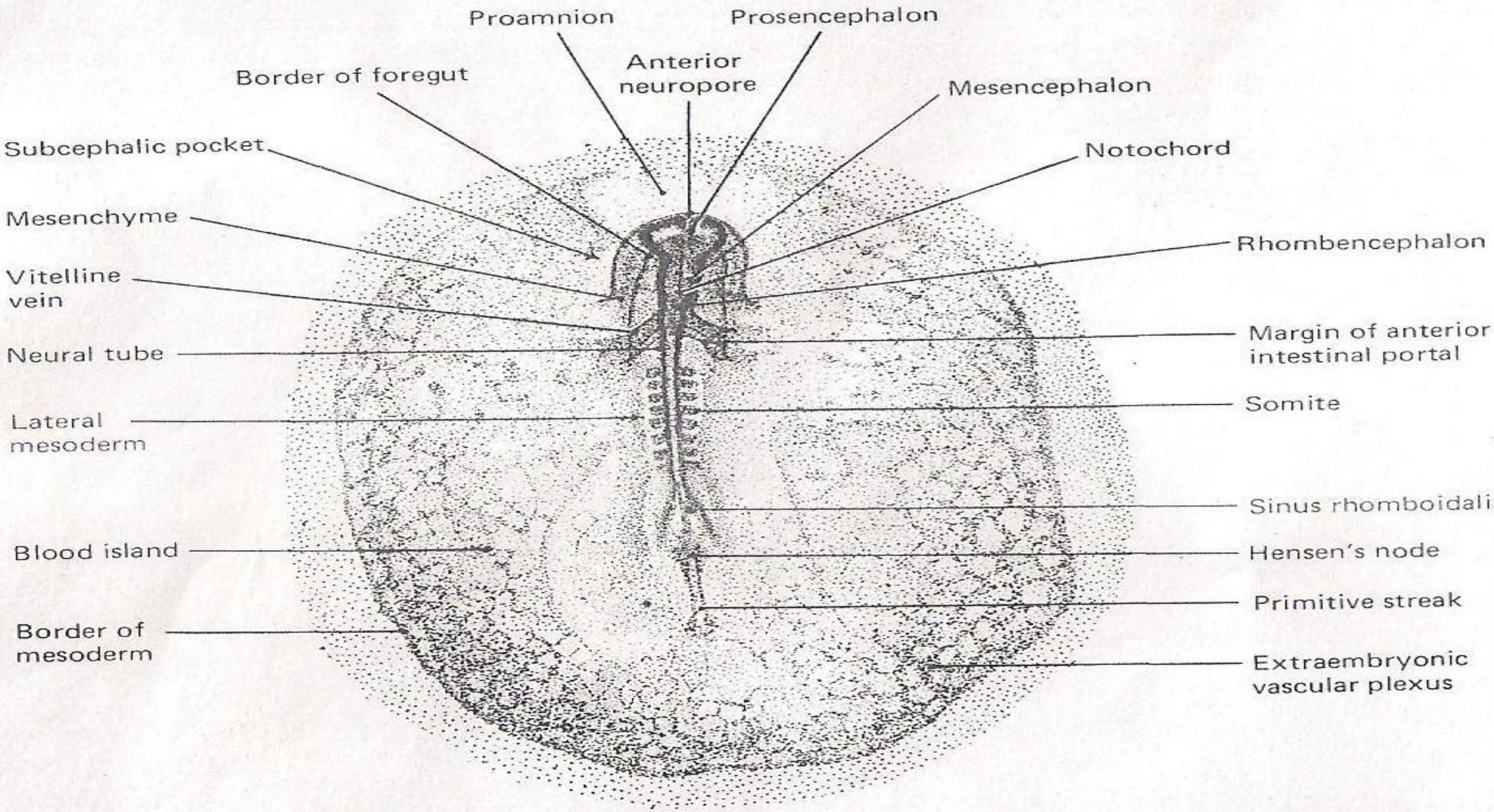


FIGURE A-15
Dorsal view (×14) of the entire chick embryo having 8 pairs of somites (about 27 to 28 hours' incubation).

- As a result of the interaction with the ectoderm, the infundibulum develops onto the neural hypophysis.
- Closure of the neural folds takes place near the anterior end of the neural groove.
- However, closure of the neural tube at the extreme anterior end of the brain is delayed, the persisting communication between the prosencephalon and the outside is called **anterior neuropore.**

- By about 33hrs of incubation it closes.
- At the other end of the body the neural tube has closed caudally to the point where the somite formation has progressed.
- Caudal to the most posterior somites, the neural groove is still open.
- The neural folds diverge to either sides.

Chick Embryo (29-30hrs)

- The most conspicuous parts of the chick embryo at this stage are the brain and spinal cord rudiments and the somites, of which there are 9 or 10 pairs.
- The brain shows subdivision into primary brain vesicles, with eye vesicles already prominent.
- However, the closure of the neural tube is not yet completed; the anterior end of the cavity of the neural tube is open to the exterior by neuropore.

- At the posterior end the neural folds have not come together and so there is still an open neural plate present.
- Further back the remnants of the primitive streak have not yet disappeared.

- Underneath the neural tube is the notochord which is continuous with the primitive streak material at the posterior end.
- Posterior to the somites lies the unsegmented mesoderm.
- The anterior part of the gut is already closed and separated from the yolk sac, but in the anterior trunk region the gut is opened ventrally.

- The blood vessels are represented by separate vessels on the right and left sides of the body.
- The rudiments of the left and right sides of the heart have started fusing together .
- At this stage the embryo as a whole is bilaterally symmetrical.

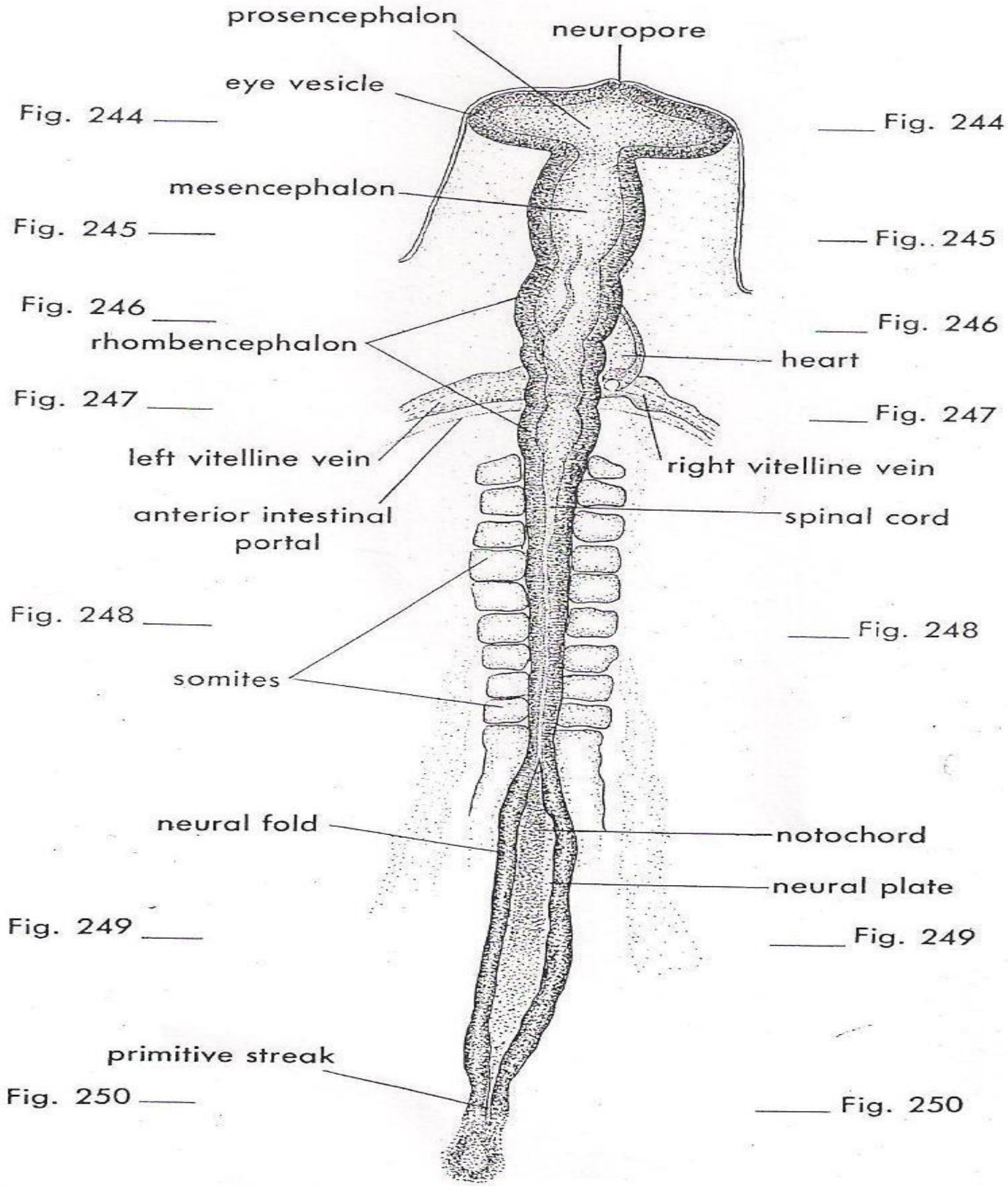


Figure 241. Chick embryo stage 10 (age 29 to 30 hours). Drawing made from a specimen cleared and mounted in Clarite. The lines indicate the levels represented by transverse sections shown in Figures 244 to 250.

The chick embryo at 33hrs of incubation

- By about 33 hrs of incubation, the optic vesicles are established as paired outgrowths of the prosencephalon.
- They soon extend to occupy the full width of the head.
- The distal portion of each vesicle comes to lie close to the superficial ectoderm. This relationship is important in the latter development of the lens.

- Initially the cavities of the optic vesicles are in contact with the cavity of the prosencephalon, but later on constrictions appear to mark the boundaries between the optic vesicles and the prosencephalon.
- At 38 hrs of incubation, the impending subdivision of the 3 primary brain vesicles to form the five regions are already beginning to appear.

4

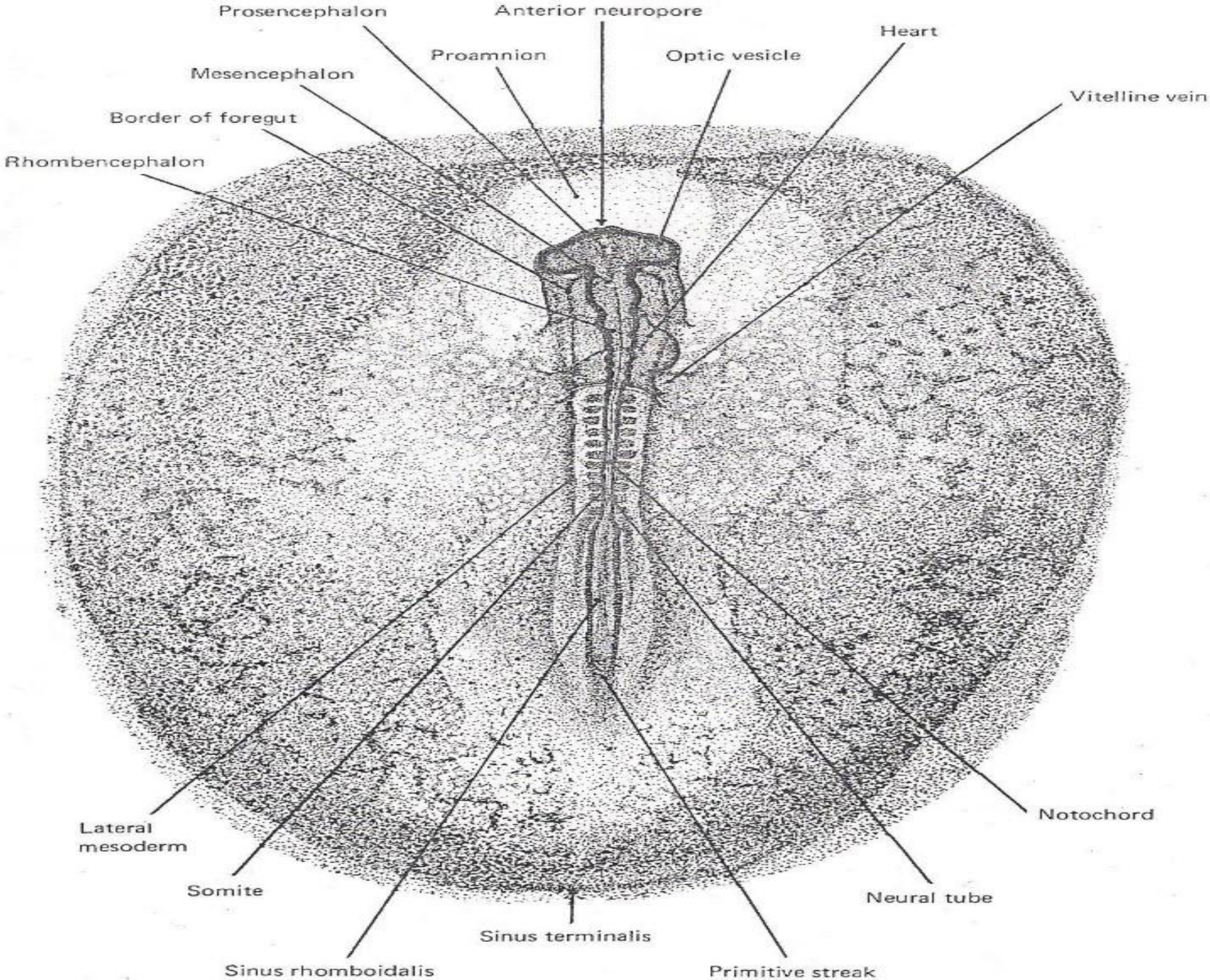


FIGURE A-18
Dorsal view (×17) of an entire chick embryo of 12 somites (about 33 hours' incubation).

- Later on the openings into the pits become narrowed and finally close so that the pits become vesicles between the superficial ectoderm and the myelencephalon.
- At this point they have no connection with the central nervous system.
- Between 50-55 hrs of incubation, the embryo undergoes a series of bending and twisting that changes its shape.

- The anterior end of the body becomes twisted so that the left side of the embryo lies flat on the surface of the yolk.
- This happens because the brain becomes bent at an angle at the midbrain as the cranial flexure.
- The parts of the brain are easily recognizable.
- The eye is already in the eyecup stage with a lens lying in the pupil.

- Prosencephalon becomes subdivided into the **telencephalon** and **diencephalon**.
- The mesencephalon remains undivided, whilst the rhombencephalon divides to form the metencephalon and myelencephalon.
- The ears arise early in development at about 35 hrs of incubation.

- At this stage a pair of thickenings called auditory placodes arise in the ectoderm of the head. By 38hrs of incubation, the auditory placodes become depressed below the ectoderm, forming the walls of a pair of cavities, the auditory pits.
- Initially the walls of the auditory pits are continuous with the superficial ectoderm.

- The lens is, however, not separated from the epidermis but it is in the form of a sac with an opening to the outside.
- The ear rudiments are in the form of pockets which open to the outside, whilst the nose rudiments is only a thickening of the epidermis.
- The number of pairs of somites has increased but at the posterior end of the body, there is still some unsegmented mesoderm.

- The neural tube is not completely closed at the posterior end, even the rudiments of the primitive streak can be found though the migration of cells from the streak has ceased.
- The first three pairs of pharyngeal pouches have been formed and the blood vascular system has undergone marked improvement.

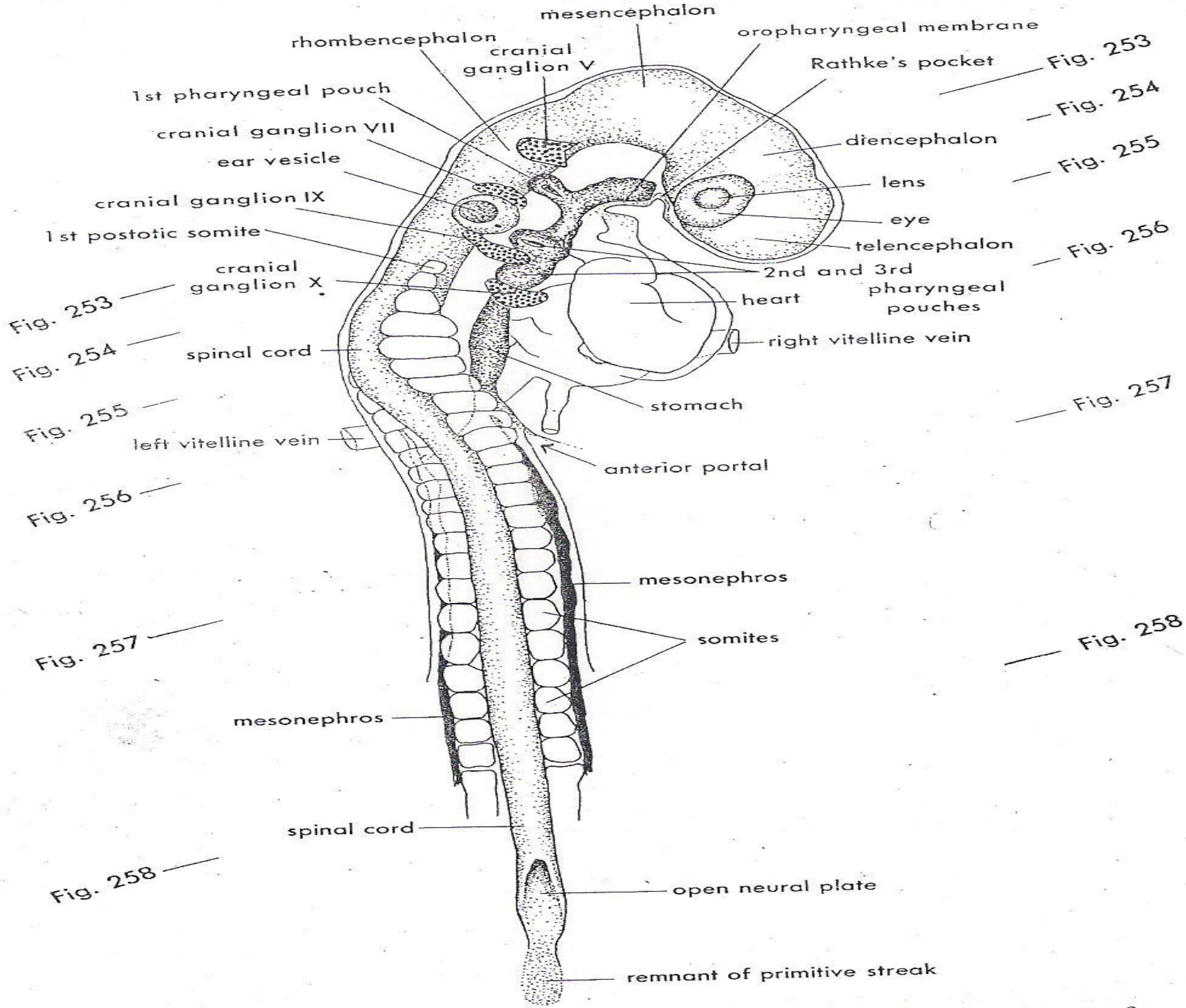


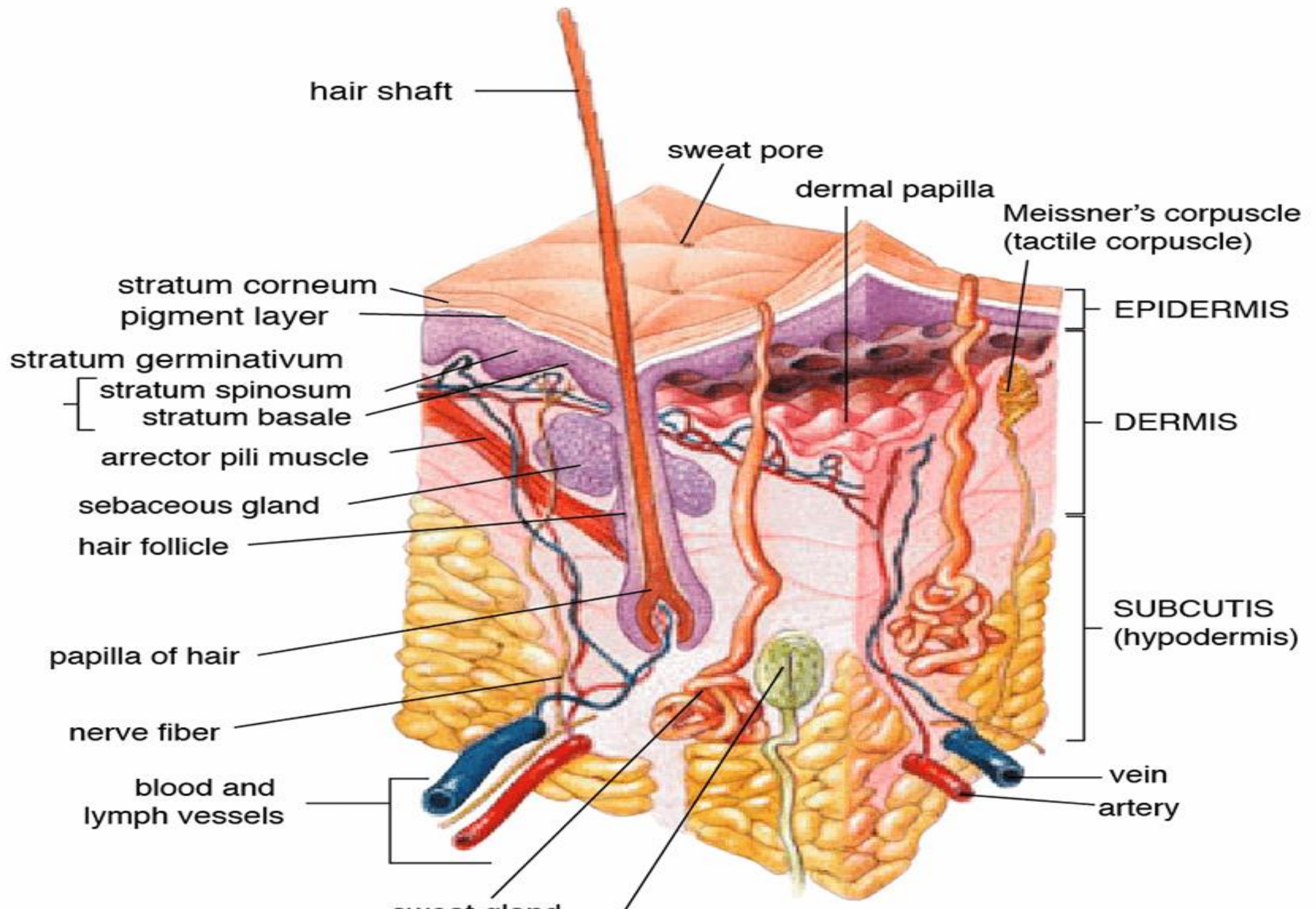
Figure 251. Chick embryo, stage 15 (age 50 to 55 hours). Reconstruction from a series of horizontal sections showing nervous system, somites, kidney rudiments and alimentary canal with gill clefts. The lines on the sides indicate the levels represented by sections shown in Figures 253 to 258. The sections used for the photographs are from a different embryo, and this accounts for some slight discrepancies between the drawing and the photographs.

INTEGUMENTARY SYSTEM OF VERTEBRATES

General structure of the Skin

- The skin of all vertebrates has 2 principal layers: a superficial epidermis and a deeper layer the dermis.
- The epidermis is derived from the ectoderm, on the surface of the embryo.
- The dermis is derived from the dermatome, supplemented by contributions form lateral and ventral somatic mesoderm.
- Cells from these sources migrate as mesenchyme and distribute themselves evenly under the ectoderm.
- Some neural crest cells also invade the developing dermis.
- The integument, with its accessory structures is a system that performs various functions (protective) that contribute to the survival of the animal.

Integumentary System



Function of the vertebrate skin

1. The tough skin of many vertebrates, often reinforced with dermal scales or bones is a protection against mechanical injury and attack by predaceous enemies.

2. The skin is a continuous unbroken defence against invasion of bacteria and other micro-organisms.

3. As a sheet of tissue which isolate the internal structures from the exterior, the skin wards off physical and chemical influences that may disturb the internal environment.

4. It aids in the regulation of water by preventing too much loss of water in marine and terrestrial vertebrate or the large influx of water in freshwater animals.

5.The skin pigments prevent the absorption of injurious amounts of light eg. melanin of mammals.

6. The skin, in addition to structures such as hairs or feathers insulate the body against gain or loss of heat and therefore plays a major role in temperature regulation in birds and mammals.

7. It plays a physiological role in the absorption and elimination of waste materials through the moist skin membrane or glandular structures e.g sweat glands.

8. Breathing is a function of the skin in many forms and in some vertebrate such as amphibians the skin is an important breathing organ.

8. The skin also functions as a sensory organ due to the possession of sensory nerves.

- The epidermis is stratified into two or more layers.
- The deepest layer rests on the dermis and consists of closely packed cells. It is called **stratum germinativum**.

- The cells of this layer pushes outward and mature to become the more superficial cells of the skin.
- The layer(s) of the epidermis that are superficial to the stratum germinativum are varied according to taxon.
- Most of these layers are secretory in nature - the secretory cells fall into 2 categories: mucous cells and proteinaceous cells.
- Mucous cells produce different types mucus, some kinds of poisonous secretions and in some fishes photophores (light producing cells).
- The proteinaceous cells produce slime, poisons, substances that elicit alarm reactions, enamel and photophores.
- The principal product of this layer is horny material, keratin, the main constituent of feathers, hairs, reptilian scales and the dead outermost layer, the stratum corneum of the dry skin of tetrapods.

- The dermis is thicker than the epidermis with fewer kinds of cells and is characterised by a meshwork of fibres.
- The most abundant are collagenous fibres.
- The dermis has an outer vascular stratum spongiosum and deeper and thicker stratum compactum.
- These merge into one another to secure the skin to the connective tissue that cover the muscles of the body wall.
- Smooth muscle fibres may be present in the dermis.
- Fat is commonly deposited below the dermis.
- There are glands in the skin and these are derived from the epidermis but usually penetrate the dermis.

Pigment Cells

- Pigment cells are also called chromatophores.
- They are derived from neural crest cells and occur, according to the taxon, at any level of the skin, but they tend to be concentrated near the epidermal-dermal boundary.
- Chromatophores of the epidermis are the characteristic of homoiotherms and are of the type called melanophores.
- They have many organelles called melanosomes which contain the pigment melanin.
- Melanin may be black, red or brown.
- Colour imparted by these cells may be responsible for morphological colour change, which may be seasonal or age-related.
- Chromatophores of the dermis are almost exclusively found in poikilothermic animals.

- Many of them maintain a constant colour, cause morphological colour change or physiological colour change eg. when a fish or lizard adapts its colour to that of the substrate.
- There are three types of dermal chromatophores:

1. Iridophores- these have organelles called reflecting platelets that contain crystalline deposits (mainly guanine), these scatter or reflect light.

2. Xanthophores- these are yellow in colour.

3. Erythrophores- these are red in colour and have their pigment (pteridines and carotenoids) in organelles called pterinosomes.

- These various kinds of chromatophores may be inter-related in the achievement of certain colour effects.
- **Colour may be used by vertebrates for concealment, for control of heat absorption and conservation, control of the synthesis of vitamin D.**

INTEGUMENT OF FISHES

- The soft parts of the earliest fishes, the Ostracoderms(jawless fishes) and the Placoderms (jawed armoured fishes) is unknown.
- The epidermis of Cyclostomes (lampreys and hagfishes) is thin with several kinds of glands.
- The most numerous of these glands are mucous glands of which there are 2 types:

1. Club glands-which produce fibrous protein.
2. Granular glands which discharge at the surface of the body.

- A thin non-cellular cuticle covers the surface of the epidermis
- The dermis may be thinner than the epidermis.
- It consists of a fibrous layer which contains collagenous fibres but no elastic fibres.
- There are no scales

Lamprey

Hagfish

GNATHOSOMES-JAWED FISHES

- The skin of Gnathosomes is usually thin and glandular and tightly fits over the body.
- With rare exceptions keratin is absent.
- The mucous glands may be unicellular but may also be multicellular.
- The slimy mucus they secrete cleans the body and acts as cuticle to prevent the entry of foreign materials.
- They also assists in osmoregulation and reduces friction as the fish swims.
- Granular and club glands are also common.
- Some fishes have poison glands, which are associated with fin spines.
- Others have multicellular light organs- contain lenses and reflectors.

The dermis

- The dermis, though thin is divided into a stratum compactum and a stratum spongiosum, except when it covers the fins, where it is reduced to a basal membrane.

Development and Structure of hard Tissues

- There are three principal types of hard tissues: enamel, dentine and bone.
- Enamel is the hardest tissue of the body.
- It is shiny, translucent in thin sections and composed of crystals of calcium hydroxyapatite.
- Enamel occurs only on teeth, superficial denticles, scales or armour plates and is usually external to any other hard tissues present.
- Enamel is produced by the ectoderm.

- Dentine is harder than bone but usually softer than enamel.
- The chemical composition of its inorganic salts is the same as that of enamel but the organic fibres is about 30% that of enamel.
- Dentine occurs only in the teeth, denticles and external armour.
- It is always present and lies internal to enamel but usually external to bone.

Types of dentine

1. Osteodentine is organized into osteons (having columns of cylinder within cylinder) These are interspersed in a matrix of bones.

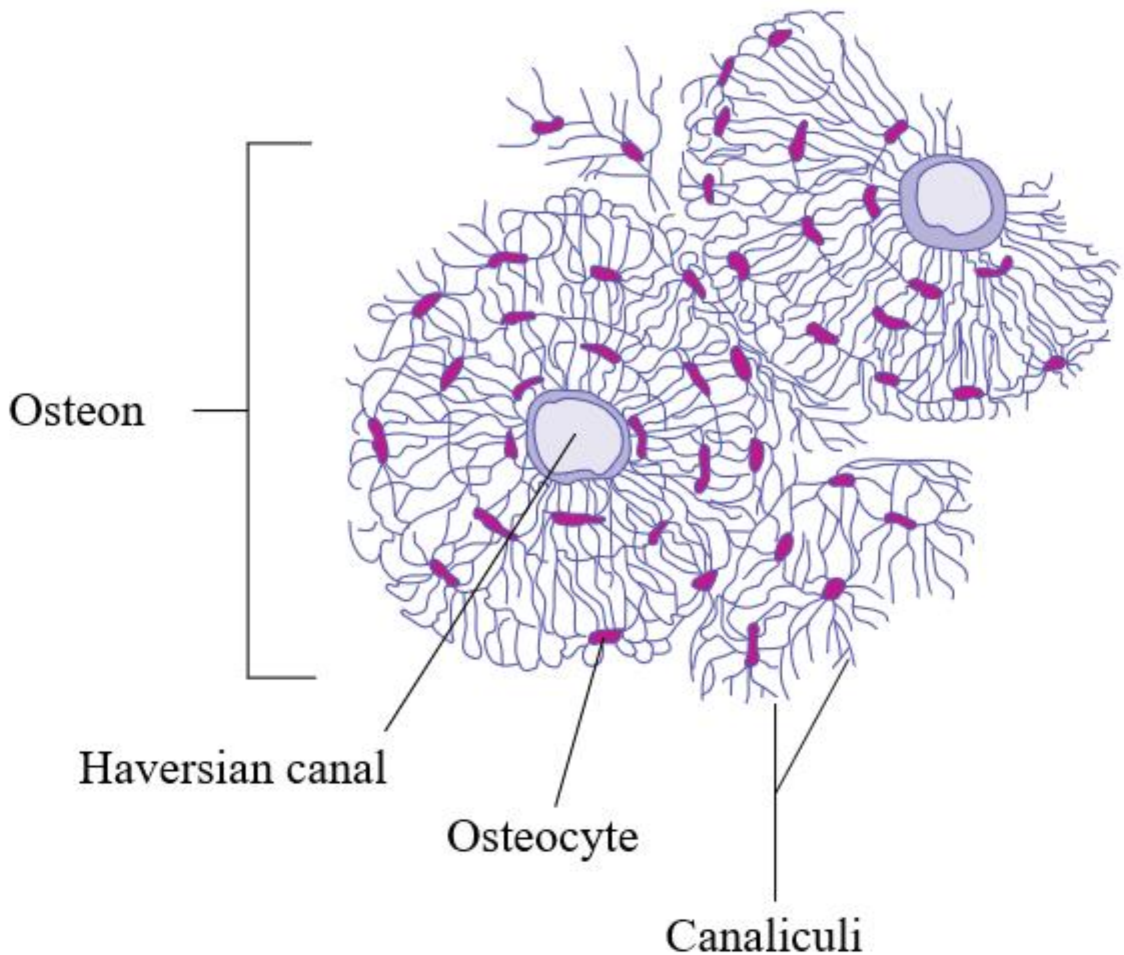
- Osteons that occur in dentines are also called denteons.

2. Orthodentine has no true osteons or bony matrix, but is either laid down in a superficial compact layer or in layers that are concentric around a central pulp cavity.

- Cosmine is dentine having characteristic tufts of tiny canals that radiate upwards and outwards from small vessels on the surface of the scale.
- When dentine is very hard, it is termed enamel-like or enameloid.

Bone

- Bone has about the same organic content as dentine, and usually occurs internal to dentine if the two are present.
- Bone develops in the deeper and less restricted part of the dermis.
- It usually has internal bone cells(osteocytes) located in lacunae which are connected by small canals called canaliculi.
- Bone, like osteodentine is characterised by osteons (harvesian canals), but when it is adjacent to internal and external surfaces it is usually deposited in laminar sheets.


Osteon
Haversian canal
Osteocyte
Canaliculi

BONY SCALE AND THEIR DERIVATIVES

1. Armour- armour shields of ostracoderms and placoderms differ only in size from the coarse scales on other parts of the body.

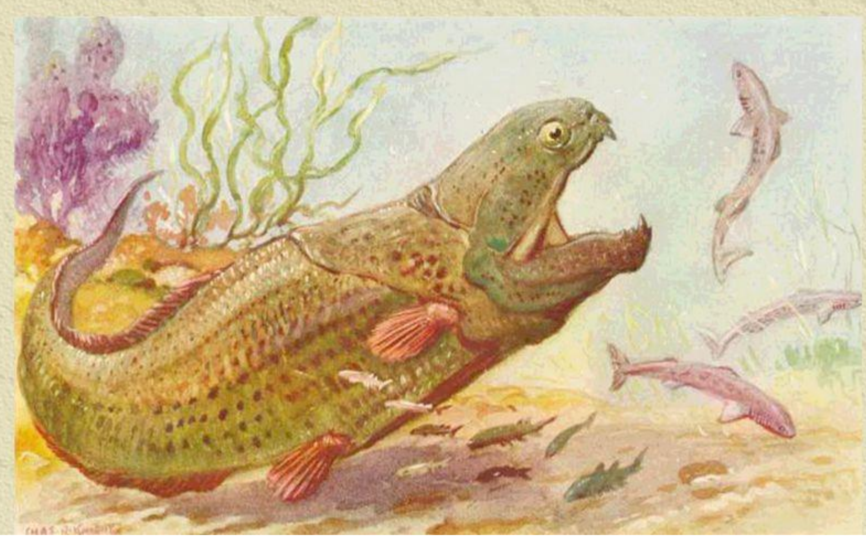
- In section it shows 3 layers:
- The surface layer is composed of dentine, capped with enamel and with surface projections called denticles.
- The middle layer is composed of spongy bone and channels of small blood vessels and sensory pits.
- The basal layer is made of lamellar bone with fewer vascular channels.

Cosmoid Scales

- Like armour, cosmoid scales have the same 3 layers.
- The surface of the scale is usually covered by enamel.
- The scales may be cycloid (round) or rhomboid (parallelogram). Cycloid scales are usually overlapping.
- Rhomboid scales usually overlap, but fit edge to edge.

Silurian

- First jawed fishes (placoderms)



- Cosmoid scales are found on the posterior parts of the bodies of Placoderms and on Crossopterygians(lobed finned fishes)
- **Ganoid scales** are thick rhomboid structures which evolved from cosmoid scales.
- There are 2 principal types**:Palaeoniscoid** and **Lepidosteoid**
- Palaeoniscoid type is more primitive. The surface is thickened during successive period of growth by laminations of the enamel called ganoine.
- Cosmine dentine is retained under the ganoine. This type of scale is found on extinct Actinopterygians and the chondrostean *Polypterou*s.
- **Lepidosteoid** type is derived from palaeoniscoid scale. The ganoine is the same but the cosmine is lost.

Lobe -finned

- The base is acellular and although the canals are present they are no longer vascular.
- This type of scale is found on the more recent Chondrostean and Holostean ray finned fishes (Subclass Teleosti).

Elasmoid scale

- Derived from ganoid scales of the Lepidosteoid type
- This type of scale is restricted to the teleosts.
- The basal layer, which forms the bulk of the scale is acellular, but is strengthened by collagenous fibres.
- The ancestral ganoine is absent, but is replaced by a surface glaze derived from the enamel.
- They are thin, imbricate and cycloid or ctenoid i.e having comb-like projections on the exposed margins.

Dermal denticles(Placoid scales)

- Dermal denticles or placoid scales are confined to the Elasmobranchs and some Placoderms
- They evolved from cosmoid scales or possibly from the integument of a Placoderm stock.
- They lack the bony basal layer of scales and are always small and isolated.
- There is a central pulp cavity surrounded by dentine and capped by a tissue of enamel-like nature.

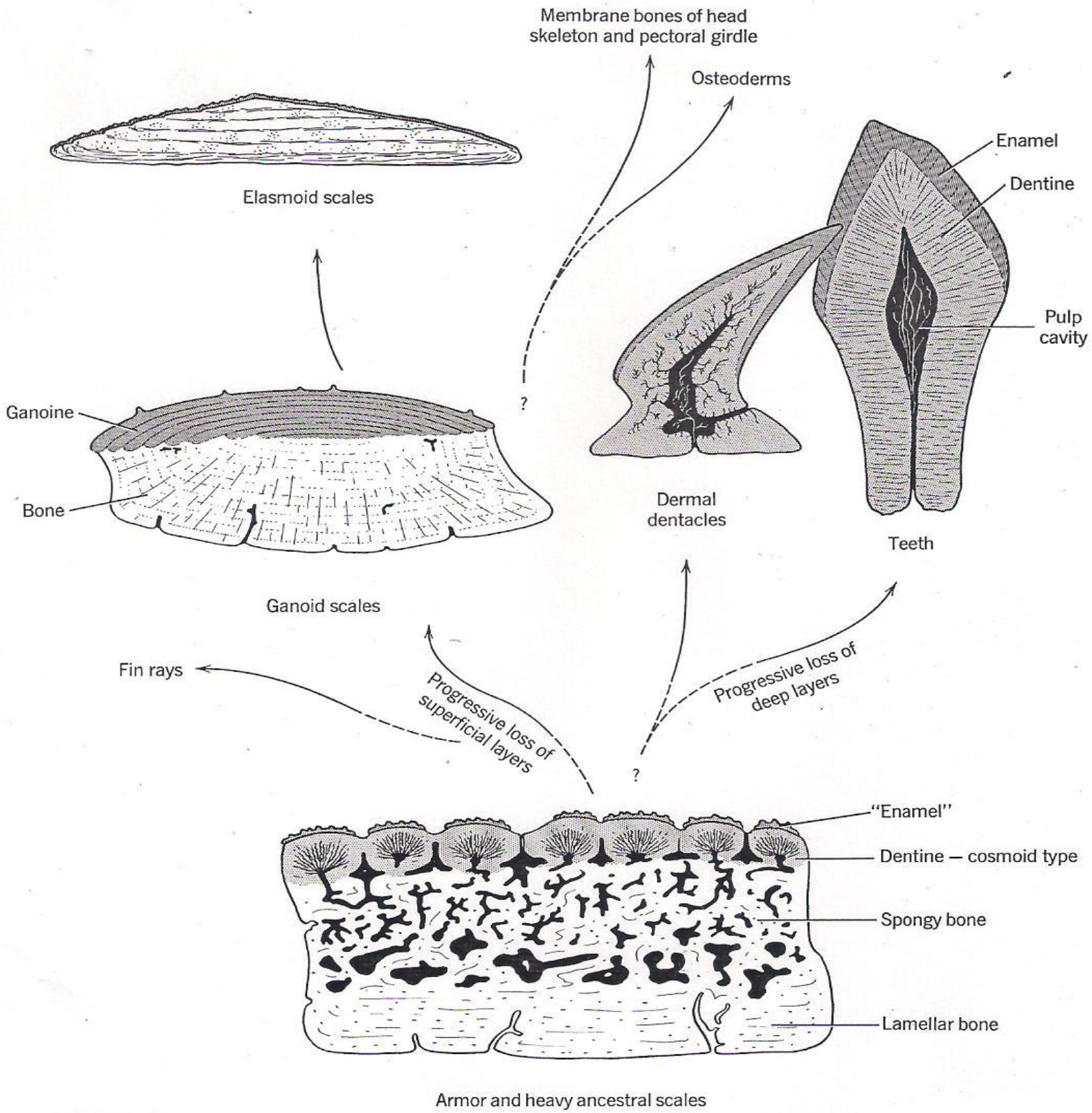


FIGURE 5-7
STRUCTURE AND RELATIONSHIPS OF DERMAL SCALES AND DERIVATIVES.

Skin of Amphibians

- The epidermis of amphibians is thin, about 5-8 cell layers, but in response to contact with air it has a particular mucopolysaccharide. This helps to control desiccation; they have a stratum corneum with keratin.
- Only the outermost layer is made of dead cells and this is shed every few days in a process of moulting, under hormonal control.
- Amphibians have two kinds of multicellular alveolar glands which originate from the epidermis and grow down into the dermis.
- The products of these glands reach the surface through ducts
- There are abundant mucous glands which secrete mucus continuously to clean and lubricate the skin.

- The mucus also keeps the skin moist so that cutaneous respiration will be possible.
- Mucous forms on the surface when mucigen(a glycoprotein) oozes onto the surface and mixes with water.
- Apart from these there are granular glands in the epidermis which are under nervous or hormonal control.
- These secrete a milky fluid which is distasteful and in some instances very toxic to predators.
- These granular glands are grouped together in the warts of toads.
- Frogs have more mucous glands than toads due to the fact that toads are less amphibious than frogs.
- On the other hand toads have more granular glands.

- Some of the granular secretions are pheromones, substances when released into the environment affect the behaviour of other animals by signalling sex identity, leaving trails, attracting insects for food.

Dermis

- The amphibian dermis is two-layered and may be provided with lymph spaces and muscle fibres.
- Terrestrial amphibians are able to withstand abrasion and desiccation largely because of keratinized structures in the epidermis.
- Because they have only a thin layer of dead keratinized cells, modern amphibians seek moist habitats or use behavioural adaptations to avoid drying out.

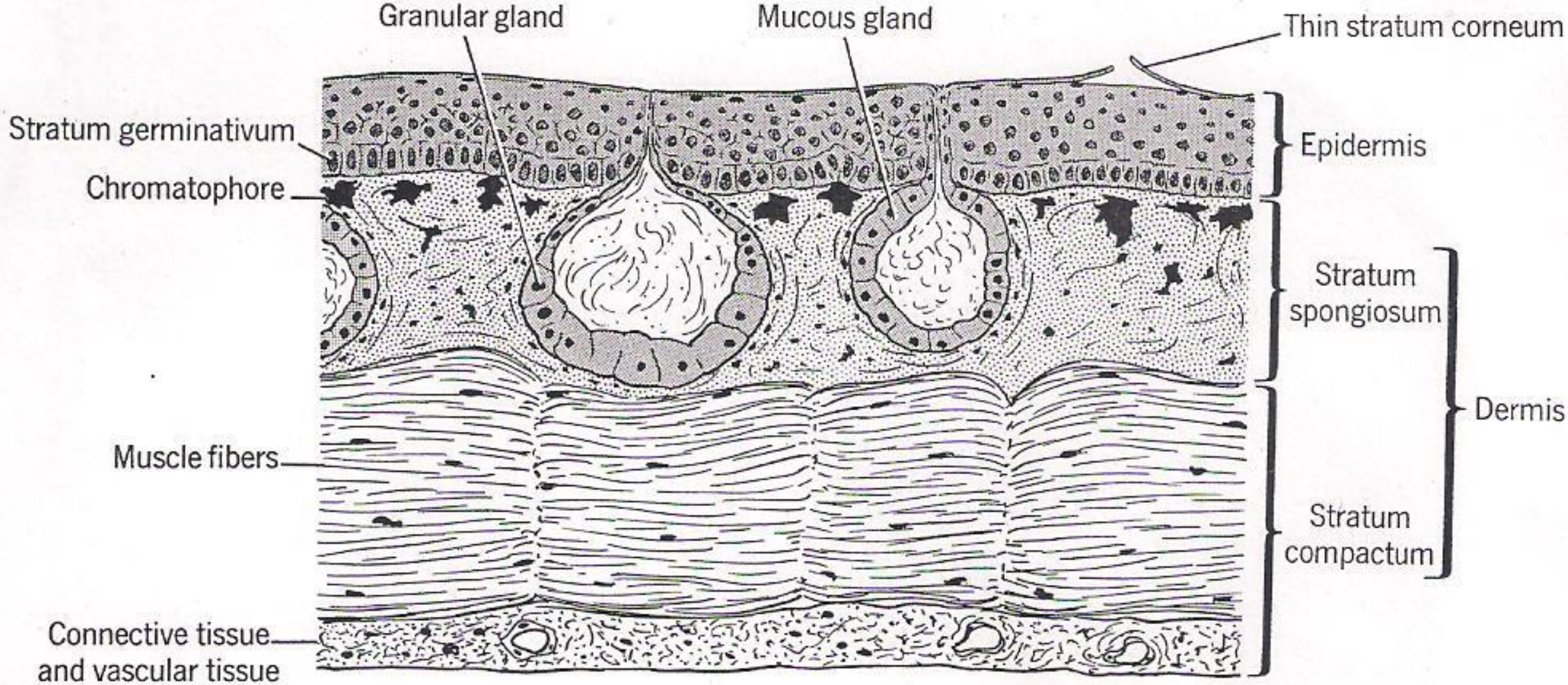


FIGURE 5-9
SECTION OF THE SKIN OF AN AMPHIBIAN.

SKIN OF REPTILES

- In reptiles, the epidermis forms a complete body covering of horny scales.
- There are joints between the scales, but these are merely regions where the horny material is thin and folded.
- In lizards and snakes, the entire generation of epidermis is shed as a single unit; this occurs several times in a year.
- The epidermis consists of the stratum germinativum and an outer epidermal generation layer which has five layers:

- From the outside inwards there is first a thick, dead acellular layer which is heavily keratinized with ß-keratin.
- The surface of this layer is called Oberhautchen and it has microscopic spicules.
- Under the ß-keratin is a thin mesos layer whose significance is unknown.
- This is followed by a moderately thick layer of loose, dead anucleate material containing α-keratin.
- Below this are two layers of living cells: an outer layer which is later taken into the α layer and an inner layer which later becomes clear and creates the separation leading to moulting.

- The keratinous plate on the outer surface of a large flat scale is called a scute.
- The scutes of crocodiles and marine turtles however are not shed.
- Growth then adds keratinized materials over the inner surface of the scute, thereby compensating for wear.
- Each wave of growth extends beyond the previous margin of a scute.
- This forms the familiar concentric rings of the turtle shell.

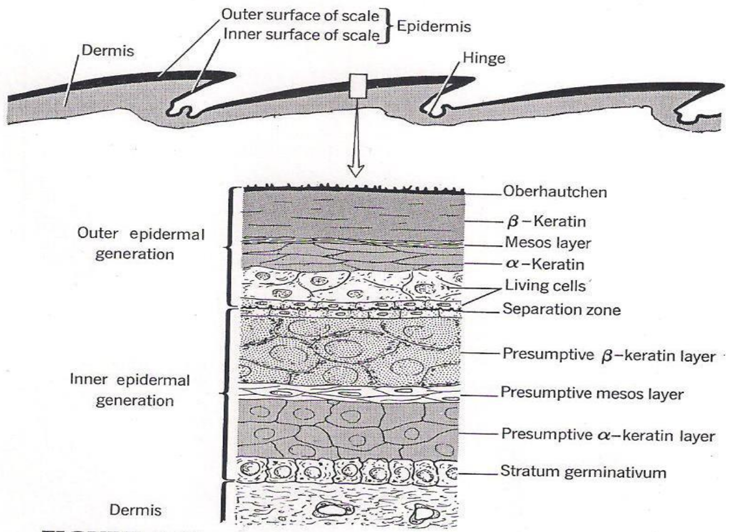


FIGURE 5-10

SECTION OF THE SKIN AND EPIDERMIS OF A SQUAMATE REPTILE shortly before a molt.

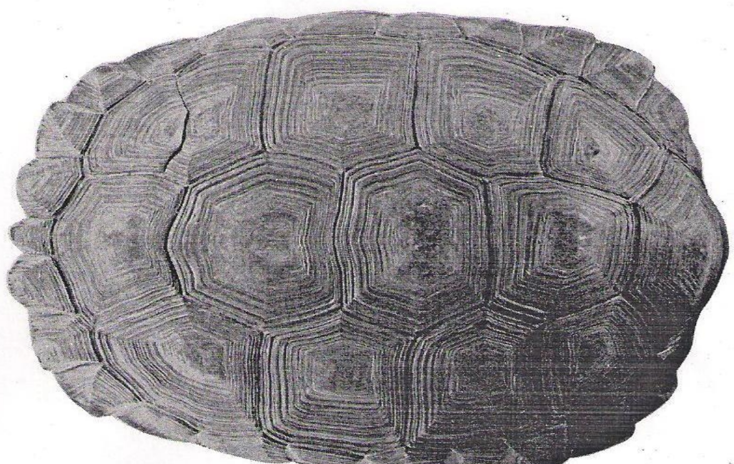


FIGURE 5-11

CARAPACE OR SHELL OF A DESERT TORTOISE, *Gopherus*, **SHOWING SCUTES WITH GROWTH LINES. Dorsal view; anterior to left.**

The dermis of reptiles

- The dermis of reptiles is thin, mucous glands are absent but there are various types of scent glands.
- These include generation glands, pre-anal glands and femoral glands.
- These normally occur on the tail of some lizards, cloacal area of some snakes, on the thighs of lizards and under the jaws of crocodiles.
- Reptiles have a number of epidermal glands, all of which are granular.
- Many of those granular glands surrounding the vent of lizards and snakes secrete pheromones.

- The only other intergumentary glands of lizards are the femoral glands on the hindlimbs of the male.
- These secrete a substance that hardens to form temporary spines to restrain the female during copulation.

Integument of Birds

- Birds have weak keratinized skin which is loosely joined to the underlying tissue.
- Only the feathers, which are appendages of the skin are heavily keratinized.
- The beak is also heavily keratinized.

- The lower part of the legs and toes as well as the facial area are covered by horny epidermal scales which are not shed.
- In birds, there are only 2 integumentary glands, both of which are oil glands.
- For example, the **uropygial** glands for birds is a swelling at the rump. This secretes oil which is transferred to the feathers during preening.
- This feature is most developed in water birds.
- There are similar oil glands that line the outer ear canal and around the vent.

Feathers

- Feathers are horny epidermal structures which were derived from reptilian scales.
- Feathers perform 2 functions:

1. They cover the body to form an effective insulation aiding in the maintenance of the high body temperature characteristics of birds

2. Aid in flight through the possession of wings.

- There 3 main types of feathers; contour, down(plumules) and filoplumes (pin feathers)
- Contour feathers are the conspicuous feathers that give the bird its shape.

- It provides the airfoils for flight.
- It consists of a horny shaft and 2 flattened vanes.
- The axis of the feather has hollow proximal quill(calamus) and a solid distal shaft or rachis.
- Each vane consists of barbs that branch from opposite sides of the shaft.
- The barbs have barbules and flanges.
- The barbules have hooklets that interlock with the flanges of adjacent barbs to strengthen the vane.
- Arising from (a notch) superior umbilicus (at the base of the rachis) is an after feather, which is shorter than the main feather.

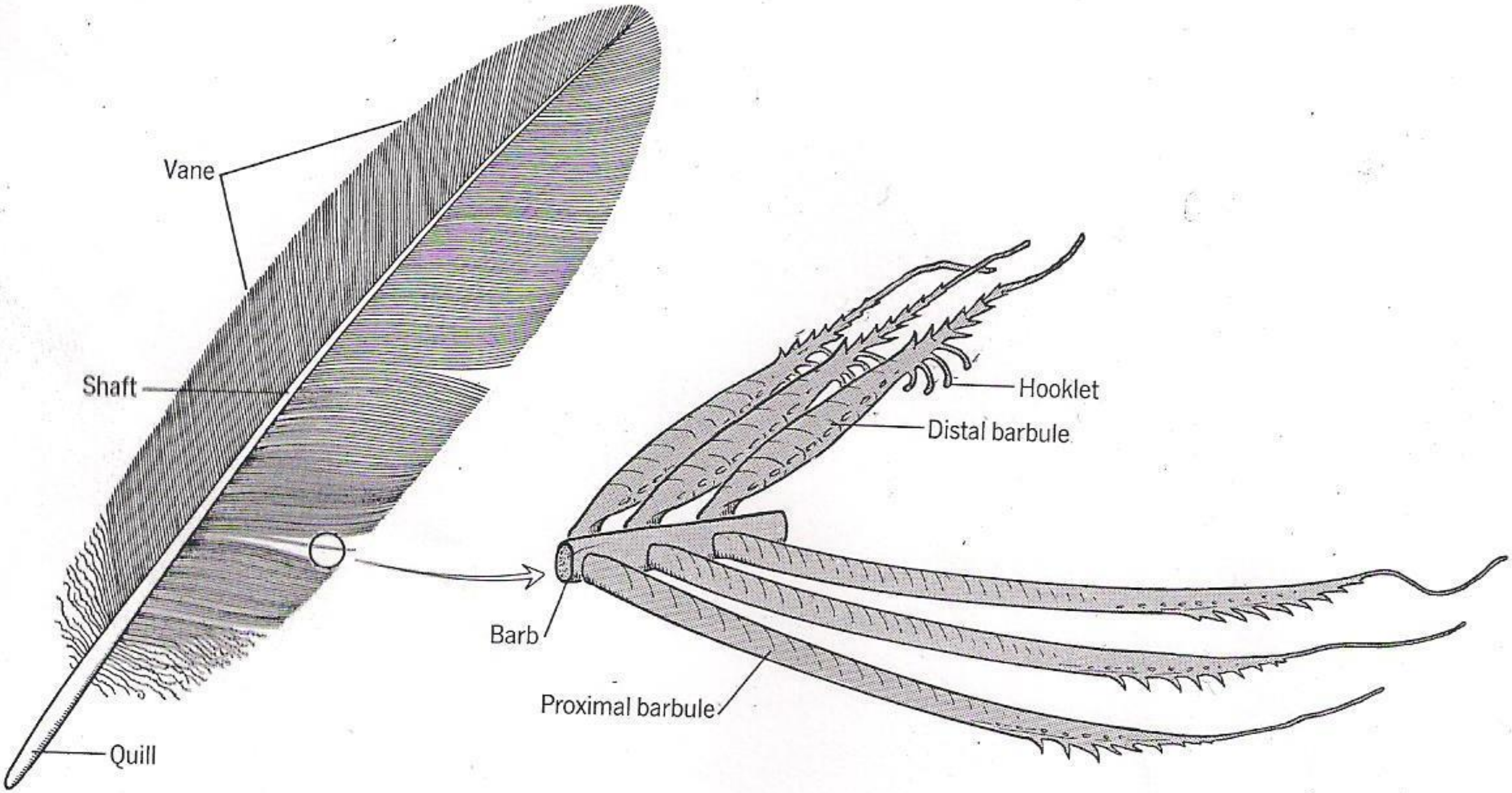


FIGURE 5-12
STRUCTURE OF A CONTOUR FEATHER.

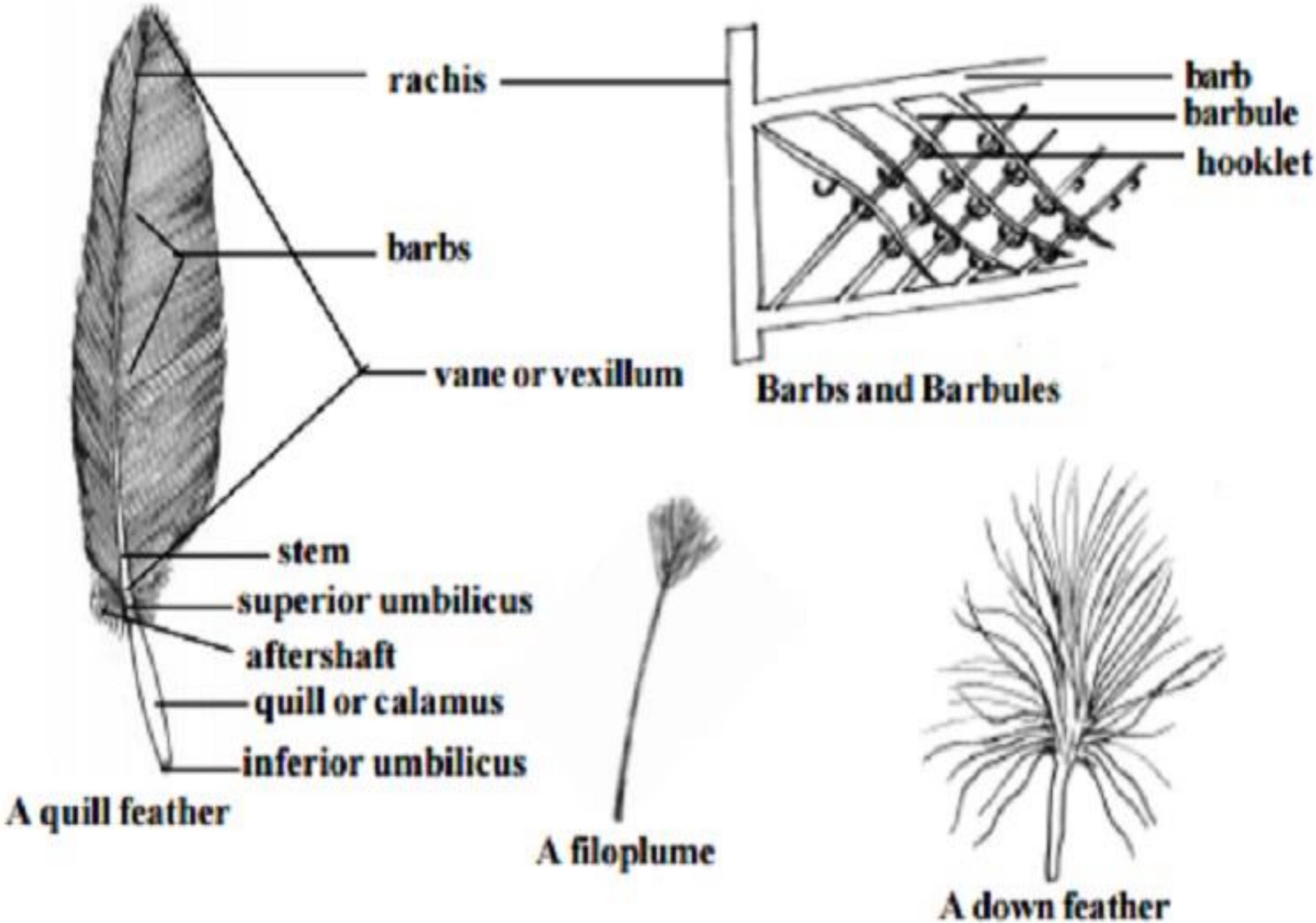


Fig. Pigeon - Feather types

- Even though contour feathers cover most of the body, the follicles from which they grow are arranged in feather tracts (pterylae).
- However, a few birds like the ostrich and penguins lack feather tracts.

Down feathers

- These are small fluffy feathers lying underneath and between contour feathers.
- They form the entire body covering of the chick.
- They have short calamus, with a crown of barbs arising from the end but no hooklets.
- Their function is insulation.

Filoplumes/pinfeathers

- These are hair like feathers consisting of thread-like shaft scattered throughout the skin.

Bristles

- They are derived from contour feathers by the partial or complete loss of the vane.
- They function to screen foreign objects from the nostril.
- They may form eyelashes as found in the ostrich.

SKIN OF MAMMALS

- The skin of mammals is relatively thick, especially the dermis from which leather is made.
- The thickness of the skin varies according to species and sometimes according to season.
- The epidermis is thick in areas where the hair is sparse and also in areas subjected to pressure and abrasion eg footpads, the kneepads of warthogs.
- Between the stratum corneum and stratum germinativum there may be one or two layers.
- The most common is the stratum granulosum.

- In some mammals, the stratum corneum may form scales as seen on the tails of beavers and opossums.

INTEGUMENTARY GLANDS

Integumentary glands reach their peak in complexity and specialization in mammals.

There are 2 kinds : Sebaceous and Sudoriferous (Sweat) Glands.

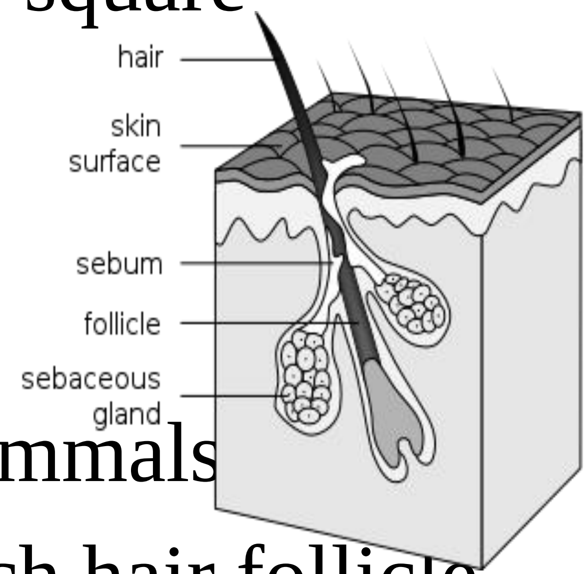
Sweat glands are unique to mammals.

May be distributed over the entire body or restricted to special areas such as soles of the feet.

They are absent in mammals like the whale, pangolin or sea cow. These have no use for them.

- In the hippopotamus they are found only on the ears, which are above the water.
- Sweat glands are coiled tubular glands that originate from the epidermis but penetrate deep into the dermis.
- They are richly supplied with blood capillaries.
- Sweat glands secrete sweat which contain sodium chloride, water and urea.
- These pass through the sweat duct onto the surface as sweat.
- On reaching the surface of the skin it evaporates. This prevents overheating of the skin.

- Certain glands in the eyelids called Moll's glands which open into the follicles of the eyelashes are sudoriferous glands.
- Humans, with less hair than most mammals have the largest number of sweat glands per square centimetre.



Sebaceous Glands

- These are also characteristic of mammals.
- One or more of these drain into each hair follicle.
- They may also occur without relation to hair eg on the nipples, lips of the genitalia (glans penis, labia minora)

- Sebaceous glands secrete an oily substance, sebum, which dresses the hair and prevents excessive drying of the skin.
- They are also found in the outer ear canal. These secrete cerumen which together with hairs trap dust which otherwise might get to the eardrum.

Scent Glands

- Sudoriferous and sebaceous glands produce a variety of scents which serve for defence recognition or sexual attraction.
- These include the scent glands on the feet of goats that leave scent trails that other members of the species are able to recognise.

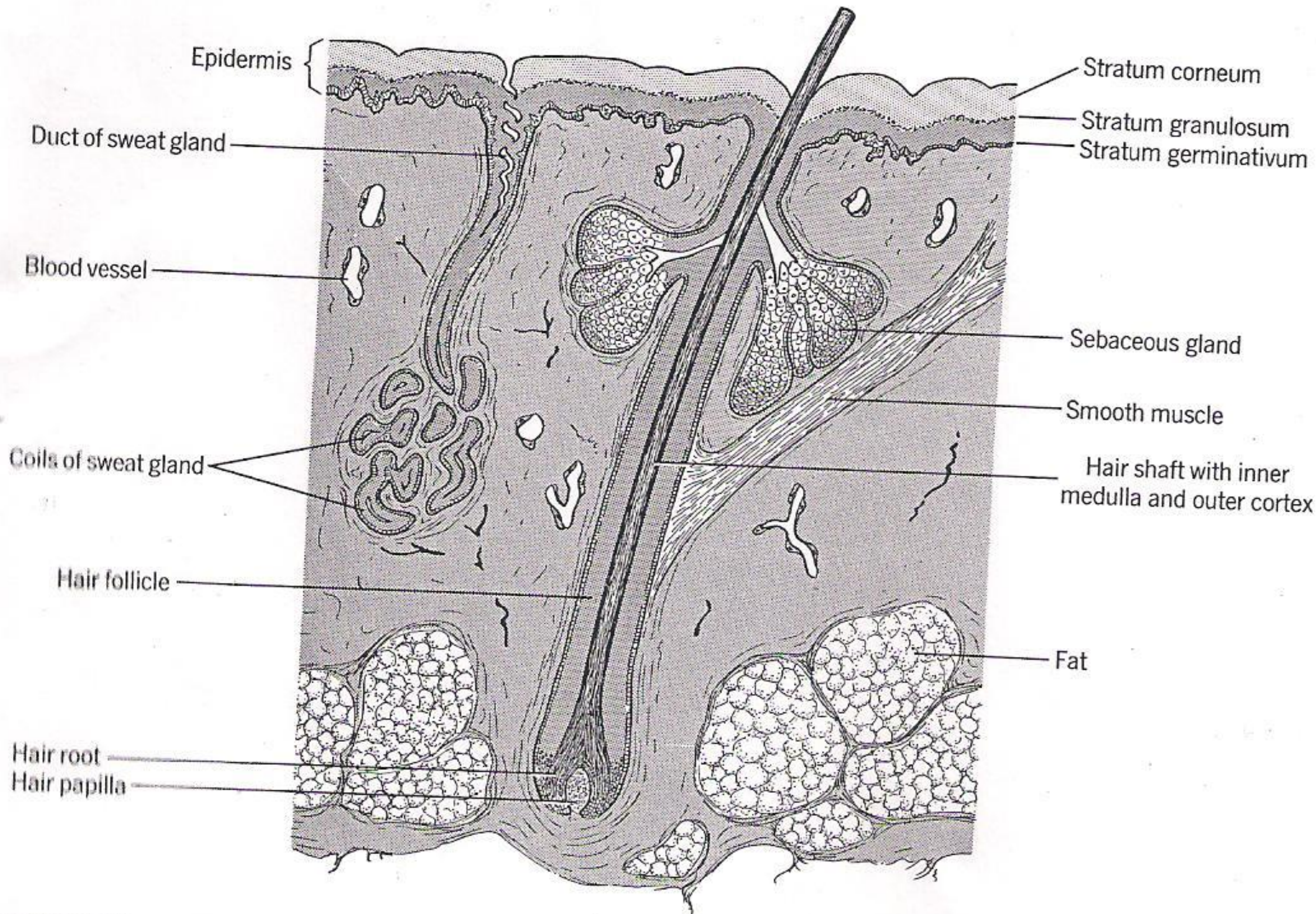


FIGURE 5-15

SECTION OF THE SKIN OF A MAMMAL.

MAMMARY GLANDS

- Mammary glands are phylogenetic derivatives of primitive sweat glands.
- They develop in both sexes from a pair of elevated ridges of ectoderm called milk lines.
- This extends along the ventrolateral body wall of the foetus.
- At intervals along the milk lines, ectoderm sinks into the dermis and a nipple forms above each patch.
- In females, these patches enlarge at maturity, push under the skin, becoming compound and alveolar.

- Mammary glands produce a fatty secretion. Much of the human breast is fat.
- Mammary glands become active at parturition under the influence of ovarian and pituitary hormones.

Hair

- Hairs are keratinized appendages of the skin
- They may form a dense furry covering over the whole body or there may be a few as in some whales
- Hairs have insulating effect when dense and is also a sensitive tactile organ.
- This is so because each root hair is surrounded by sensory nerve endings.

- Displacement of the hair root initiates a sensory impulse to the brain.

Morphology

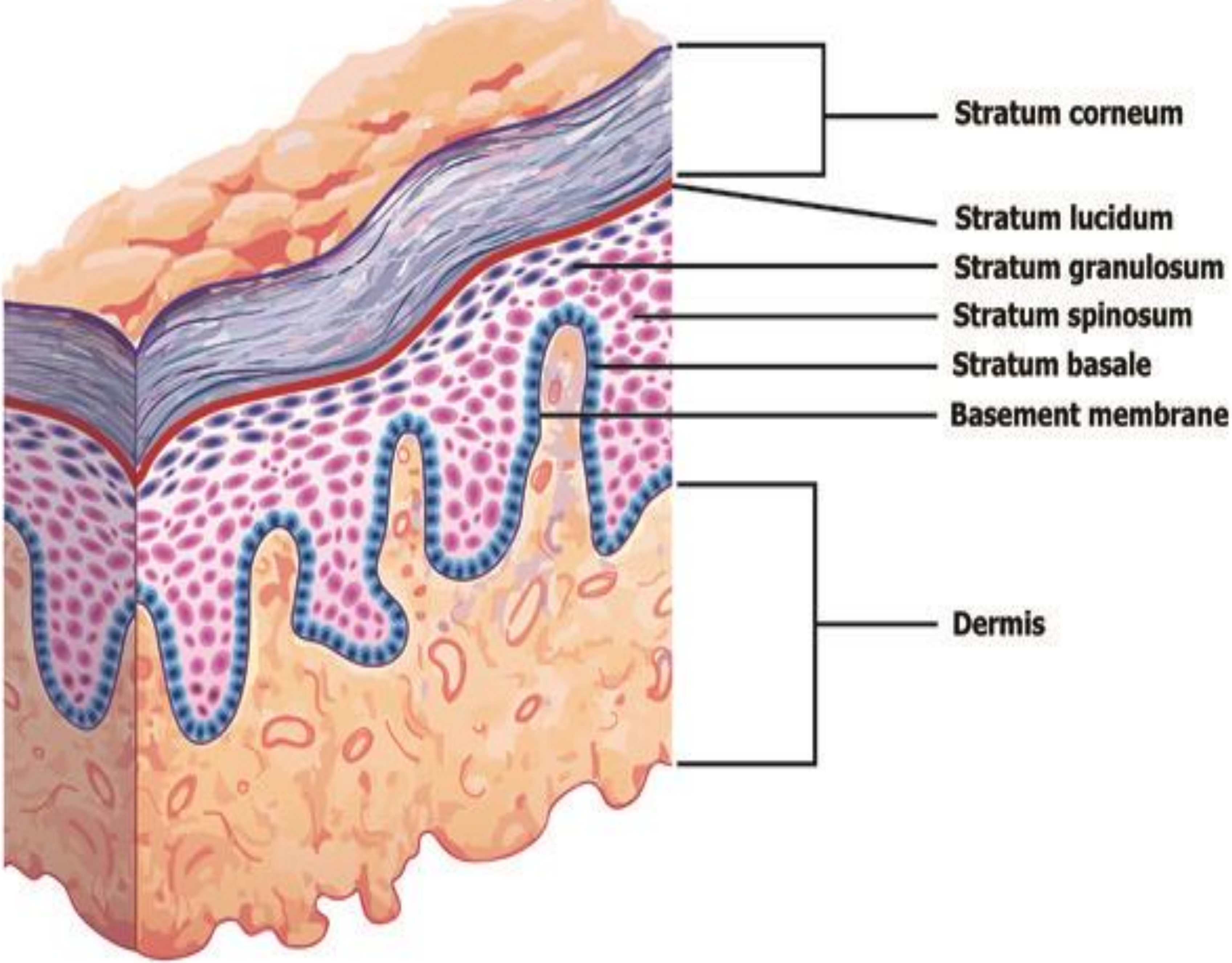
- Hairs grow from hair follicles and elongate as a result of mitosis in the bulb.
- Within the bulb is a dermal papilla which provides oxygen and nutrients for growth.
- The hair root is the part within the follicle where the hair cells cornify.
- The remainder of the hair is the shaft which commences just below the opening from the sebaceous glands.

- A single hair consists of dense keratin from disintegrated cornified cells, vacuoles and melanin granules.
- Hair is covered by cuticle, composed of thin transparent cornified squamous cells.
- Attached to the wall of each hair follicle is a tiny smooth muscle, **arrector pili**.
- When it contracts in response to cold, the hair stands perpendicular to the surface of the skin resulting in the formation of goose pimples/flesh.
- Hair colour is determined by the type and amount of pigment in the **stratum basale** at the base of the hair follicle.

- Varying amounts of melanin produce hair ranging in colour from blond to black.
- The more abundant the melanin, the darker the hair.
- A pigment with an iron base (trichosiderin) produces red hair.
- Grey and white hair is the result of lack of melanin- could be due to ageing.
- Hair texture is determined by the cross-sectional area and shape.
- Straight hair is round in cross sectional area whilst wavy hair is oval.

Keratinized Skin Structures

- In mammals keratin-filled epithelium develops into a variety of special structures.
- These include claws, hoofs and nails.
- These are modifications of the stratum corneum.
- They are keratinized structures at the end of digits.
- The claw is the original structure, hoofs and nails are mammalian modifications.
- Claws first appeared in reptiles and have persisted in birds and most mammals.
- Claws evolved into nails in primates and into hoofs in ungulates.


Stratum corneum
Stratum lucidum
Stratum granulosum
Stratum spinosum
Stratum basale
Basement membrane
Dermis

- Claws, hoofs and nails have the same basic structure
- They consist of two curved plates: a dorsal horny plate called the **ungius** and a softer ventral plate called **subunguis**.
- The two plates wrap partially around the terminal phalanx which is pointed in a claw and blunt when associated with a hoof or nail.
- A softer cornified pad, the cuneus which is present only in ungulates is partially surrounded by the subunguis.
- A claw forms a protection from the top, sides and tip of a terminal toe joint.

- **A claw** is an inverted V in cross section. It becomes narrow distally and curves downwards beyond the tip of the toe.
- Beneath the claw is a germinative layer and this is protected at the base by a fold of skin.
- **A nail** is broadened and flattened. It is restricted to the upper surface of the finger or toe.
- The germinative nail bed is confined to the proximal end of the structure.
- This is seen as a white area in the translucent human nail.
- **Hoofs** are characteristic of ungulate mammals which have undergone toe reduction.

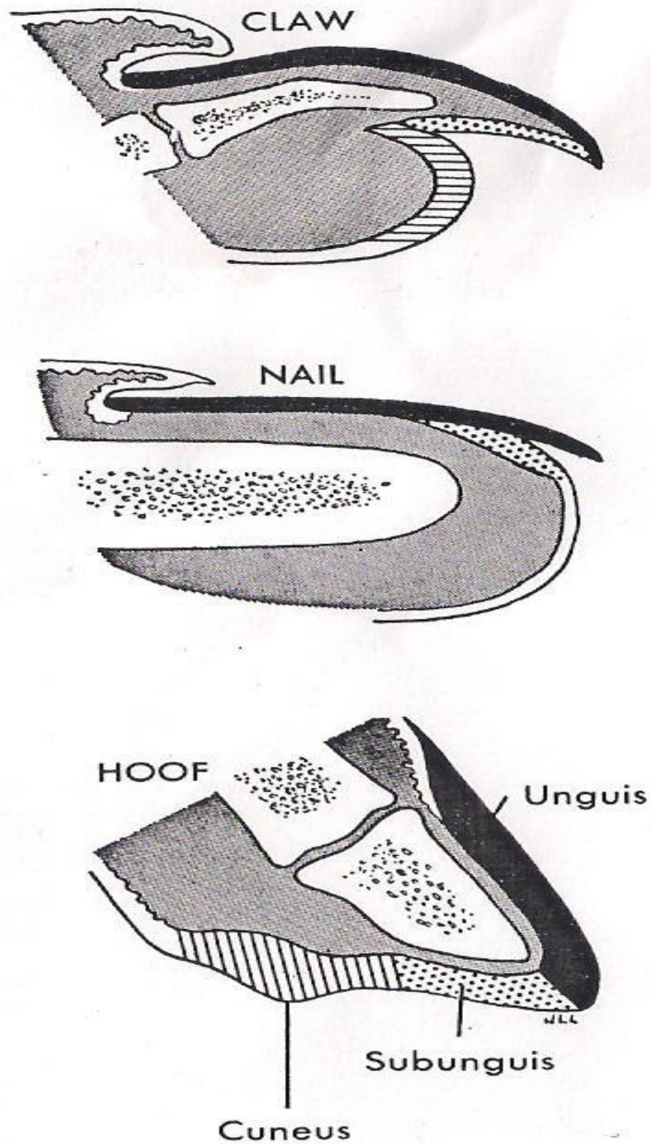


FIGURE 6-21

Claw, nail, and hoof with terminal phalanx, sagittal section.

- They therefore walk on the remaining digit(s)
- The original claw has shortened and broadened to become a hemicylinder that covers the tip of the toe.
- The curved distal end of the hoof rests on the ground

Horns and antlers

- True horn: A true horn has a surface composed of keratin.
- True horn is seen in sheep, goats and antelopes.
- The core of the horn is bone arising from the skull.
- Sheathing and extending over this is a hollow cone of true horn substance formed by the keratinization of the skin epidermis.

- Neither the core nor sheath is shed. Although they are curved they are never branched.
- There are 3 varieties of mammalian horns: bovine horns, hair horns and pronghorn of antelopes.
- **Bovine horns** are usually curved and never shed, found in sheep, goats true antelopes.
- **Pronghorn** are branched, the horny covering, but not the bony core is shed annually.
- **Hair horns** differ from other horns in that they are entirely composed of keratinized hair-like epidermal fibres. This forms a solid horn located on a roughened area of the nasal bone.




- Both sexes have them and is not shed eg. in **rhinoceros**.

Antlers

- Antlers are characteristic of the deer family.
- They are not cornified structures but branched dermal bones.
- New growing antlers are covered with soft vascular skin and velvety hairs.
- Antlers develop in males, except in caribou and reindeer where it occurs in both sexes.
- They are usually branched and is shed and replaced annually.

FIGURE 5-17
SOME HORNS AND ANTLERS.

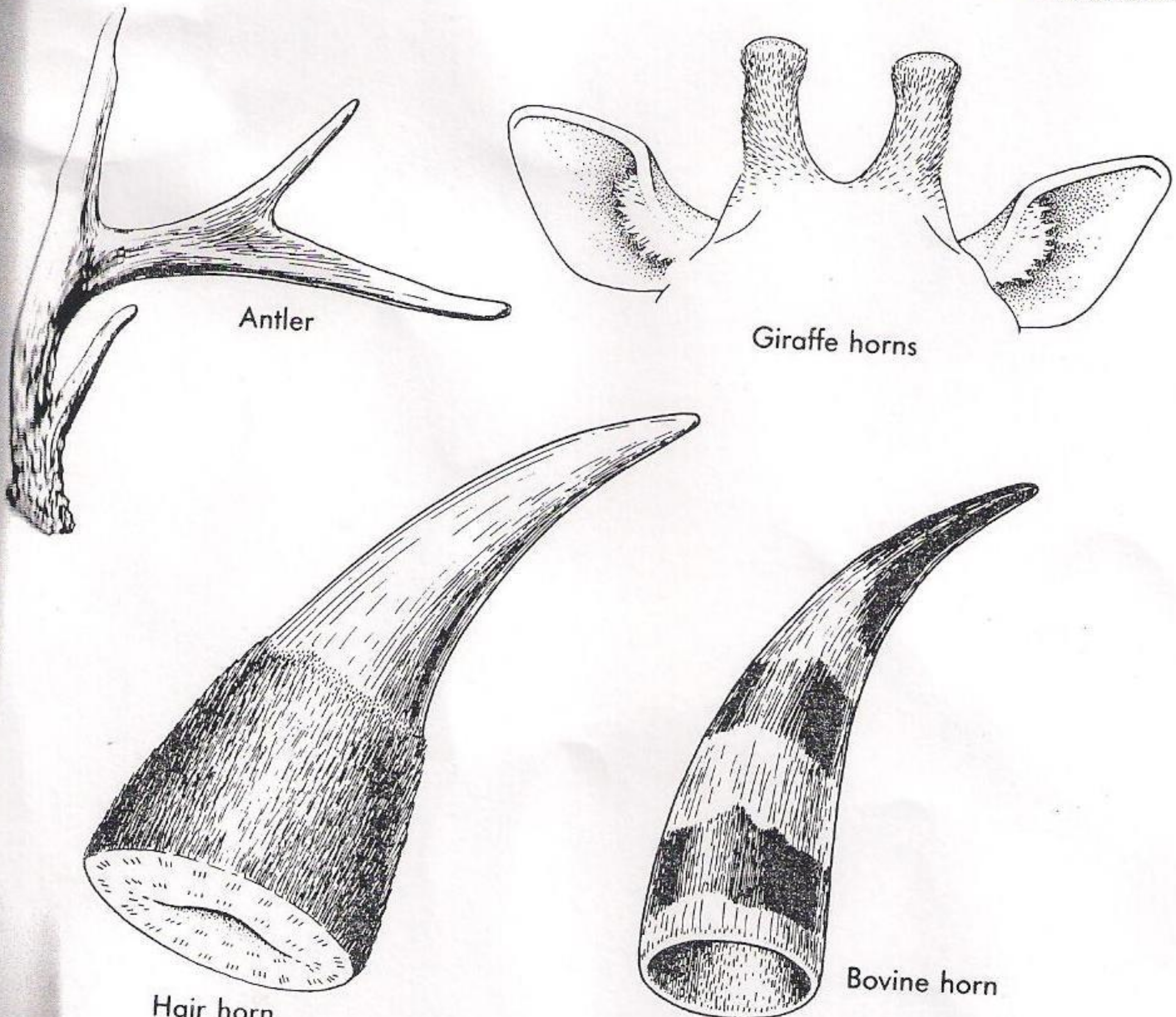


FIGURE 6-27
Mammalian horns and antlers.

THE SKELETAL SYSTEM

The skeletal system can be divided into the following:

1. Axial skeleton-notochord and vertebral column, ribs and sternum, skull and visceral skeleton.

2. Appendicular skeleton- pectoral and pelvic girdles, skeleton of the paired fins and limbs, skeleton of median fins of fishes.

Components of the head skeleton

The components of the head skeleton are:

1. Chondrocranium (Neurocranium)

2. Visceral skeleton (Splanchnocranium)

3. Dermatocranuim (Dermal elements)

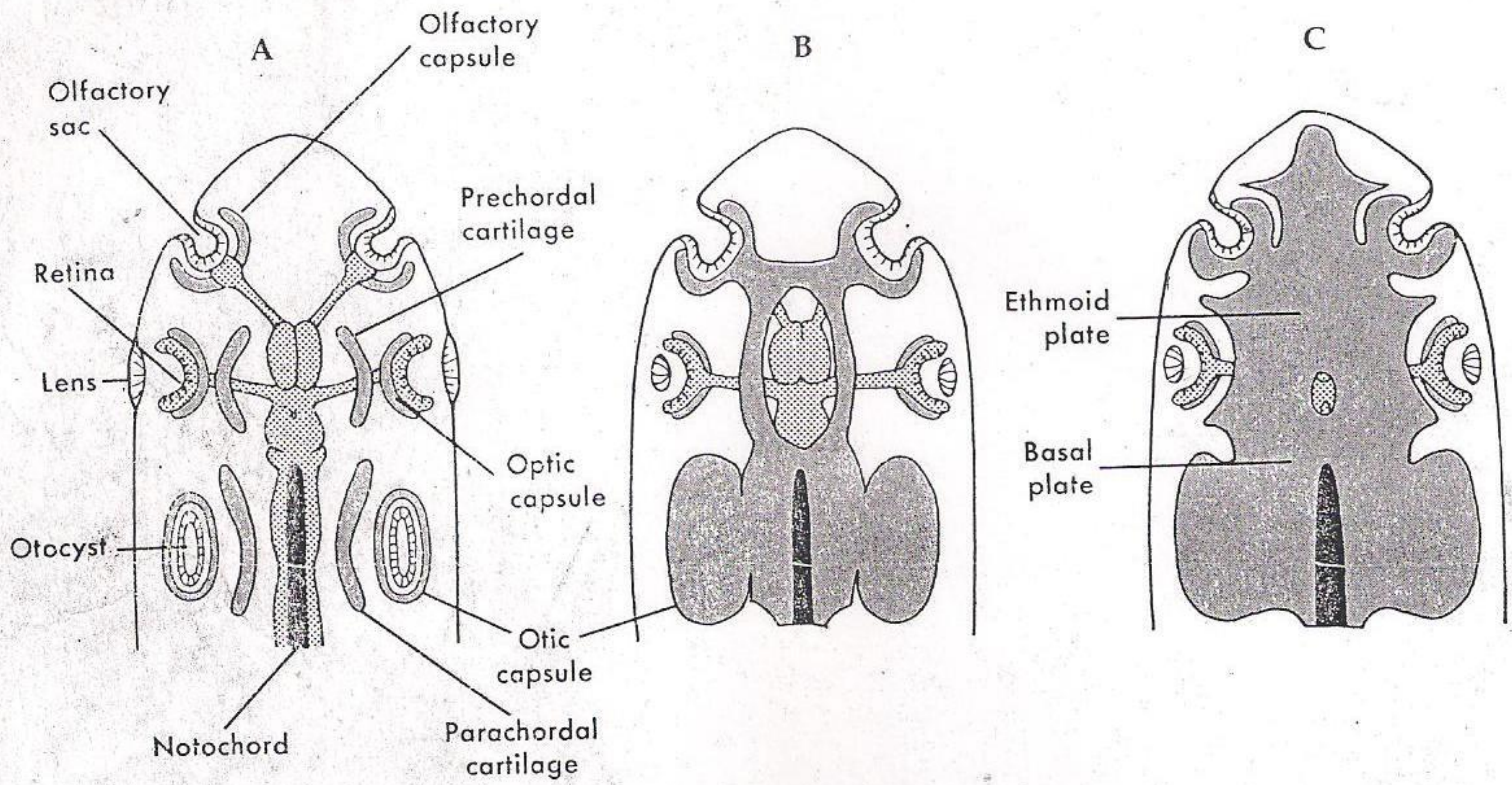
- The chondrocranium supports the brain and organs of special sense(olfactory organs, eye, internal ears)
- The visceral skeleton supports the gill arches and their derivatives.
- The dermatocranium completes the framework of the skull.
- The chondrocranium and visceral skeleton may remain cartilaginous or may become bony, but they are always present.
- The dermal element is always bony and usually present but has been lost in several major vertebrate groups.

Chondrocranium and its derivatives

- The chondrocranium is a single unit but is composed of various elements which are distinct in the embryo

1. **Notochord-** the notochord lies within, above or just below the developing chondrocranium.

- It may remain free when present or may disappear.
- It usually becomes cartilaginous and joins the chondrocranium.
- Anterior to the notochord is a pair of bars called the prechordal cartilage or trabeculae cranii.
- When the prechordal plates fuse they form the ethmoid plate.



A
B
C
Olfactory capsule
Olfactory sac
Prechordal cartilage
Retina
Lens
Optic capsule
Otocyst
Otic capsule
Notochord
Parachordal cartilage
Ethmoid plate
Basal plate

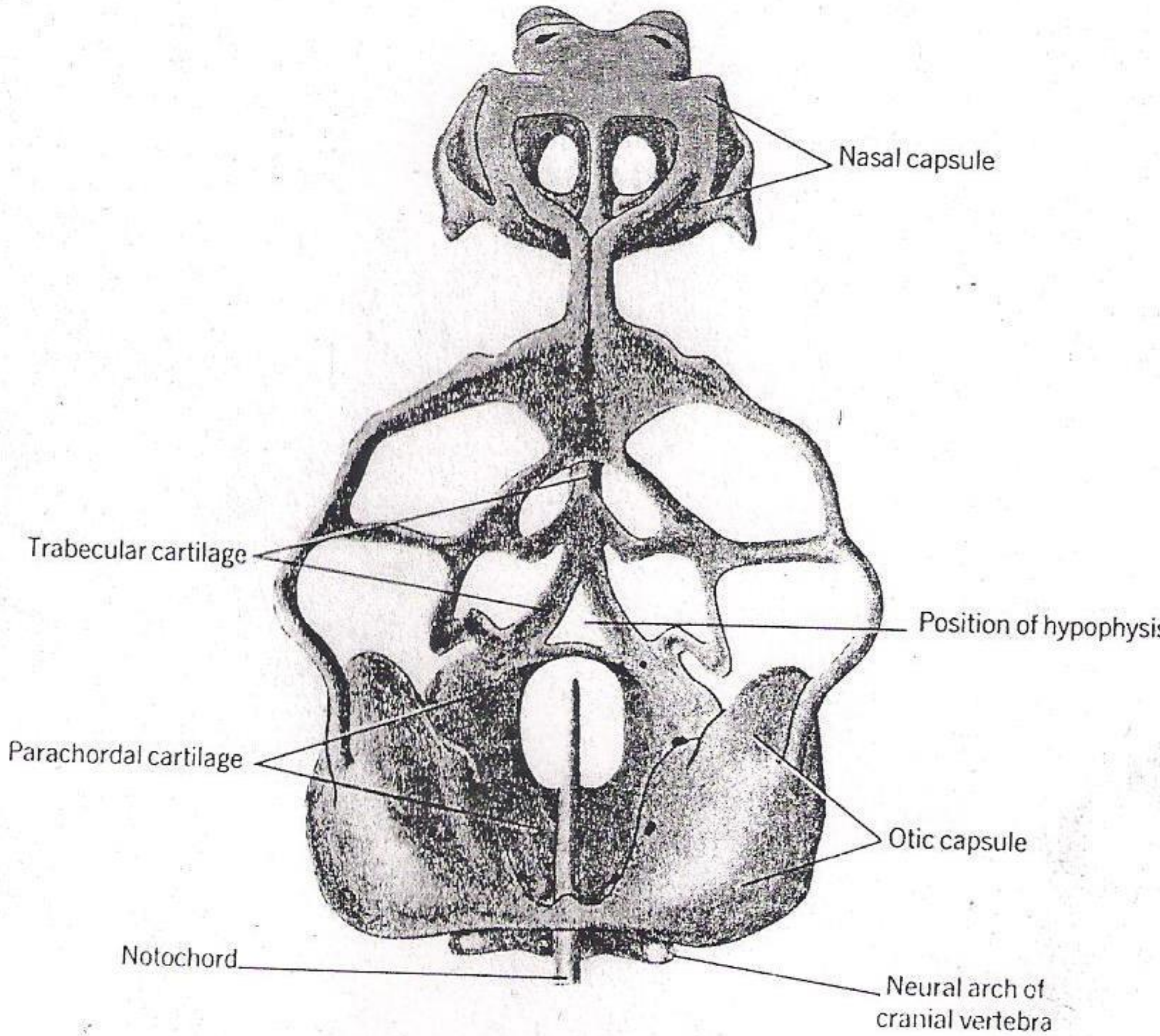


FIGURE 7-2

COMPONENTS OF THE VERTEBRATE CHONDROCRANIUM seen in dorsal view. Slightly simplified from the 25 mm stage of development of the lizard *Lacerta*.

- In lower vertebrates that have broad heads the two plates remain free and widely separated. This is the **platytrabic** condition.
- Sometimes they are joined by a plate of cartilage and usually fused at the anterior end to form a Y-shaped structure- this is the **tropitrabic** condition

2. Behind the trabeculae and flanking the notochord are another pair of cartilages, the **parachordal** cartilages.

- These merge above, below or around the notochord to form the **basal plate.**
- The anterior part of the plate encloses a large cavity with the lateral edges pierced by a foramina for the

passage of the cranial nerves.

3. At the back of the basal plate are two or more projections called **occipital condyles** which articulate with the first vertebra of the spine.

4. A fourth contribution to the chondrocranium consists of one or more pairs of arches that arise from the posterior angles of the basal plate to encircle the spinal cord at the point where it enters the skull.

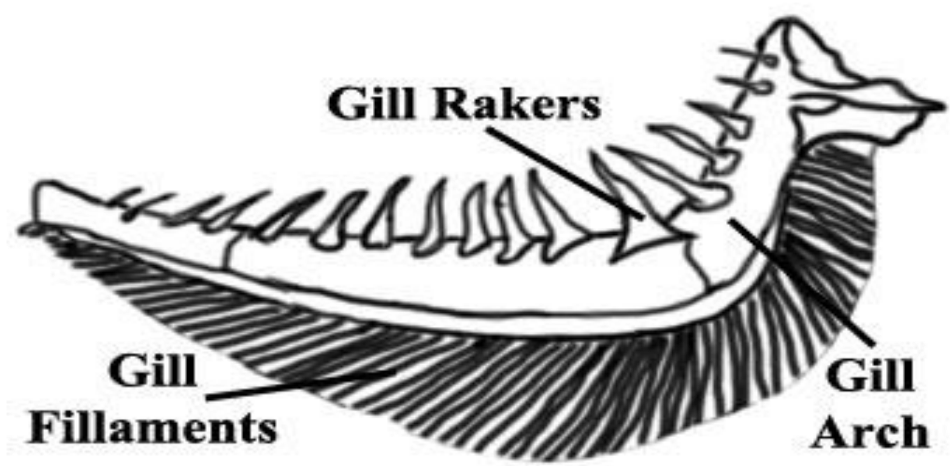
- These clearly are the neural arches of the cranial vertebrae.

- The final contribution to the chondrocranium is the sense capsule that house the nasal chambers and the inner ear.
- The nasal capsules join the anterior ends of the trabeculae cranii.
- The otic(auditory) capsules join the margins of the occipital arch.
- The eyes are also enclosed in capsules of cartilages.
- These remain free because if they are joined to the chondrocranium the eyes cannot be moved independently of the head.

- Bones develop in the chondrocranium of five out of the 8 classes of vertebrates with the exception of Agnatha, Placodermii and Chondrichthyes.

VISCERAL SKELETON

This is the skeleton of the pharyngeal pouches.
In fishes it is the skeleton of the jaws and the gill arches.
In vertebrates it has been modified to perform new functions on land.
In jawless vertebrates each gill bar is supported by a single cartilaginous rod which may be bent but not jointed.



- In gnathosomes(j) the visceral arch is jointed and the basic number of paired segments is four per arch.
- There are 7 visceral arches.
- Out of the 4 segments, the middle 2, the epibranchial(above) and ceratobranchial (below) are very important.
- The first visceral arch enlarges to become the jaws and is therefore called the **mandibular arch**.
- Its epibranchial forms the upper jaw and is called the **palotoquadrate**.
- Its ceratobranchial forms the lower jaw and is called **mandibular cartilage** or Meckel's cartilage.

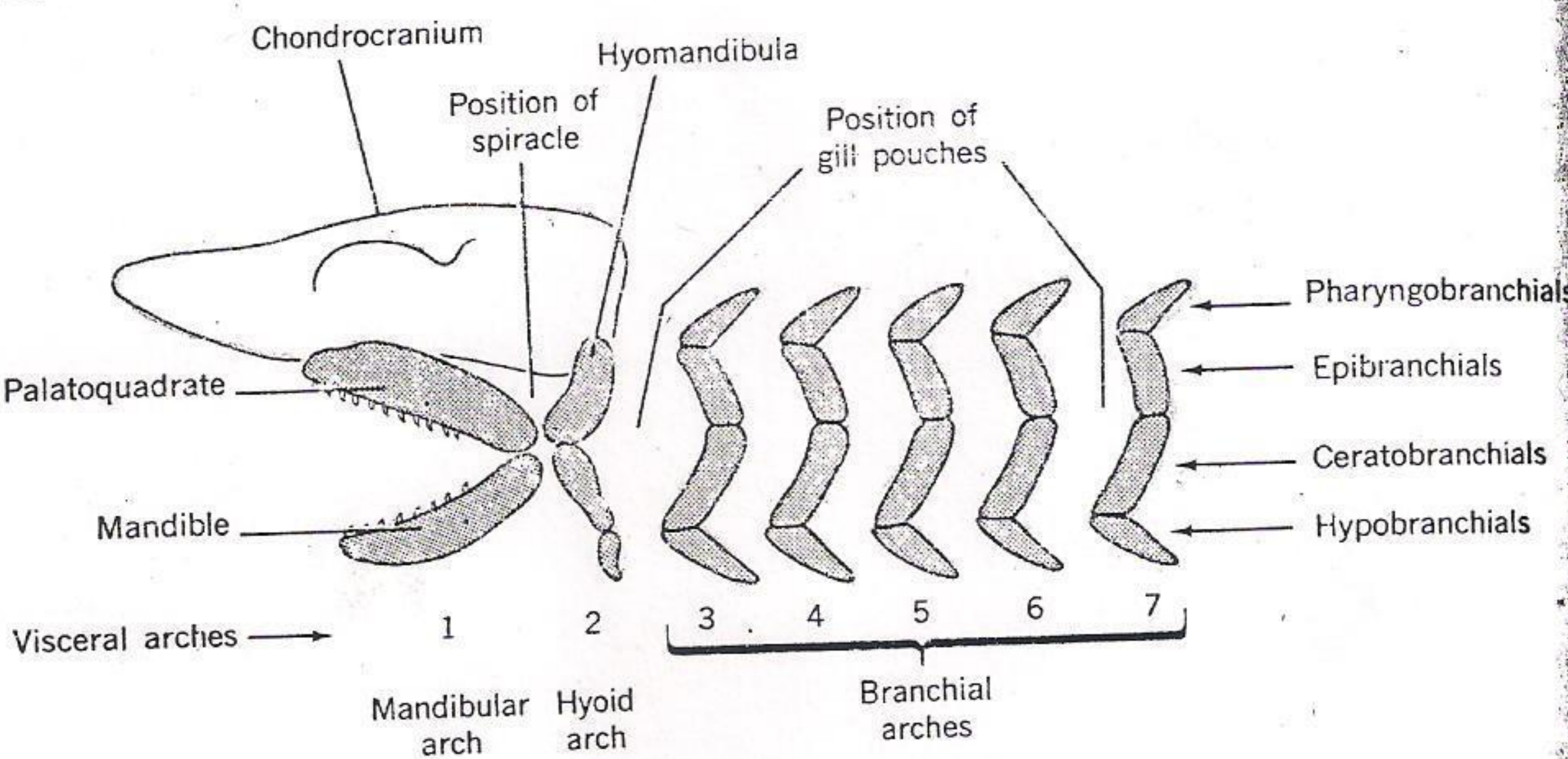


FIGURE 7-4
PRIMITIVE VISCERAL SKELETON represented by a stylized elasmobranch

- The second visceral arch is the hyoid arch.
- It consists of paired hyomandibular cartilages dorsally and gill-bearing ceratohyals laterally.
- Succeeding arches serve respiratory functions and are therefore called branchial arches thus the 3rd visceral arch is the 1st branchial arch.
- The left and right palatoquadrate cartilages meet in the midline dorsally to form the upper jaw and Meckel’s cartilages meet in the midline ventrally to form the lower jaw.

Dermal elements (dermatocranium)

The dermal elements are divided into 4

1. Bones that form above and alongside the brain and neurocranium i.e the roofing bones.

2. Dermal bones of the upper jaw.

3. Bones of the primary palate.

4.Opercular bones.

1. Roofing Bones

- The roofing bones provide a protective shield over the brain and special sense organs.
- In crossopterygian (Lf)fishes, a series of paired and unpaired bones extend along the midline from the

nares to the occiput.

- In Labyrinthondonts, the unpaired bones are missing and these have been replaced by a number of paired bones.
- These are nasals, frontals parietals and postparietals.
- Forming a ring around the orbit in the generalized skull are lacrimal, prefrontal, post-frontal, post-orbital and infraorbital.
- At the posterior angle of the skull are the intertemporal, supratemporal, tabular and lower down, the squamosal and quadratojugal bones.

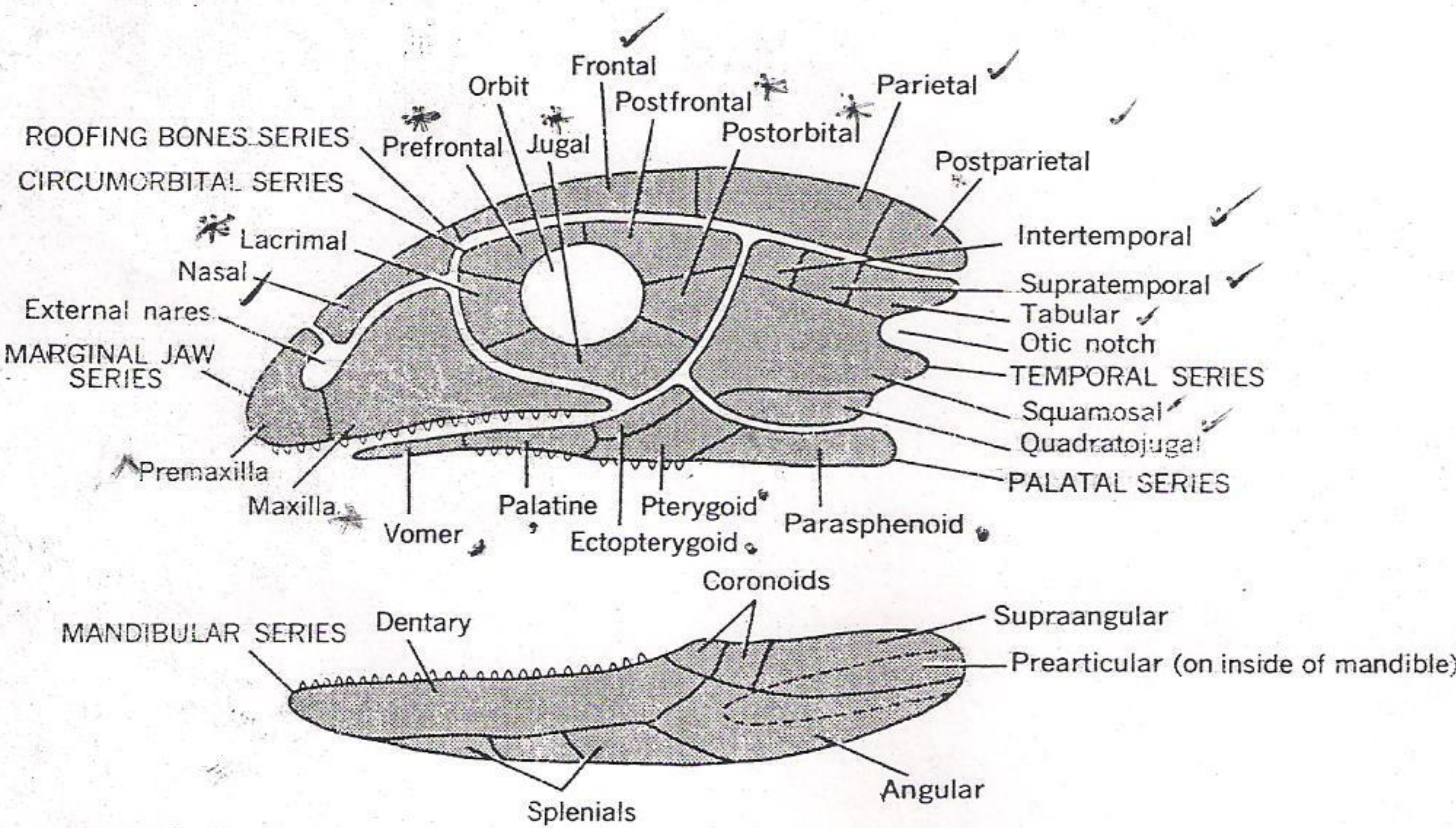


FIGURE 7-5

PRINCIPAL DERMAL BONES OF THE SKULL AND MANDIBLE AT THE EARLY TETRAPOD STAGE OF EVOLUTION.

2. Dermal bones of the upper jaw

- The upper jaw of the bony vertebrates were derived from the palatoquadrate of cartilaginous fishes.
- These cartilages were replaced with tooth-bearing dermal bones- premaxillae and maxillae, which became part of the dermatocranium.
- The completed upper jaw of bony vertebrates became part of the skull.

3. Primary palatal bones

- This forms the roof of the oropharyngeal cavity of fishes and oral cavity of lower tetrapods.
- In sharks, it is cartilaginous.

- In early tetrapods these membrane bones are unpaired parasphenoid, paired vomers, paired palatines, pterygoids and ectoptrygoids.

4. **Opercular bones**

- The operculum is a flap of tissue that arises as an outgrowth of the hyoid arch and extends over the gill slits.
- In bony fishes it is strengthened by plates of dermal bones.
- Most prominent of these are large opercular, smaller preopercular, subopercular and interoperculars.

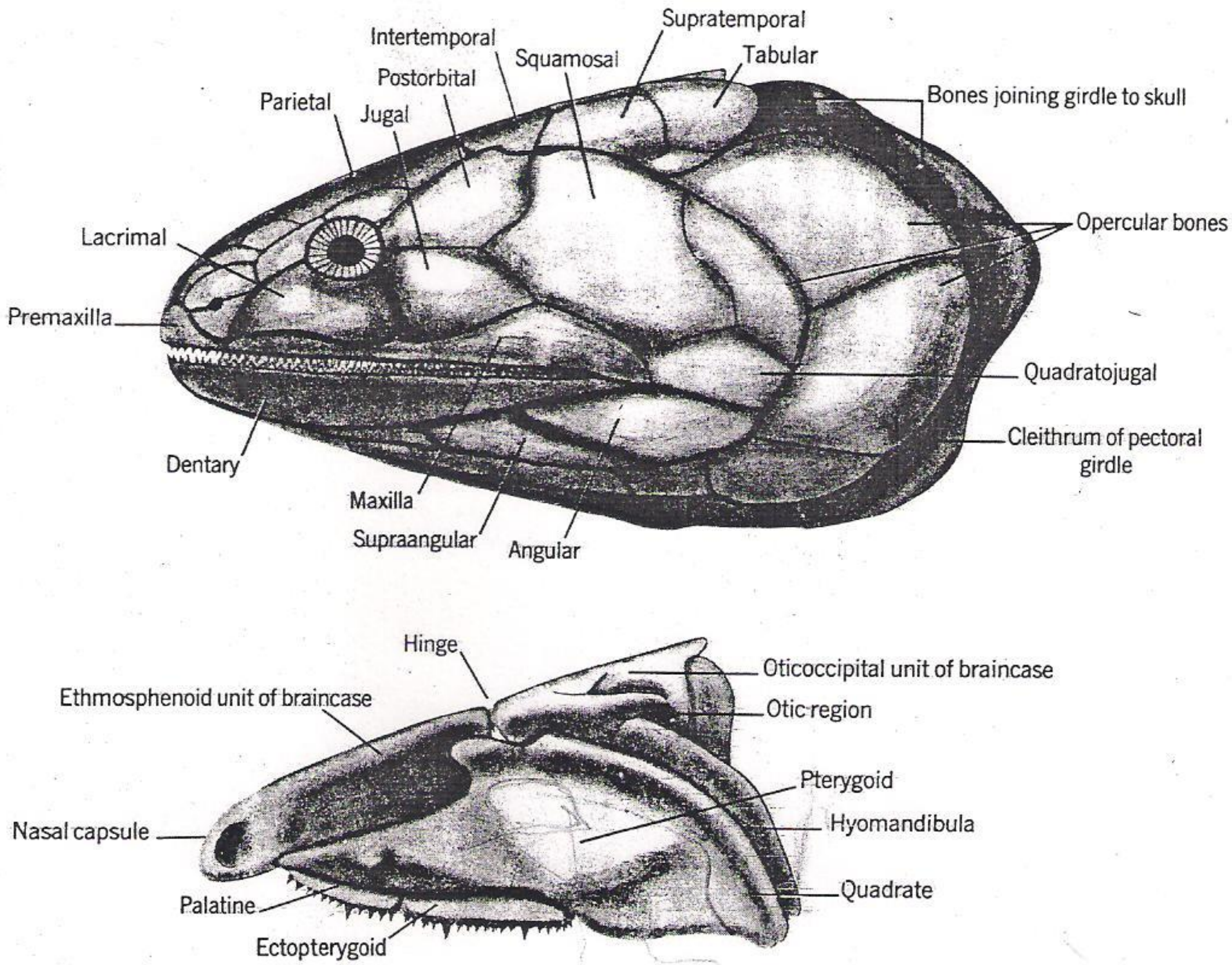


FIGURE 7-9

HEAD SKELETON OF *Eusthenopteron*, A CROSSOPTERYGIAN OF THE RHIPIDISTIAN GROUP. Superficial dermal bones are shown in the upper drawing; the hinged chondrocranium and some other deep parts of the skeleton are shown in the lower drawing.

Comparative anatomy of the head skeleton

Cartilaginous fishes: they have lacked bones throughout their history.

- To provide protection, the chondrocranium has become unusually solid, with side walls and a roof.
- The chondrocranium never ossifies but sometimes strengthened with granules of calcium salts.
- The jaw suspension is usually **amphystylic** i.e the hyomandibula and one or more processes of the palotoquadrate are braced independently against the braincase.
- It may also be **hyostylic** i.e the hyomandibular cartilage is braced against the otic capsule and the

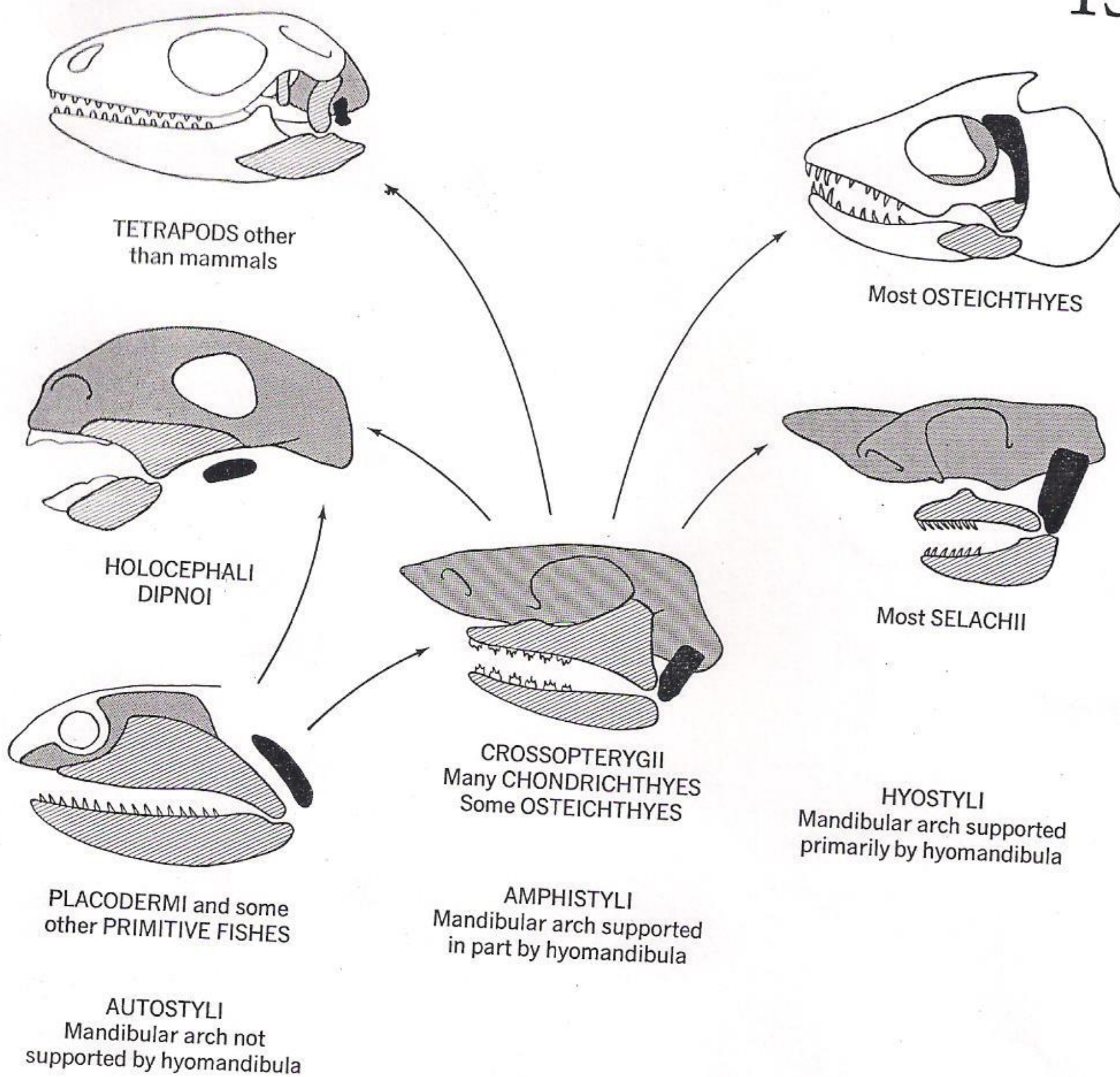


FIGURE 7-6

PRINCIPAL TYPES OF JAW SUSPENSION. Mandibular arch and derivatives are hatched, hyomandibula and derivatives are black, chondrocranium is shaded, teeth and extent of membrane bones are indicated in outline.

posterior end of the palatoquadrate cartilage is braced against the hyomandibular.

- In some of them the jaw suspension is strengthened by fusing with the braincase-a form of **autostyly**.
- There are usually 6 but as many as 8 post-mandibular arches.

Bony Fishes

- The chondrocrania of earliest bony fishes were well ossified in one unit without sutures.
- The visceral skeleton is almost the same among the 3 subclasses.***
- Dermal bones support the teeth and hence the mandibular arch is reduced.

- It is only in the Dipnoans that the palatoquadrate is fused to the braincase to become autostylic.
- The hyomandibula of the second visceral arch supports the jaw, which is therefore hyostylic or amphystylic.

There are 5 branchial arches.

- The gill arches may be bony or cartilaginous and not too different from those of cartilaginous fishes.
- With few exceptions, bony fishes have dermal skeleton of bones.
- There are a series of bones that join the pectoral girdle to the skull and there is a movable operculum that covers the gills.

Amphibians

- When the progeny of amphibians came out of water, they lost characters such as gill bars and operculum.
- Changes then occurred in the palate, skull roof and jaw mechanism.
- The most significant changes that occurred in the skull during the transition from fish to amphibia concerned the visceral skeleton.
- The quadrate of the upper jaw articulates with the squamosal without an assistance from the hyomandibular-i.e. autostylic, remaining so during subsequent vertebrate evolution.

- The ventral elements of the hyoid arch supports the tongue.
- The more posterior arches function as branchial arches only in the larvae and those that retain gills in the adult stage.
- Normally these are reduced to three and modified to support the tongue.
- The hyomandibular forms the ear ossicle, stappes.
- In the case of the membrane bones, the operculum is lost and the pectoral girdle is no longer joined to the skull.

Reptiles and Birds

- The skull of birds is similar to their reptilian ancestors, and so birds can be considered as specialized reptiles.
- In birds all the replacement bones fuse with one another and with the braincase before or soon after hatching.
- There are no traces of sutures in the adult.
- Reptiles and birds have one occipital condyle each.
- The visceral skeleton remains the same as that of amphibians.
- Quadrate, articular and some cartilages form from

the first visceral arch; stapes from the 2^{nd} arch, hyoid apparatus mainly from the 2^{nd} arch, but also from the 3^{rd} and sometimes the 4^{th} arches.

- Larynx and tracheal rings form from the 6^{th} and 7^{th} arches.
- As the dentary bone of the lower jaw became larger the articular bone became smaller, losing its position as the lower element in the hinge of the lower jaw.
- The quadrate also became smaller, losing its position as the upper element of the hinge.
- The articular and quadrate now become the ear ossicles; the articular forms the malleus, whilst the quadrate forms the incus.

Mammals

- The mammalian skull is variable with regard to adaptive features such as strength and proportion.
- Temporal structure, jaw suspension, ear ossicles and secondary palate remain as inherited from the reptiles.
- The brain is larger than that of other vertebrates.
- This has contributed to the fusion of the replacement and membrane bones of the braincase.
- There are two occipital condyles.
- Cranial sutures are very prominent.

- In mammals, the anterior bony nares have merged to form a common opening, the nasal chamber which is filled with scrolls of bone known as the **turbinates**.
- These bones are outgrowths of the maxillas, nasals and ethmoids.
- They are covered with epithelium which serve to clean and warm inspired air before it reaches the lungs.
- The skull has become simplified by the loss of certain bones.
- Bones that are characteristic of amphibians and reptiles but which are not seen in mammals include the following:

prefrontal, postfrontal, postorbital, ectopterygoids, quadratojugals, parasphenoids and all the membrane bones of the lower jaw, except the angular, prereticular and the dentary.

- In mammals, the prearticular contributes to the formation of the malleus and the angular contributes to the formation of the tympanic bulla which helps enclose the middle ear.

Vertebral column

General structure

- The main part of the vertebra is the **centrum**, which lies just below the spinal cord where it either surrounds, restricts or replaces the notochord.
- The centrum may consists of one or two elements.
- If a centrum has two elements, then the more anterior is called the intercentrum and the posterior one is called the pleurocentrum.
- If a tetrapod has only one central element, it may either be the intercentrum or pleurocentrum.

- Extending from the dorsal part of the centrum are bony structures, one on either side that unite to form the neural arch.
- A neural spine may arise from the neural arch.
- Sometimes a similar arch, the hemal arch extends from the ventral side of the centrum. This may continue as **hemal spine** eg. salmon.
- The centrum may accommodate the head or capitulum of a rib.
- Any lateral (side) process is a transverse process.
- Adjacent vertebrae always articulate by their centra.

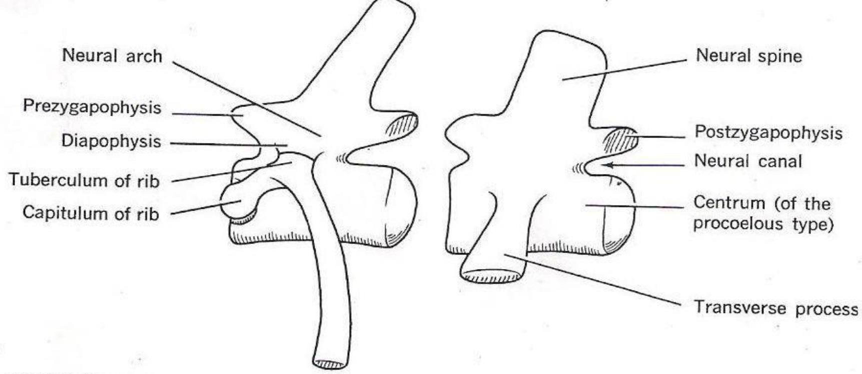


FIGURE 8-1
SOME FEATURES OF VERTEBRAE.

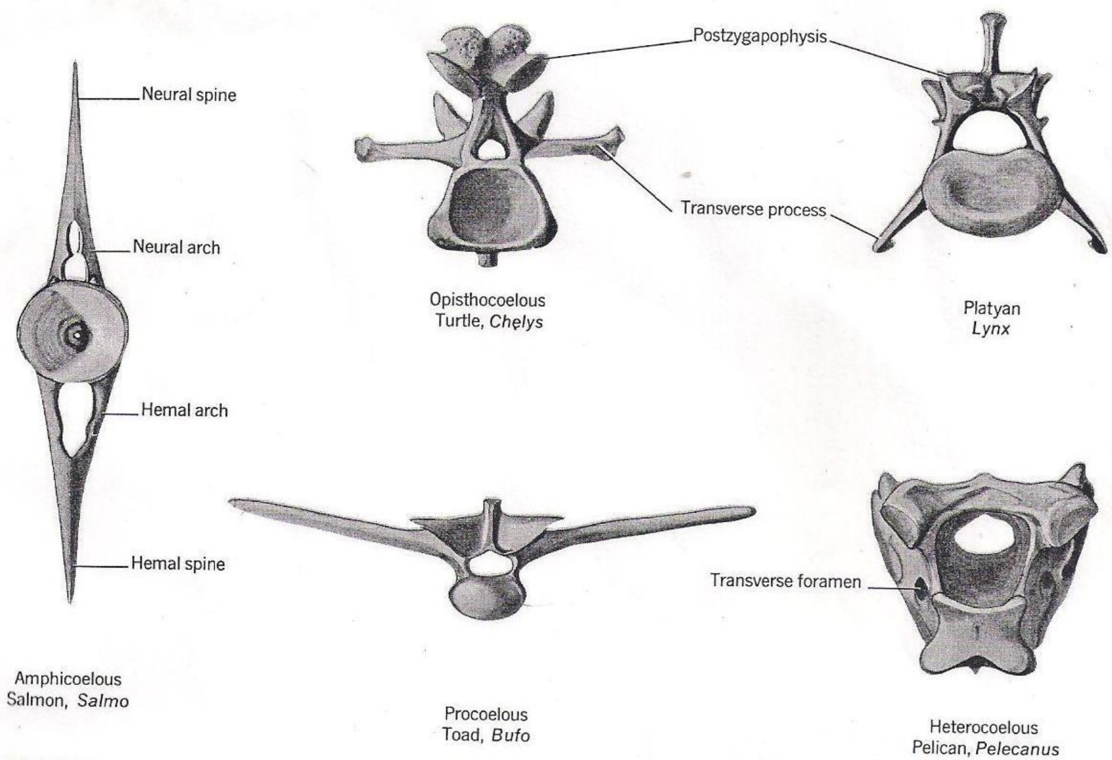


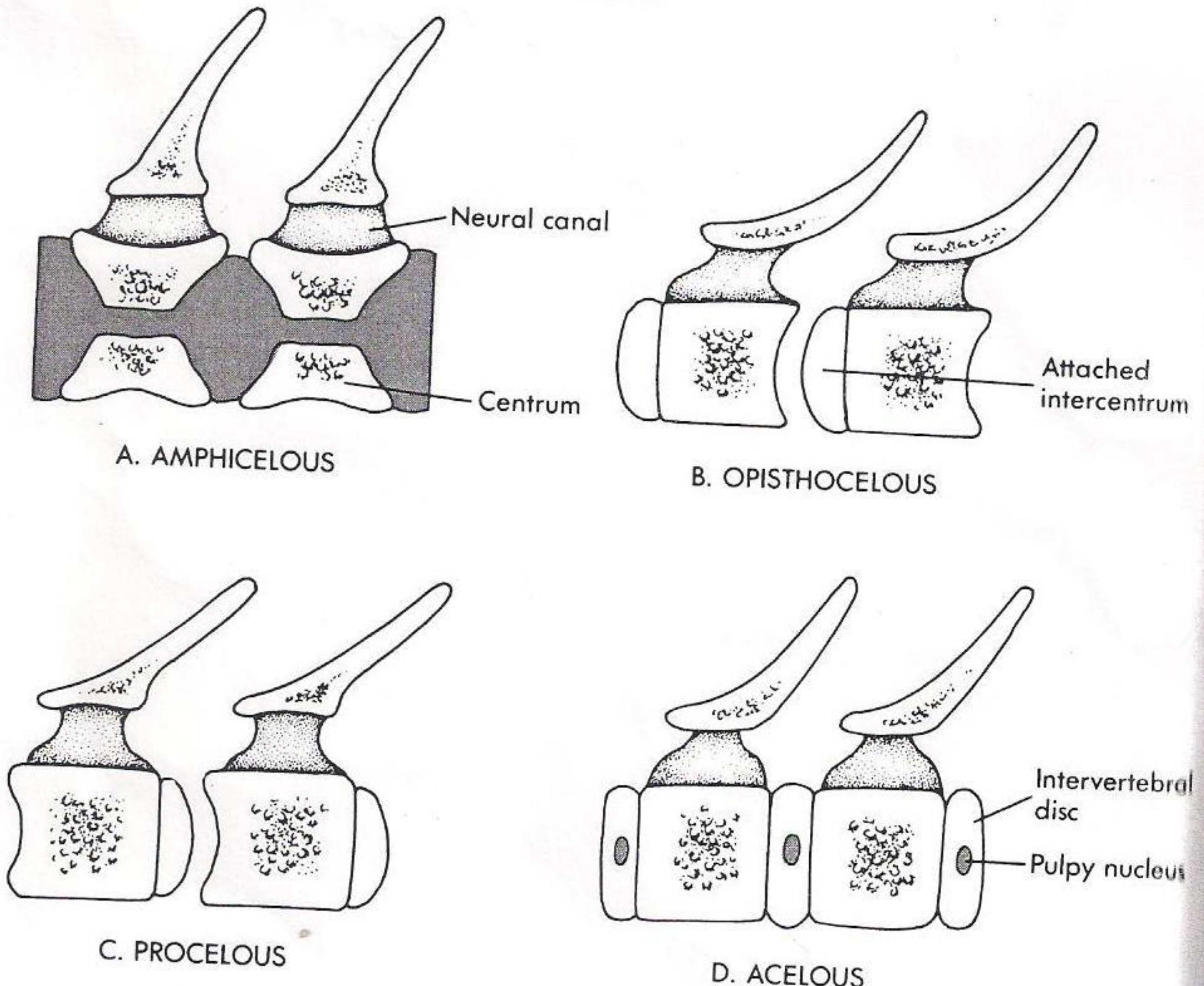
FIGURE 8-2
VERTEBRAE SHOWING VARIOUS SHAPES OF CENTRUM and other features as seen in posterior view.

- In tetrapods they also articulate by processes called zygapophyses.
- The pre-zygapophysis on the anterior end of one vertebra articulates with the postzygapophysis on the posterior end of the other vertebra.
- The shapes of the articulating surfaces of the ends of the vertebra are of evolutionary, functional or systematic importance.
- If each of the articulating surface is concave, the centrum is said to be **amphicoelus** eg salmon.
- Such centra touch only at the periphery of the intervertebral joint.

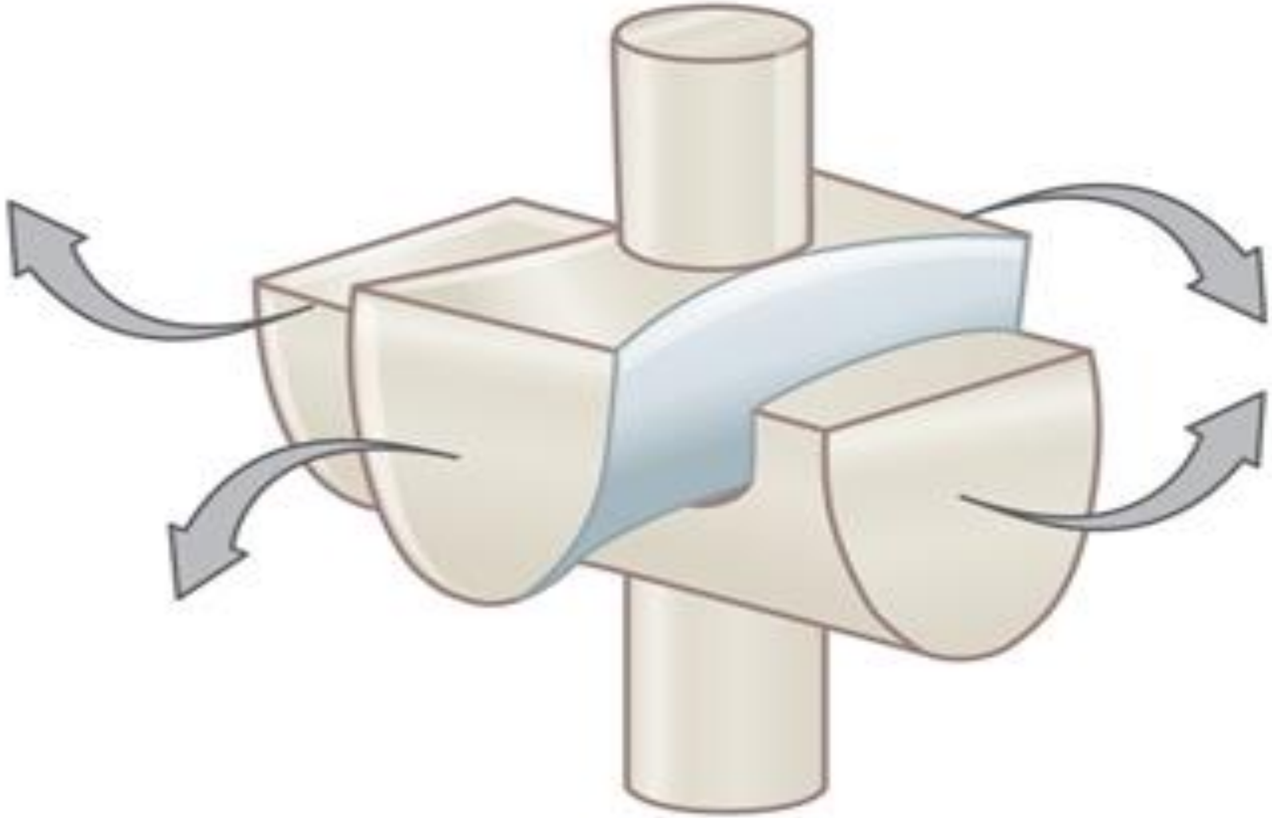
- Within the joint is a space filled by connective tissue, cartilage or remains of the notochord.
- When the centrum is concave anteriorly and convex posteriorly, it is **procoelous** eg Bufo.
- The bulge of one vertebra fits into the hollow of the next.
- An **opisthocoelous** centrum is convex anteriorly and concave posteriorly eg turtle.
- Joints between opisthocoelous type and procoelous vertebrae permit motion in any direction.
- Some centra have flat surfaces and are said to be **acoelous/platyan**.

FIGURE 8-5

Vertebral types based on articular surfaces of centra. Midsagittal section, head to the left. Amphicelous vertebrae are found in nearly all fishes, and in apodans, generalized urodeles, and primitive lizards; opisthocelous in garfishes and terrestrial salamanders; procelous in anurans and modern reptiles; acelous in mammals. A heterocelous vertebra is seen in Fig. 8-1, *F*. Color indicates notochordal tissue.



some other centra have saddle-shaped ends and are called **heterocoelous** eg pelican.



Comparative anatomy of the spine

Some fishes have evolved veretebra with firm centra that articulate with one another.

The amphicoelous centra restrict the notochord, thus reducing its function.

This type of spine is stronger than the notochord and provides greater anchorage for muscles.

Some cartilaginous fishes have centra and neural arches which are in continuous contact. Such an arrangement will immobilize a bony spine.

- However, the cartilaginous nature of the spine makes it slightly flexible.
- The vertebrae of bony fishes usually have one central element, a neural arch with a spine and in the tail a hemal arch with a spine.
- The centrum usually ossifies from mesenchyme surrounding the notochord.

Amphibians

- The vertebral column is divided into 2 regions: caudal vertebrae in the tail with hemal arches and trunk vertebrae lacking hemal arches.
- Amphibians, like other tetapods have zygapophyses to strengthen the spine and control its flexibility.

- The centra are amphicoelous, procoelous or opisthocoelous.
- The first trunk vertebra is modified for articulation with the skull and to give increased mobility to the head.
- This is the **atlas**, the 1st cervical vertebra and in some amphibians the only cervical vertebra.
- The trunk vertebrae bear ribs (except in Anurans)
- There is a single sacral vertebra, enlarged to articulate with the pelvic girdle.
- Caudal vertebrae lack zygapophyses, but have hemal arches.

- Anurans (frogs and toads) do not have free caudal vertebrae, instead there is a rod-like urostyle derived from the fusion of several caudal vertebrae.
- Modern amphibians show variation in total vertebrae.
- Apodans may have as many as 200, whilst Anurans have only 9 vertebrae.

Reptiles

- Reptiles provided the 1st manifestation of the 5 subdivisions of the vertebral column.
- Reptiles have more distinct cervical regions because of longer necks.

- They have 2 or more sacral vertebrae instead of one.
- Centra are usually procoelous, but may take other shapes.
- Hemal arches are retained only in the caudal region and are called **chevron bones**.
- The ancestral intercentra have disappeared and so they articulate with the spine at the intervetebral joints. Such arches are called chevron bones.
- The atlas differs from other cervical vertebrae.
- The centrum of the atlas associates with the centrum of the axis to form the **odontoid process**. Serves as a pivot upon which the head and atlas turn.

- The remaining cervical vertebrae are alike and all bear short ribs.
- These do not meet the sternum as the ribs of the thoracic vertebrae do.
- The sacrum consists of 2 fused sacral vertebrae which joins the pelvic girdle.
- Caudal vertebrae follow the sacrum.
- They have no true hemal arches, but rudimentary chevron bones on the ventral side of the vertebrae.

Birds

- The 5 subdivisions of the vertebral column are always present, even though there are fusions of bones to give rigidity.
- The fusion of bones involve all regions except the cervical region.
- Birds have more specialized and more uniform spines as a result of flight.
- The cervical vertebrae vary from 8-25 (commonly 15-20)
- The vertebrae are heterocoelous, bearing short ribs.
- Thoracic vertebrae are 6-10, bear ribs and are joined ventrally to the sternum.

- The last thoracic, all the lumbar vertebrae, the sacral vertebrae and the first few caudal vertebrae are fused to form a solid unit called **synsacrum**.
- The remaining caudal vertebrae (6-10) are usually fused to form a short pygostyle which support the tail feathers.

Mammals

- Divided into 5 regions-cervical, thoracic, lumbar, sacrum and caudal.
- In mammals there is a bony plate-like cap or epiphyses at the ends of their centra.
- When mature these fuse to the centra.

- With few exceptions mammals have 7 cervical vertebrae.
- Usually all bear short ribs, fused to the transverse processes and never reach the sternum.
- There are 20 trunk vertebrae, anterior thoracic and posterior lumbar.
- The thoracic vertebrae articulate with the ribs.
- Lumbar vertebrae have longer transverse processes than thoracic vertebrae.

- There are 3-5 sacral vertebrae fused to form a sacrum to support the pelvic girdle.
- Caudal vertebrae range from 3 or 4 in humans to

40 or more in mammals with tails (eg monkey)

- Chevron bones are usually restricted to the base of the tail.

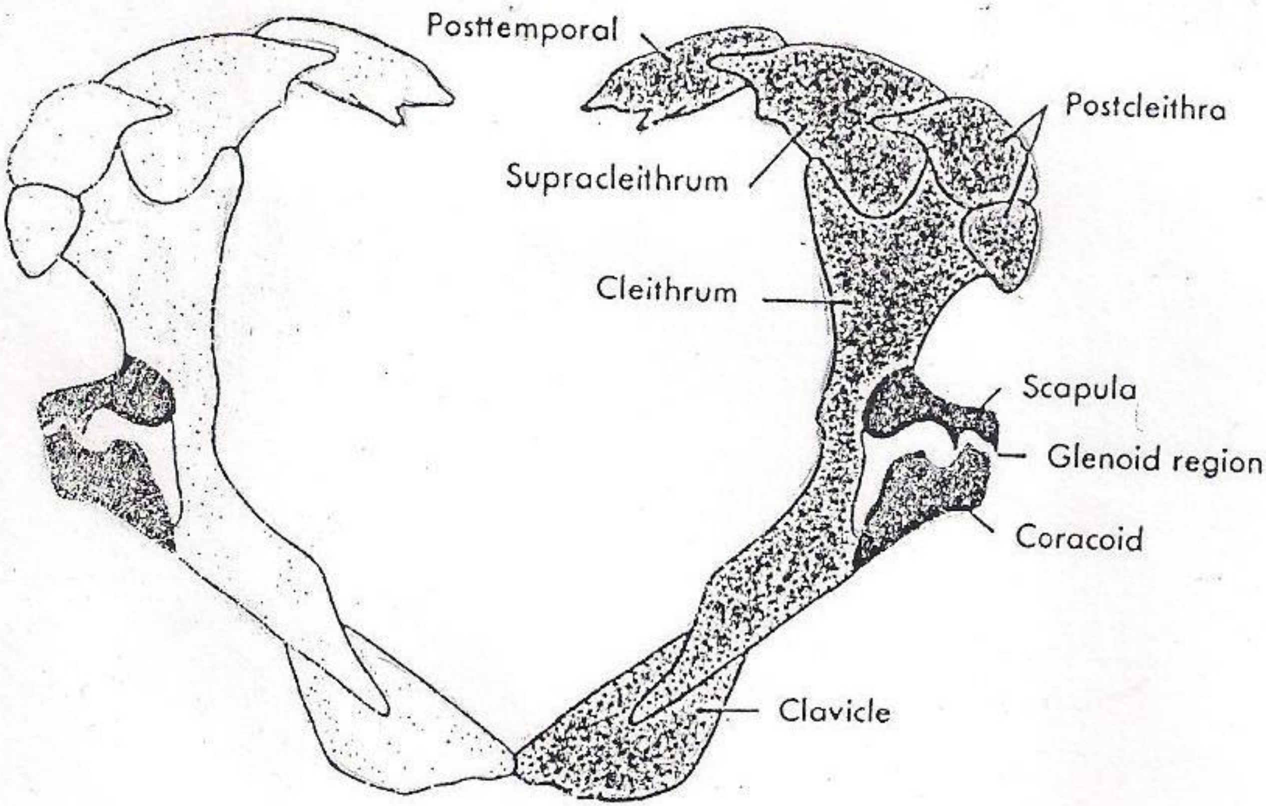
Appendicular Skeleton

Formed by the pectoral and pelvic girdles, skeleton of fins and limbs.

The pectoral girdle is immediately behind the head.

The basic form of the girdle consists of the following:

Replacement bones: a ventral coracoid, a scapula and a suprascapula.



PECTORAL GIRDLE
CHONDROSTEAN

FIGURE 10-2

Pectoral girdle of *Polypterus*. Dermal bones are red; replacement bones are black. Compare Fig. 10-1, ganoid fish.

- Dermal bones- clavicle, that meet the opposite clavicle in a mid-ventral symphysis, a cleithrum, a post-temporal bone that anchored the girdle to the skull and one or two post-cleithra.
- Early tetrapods have an additional membrane bone, the interclavicle, but have lost the post-temporal which braced the girdle against the skull in fishes.

Amphibians

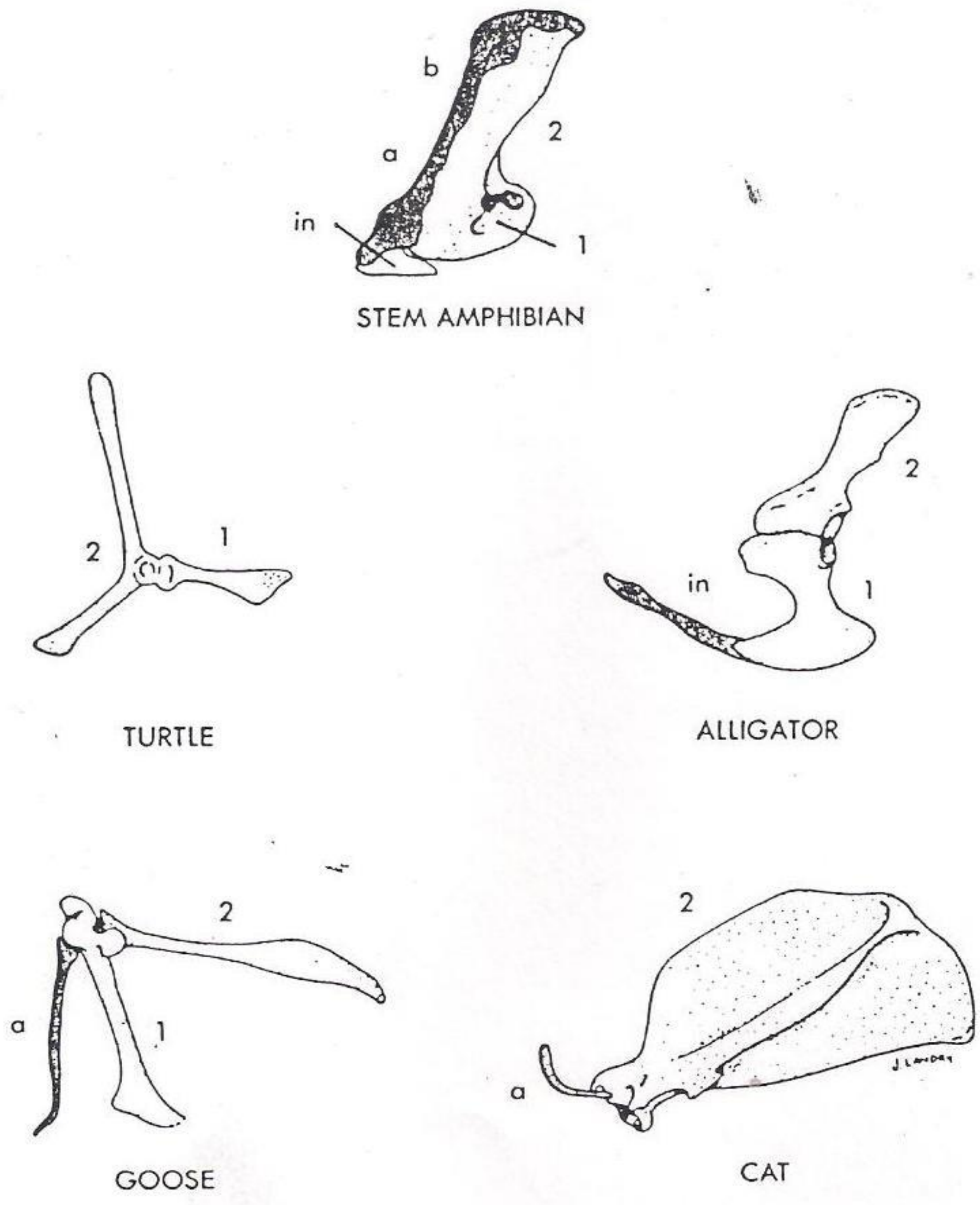
- In amphibians, the replacement bones are larger.
- All membrane bones are reduced.
- All bones dorsal to the cleithrum have been lost and so contact with the head was broken and the head was free to turn on the evolving neck.

- There are 2 replacement bones: a dorsal scapula and a ventral coracoid.
- Among the modern amphibians, the Urodela have no membrane bones at all in the girdle i.e no interclavicle.

- Anurans have no interclavicle and usually lack the cleithrum.

Reptiles

- Reptiles have full complement of bones.
- Interclavicle and clavicle are present. The cleithrum is present in the more primitive reptiles.
- The scapula is large and there are 2 coracoids: an anterior coracoid and posterior coracoid.



PECTORAL GIRDLES

FIGURE 10-5

Left half of the pectoral girdles of selected tetrapods, lateral views. Dermal bones are red, replacement bones are stippled. *1*, Coracoid or procoracoid; *2*, scapula; *3*, scapular spine. *a*, Clavicle; *b*, cleithrum; *in*, interclavicle. In turtles the clavicles and interclavicle are fused with the shell.

- However, some reptiles like the turtle have lost the posterior coracoid.

Birds

- Birds have a blade-like scapula which is parallel to the spine.
- The anterior coracoid is large and articulates with the sternum.
- The posterior coracoid is lost.
- The two clavicles fuse ventrally to form the wishbone or furcula.

Inter-clavicle is absent, but may be incorporated into the furcula in some birds.

Mammals

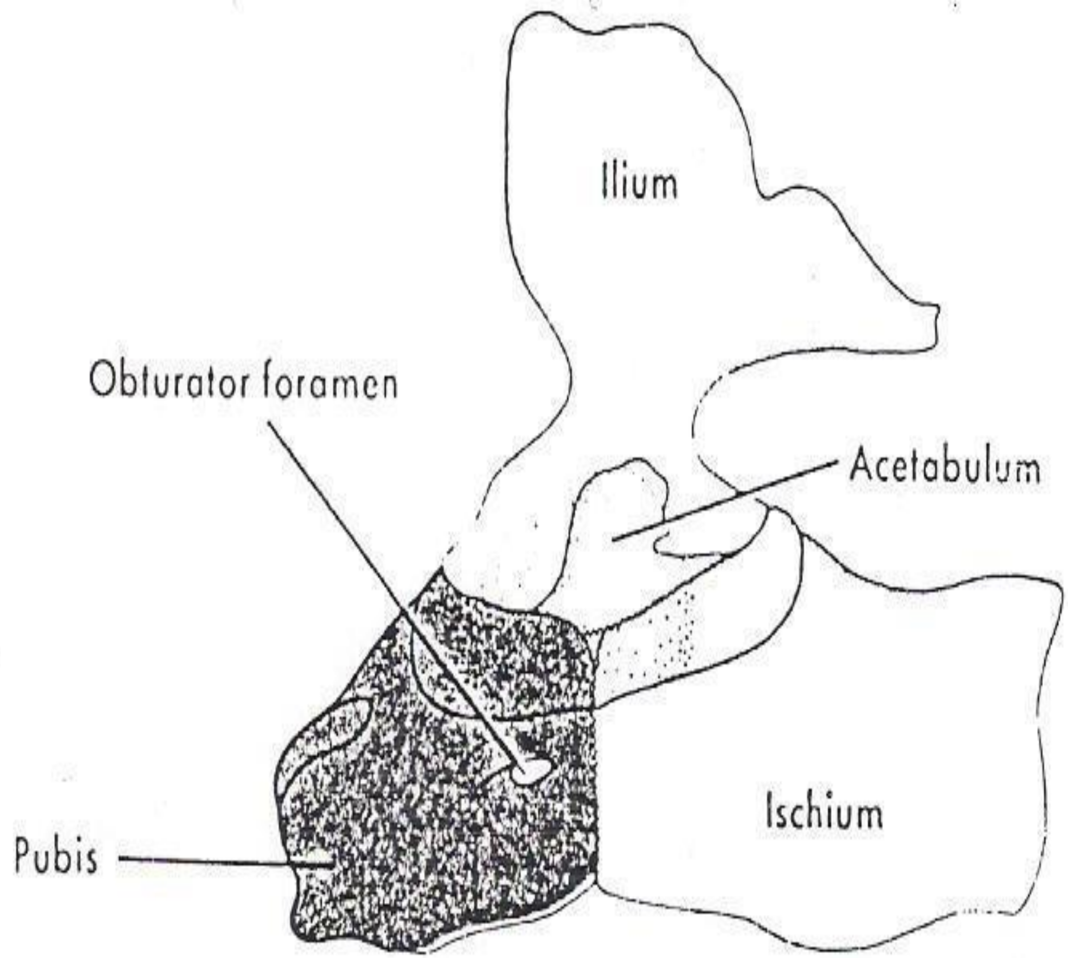
- The clavicle is the only membrane bone retained. It may, however, be missing in others.
- The anterior coracoid is completely lost.
- The posterior coracoid ossifies in the foetus and fuses with the scapula forming the coracoid process of that bone.
- The scapula is unique because it has a spine.
- The ventral end of the spine continues as the acromion process to articulate with the clavicle.

Pelvic Girdle

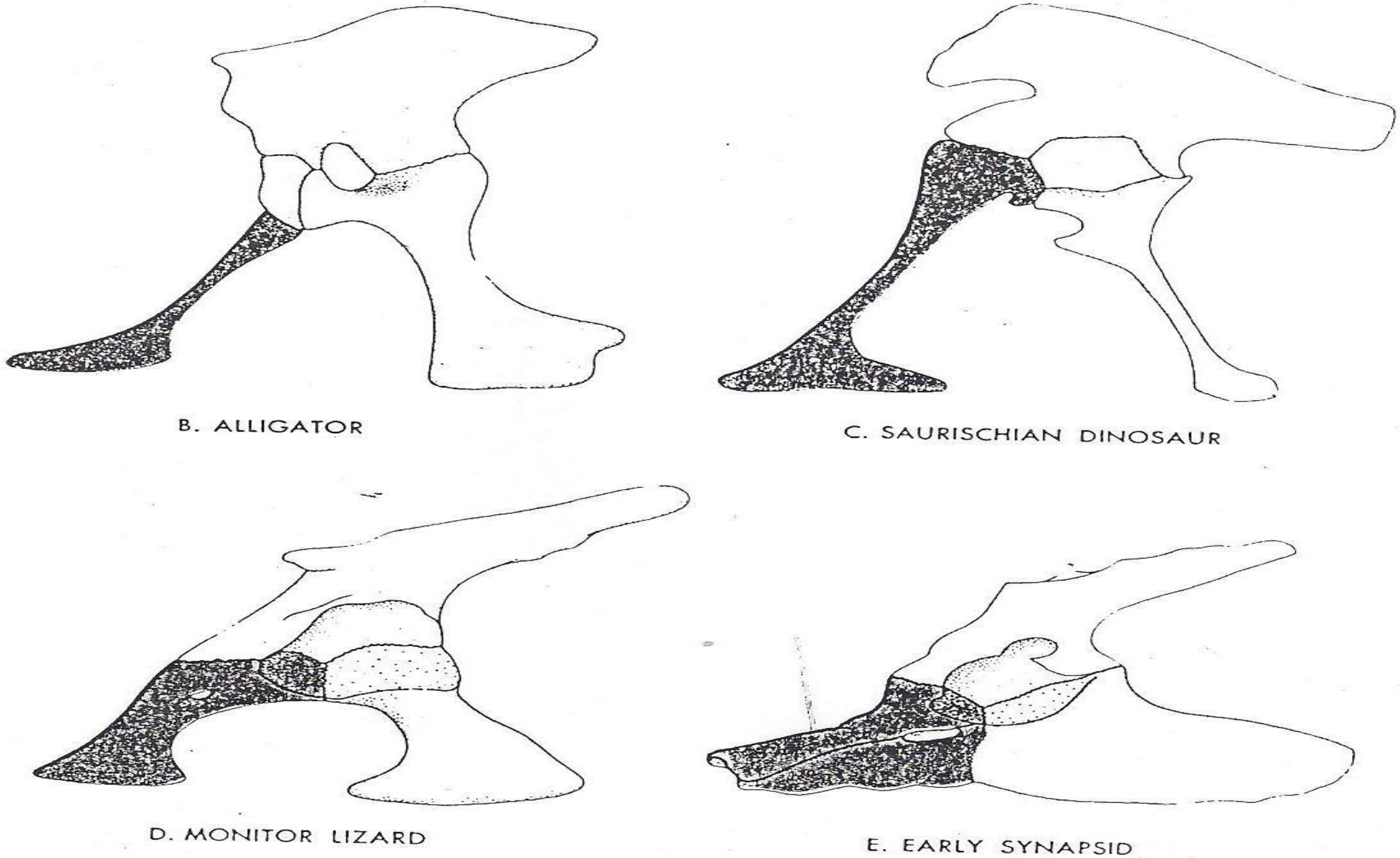
- **Fishes** - consists of a pair of cartilaginous or bony plates that meet in mid-ventral pelvic symphysis.
- In fishes it provides a brace for the pelvic fins.
- In cartilaginous fishes the 2 embryonic cartilages unite to form one adult plate.
- In Teleosts, the pelvic plate lies behind or below the pectoral girdle and is often attached to it.
- It may be as far forward as the pectoral fins or may appear anterior to the pectorals.
- **Tetrapods :** the pelvic girdle is much enlarged than that of fishes.

FIGURE 10-12

Left half of pelvic girdle of a primitive tetrapod, selected reptiles, and a modern mammal (lateral views, head to the left). The pubis and ischia are differentially colored. A, *Seymouria*, a borderline reptile-like amphibian.



A. PRIMITIVE TETRAPOD



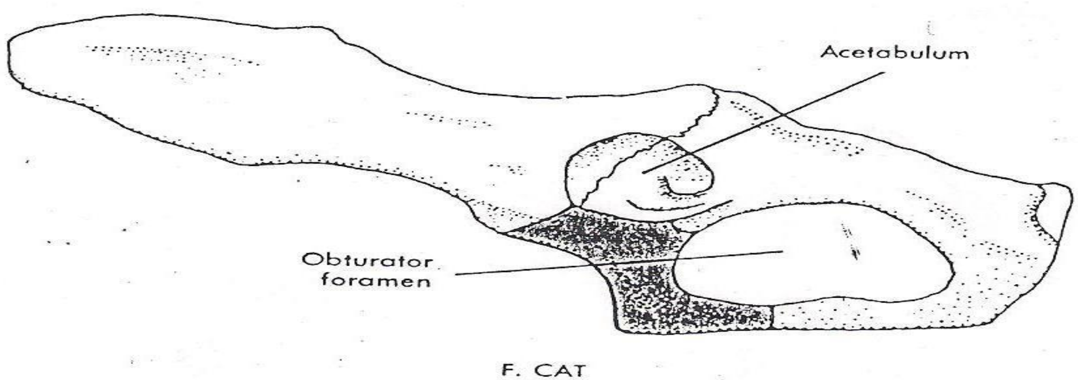


FIGURE 10-12, cont'd.

B, *Alligator*. C, *Allosaurus*. D, *Varanus*. E, *Ophiacodon*, a primitive reptile in the mammalian line. F, Coxal (innominate) bone of cat. In B, the anterior acetabular wall (gray) is partly cartilaginous, and in B and C the medial wall of the acetabulum is incomplete. Note the craniad reorientation of the ilium in the modern mammal. (E, redrawn from Osteology of the Reptiles by A.S. Romer by permission of The University of Chicago Press, copyright 1956 by the International Copyright Union.)

- Each half is a single cartilaginous unit in the embryo
- In adults, each unit is made up of 3 bones: a dorsal **ilium**, anterior **pubis** and posterior **ischium**.
- The 3 bones of one side fuse in the adult to form the innominate bone.
- One or both of the posterior bones articulate or fuse in the midventral line, and the line of contact is the pelvic symphysis.
- In Amphibians, the girdle was solid and triangular shaped with the ilium forming the apex.
- The pubis is distinguished from the ischium by the presence of a **foramen**, which accommodates a nerve.

Reptiles

- The girdle has various shapes
- Contact with the spine is firmer
- A fenestrum is usually present between the pubis and ischium

Birds

- The girdle is large and firmly attached to the synsacrum.
- The ilium is long and the pubis is turned below the ischium.
- There is no symphysis.

Mammals

- Mammals have a long ilium, extending forward from the acetabulum.
- A large obturator fenestrum represents both the obturator foramen and the pubo-ischiadic fenestrum of the ancestor.
- A symphysis is always present.

Tetrapod Limbs

Although tetrapods have 4 limbs, some have lost one or both pairs.

Others have been modified as wings or paddles.

The tetrapod limb consists of 5 segments: **propodium, epipodium, mesopodium, metapodium** and **phalanges.**

In the forelimb these correspond to the bones of the upper arm, forearm, wrist, palm and digits.

The last three constitutes the manus or hand

Propodium and Epipodium

- The humerus is the bone of the upper arm and is similar in all tetrapods with slight variations.
- The radius and ulna are the bones of the forearm.
- The radius articulates proximally with the humerus and distally with the wrist bones on the thumb side of the hand.

FIGURE 10-20
Generalized pattern of a right anterior limb, viewed from above, palm down. *1* to 5, First to fifth digits.

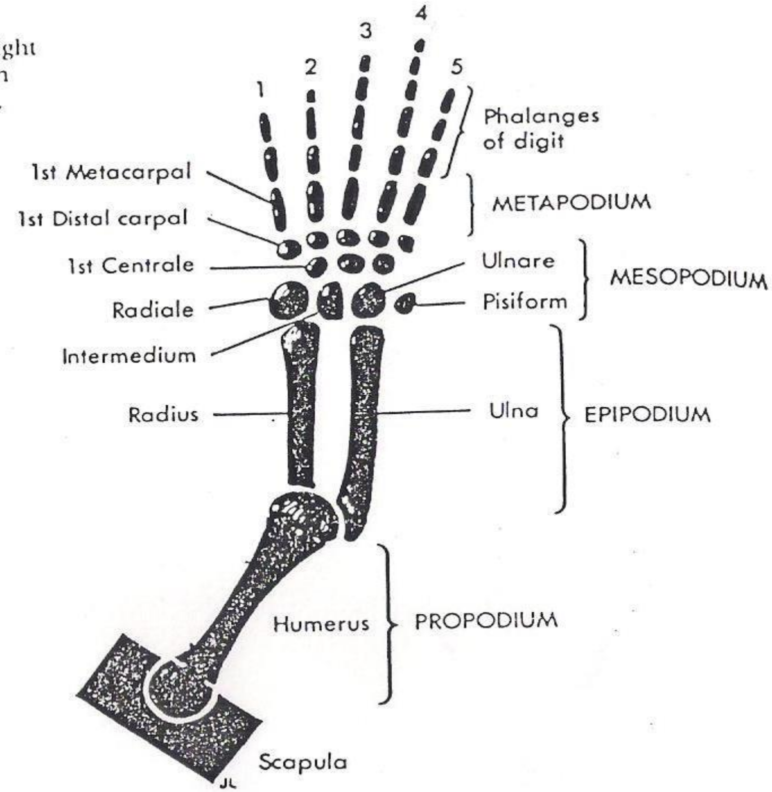


TABLE 10-1 Homologous Segments in Anterior and Posterior Limbs of Tetrapods

	NAME OF SEGMENT		SKELETON
Anterior Limb	1 Upper arm (brachium)		Humerus
	2 Forearm (antebrachium)		Radius and ulna
	3 Wrist (carpus)	Manus	Carpals
	4 Palm (metacarpus)		Metacarpals
	5 Digits		Phalanges
Posterior Limb	1 Thigh (femur)		Femur
	2 Shank (crus)		Tibia and fibula
	3 Ankle (tarsus)	Pes	Tarsals
	4 Instep (metatarsus)		Metatarsal
	5 Digits		Phalanges

The ulna is a longer bone.

- It articulates proximally with the humerus and radius, and distally with the wrist bones on the opposite side of the thumb.
- The ulna sometimes fuses with the radius or may be vestigial as in the frog or bat.
- The femur is the propodial bone of the thigh, whilst the tibia and fibula are the bones of the lower leg.
- A small triangular bone, the patella/knee cap develops in birds and mammals.
- The patella protects the abrasive action of the tendon

- The fibula may partially or completely fuse with the tibia to form a tibiofibula eg frogs.
- It may be reduced to form a splinter bone or may be lost as in deer and other ungulates.
- In birds, the tibia fuses with the proximal row of tarsals to form the tibiotarsus.

Manus

- Formed by the wrist, palm and digits.
- The wrist of pentadactyl hand consists of 3 rows of carpal bones.
- The proximal row has a radial carpal (radiale) at the distal end of the radius.

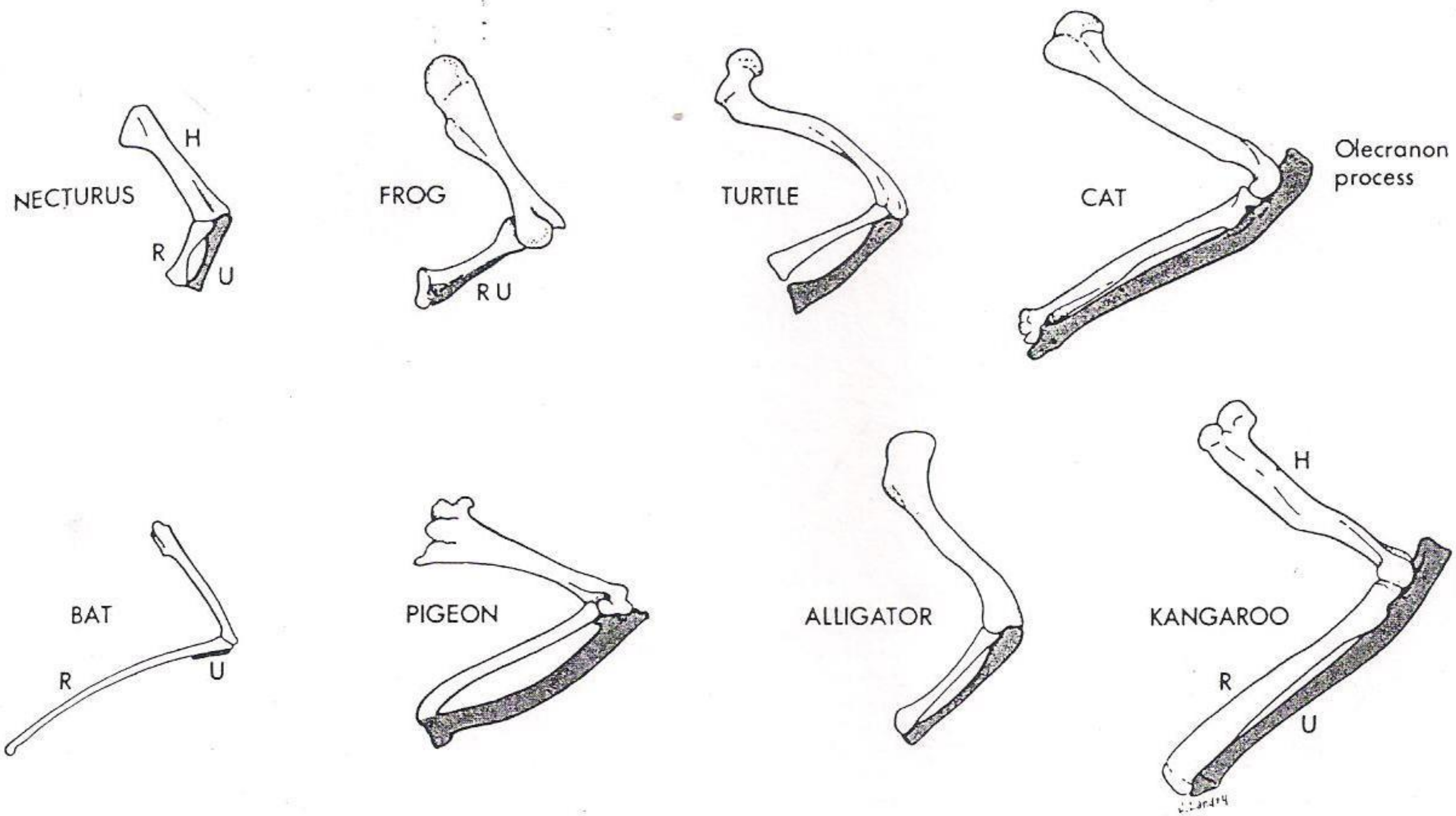


FIGURE 10-21

Humerus, radius, and ulna of the left forelimb (lateral views). *H,* Humerus; *R,* radius; *U,* ulna. In the frog the radius and ulna have united to form a radioulna, *RU.* In the bat the ulna is vestigial.

sive shoulder muscles for digging. The humeri of carinate birds have a slender central cavity containing diverticula from the lungs.

The radius and ulna are bones of the forearm. The radius is a preaxial bone articulating proximally with the humerus and distally with wrist bones on the thumb side of the hand. It bears most of the force being transmitted from wrist to humerus. The ulna is a longer, postaxial bone articulating proximally with the humerus and radius and distally with wrist bones on the side opposite the thumb. The ulna sometimes fuses with the radius, or it may be vestigial, as in frogs and bats (Fig. 10-21).

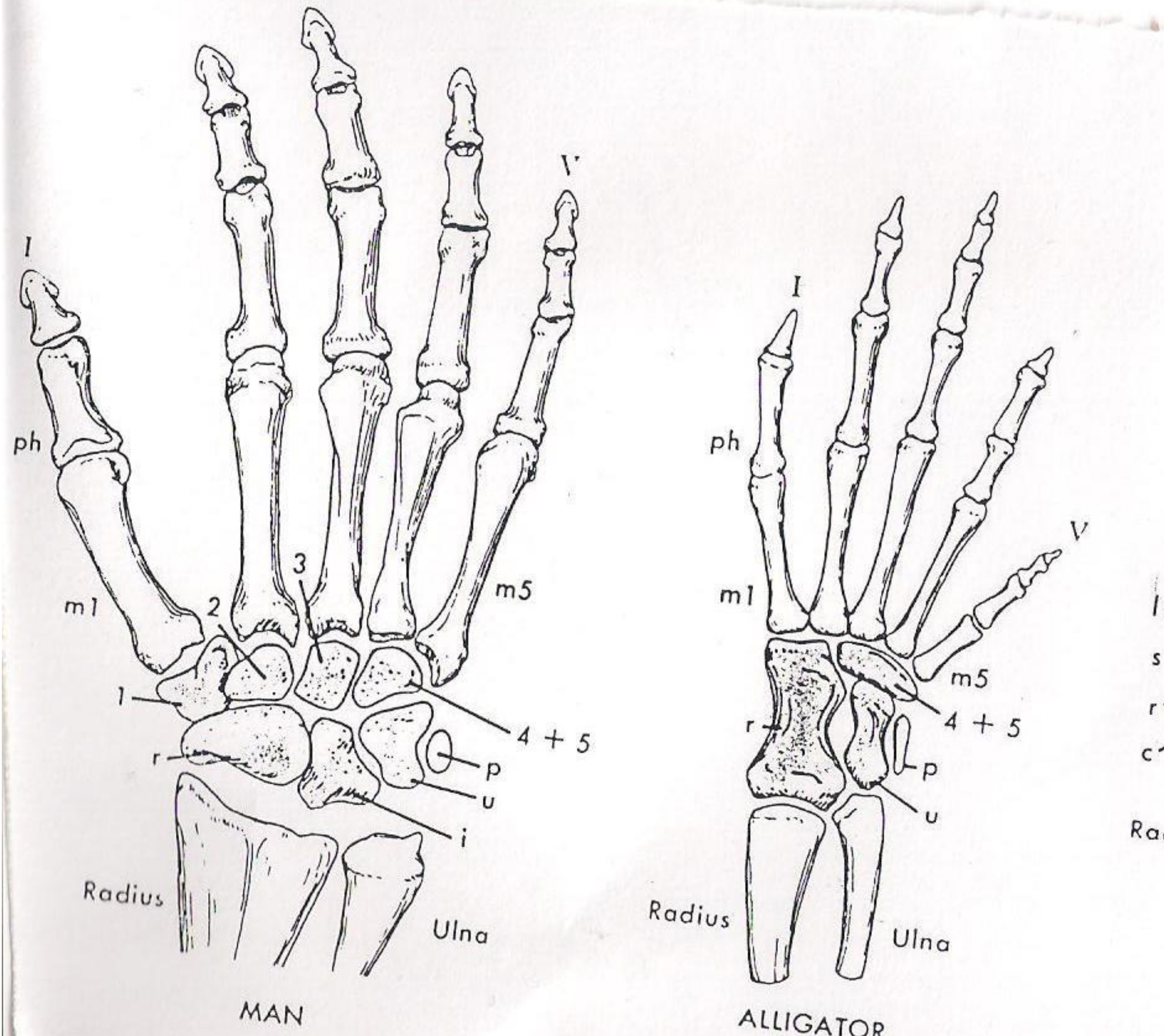


FIGURE 10-25

Right manus of man, alligator, and turtle (dorsals views, carpal bones in red). *c*, Centrale; *I*, intermedium; *ml* and *m5*, first and fifth metacarpals; *p*, pisiform; *ph*, proximal phalanx, *r*, radiale; *s*, radial sesamoid; *u*, ulnare; *1* to *5*, distal carpals; *I* and *V*, first and fifth digits. The alligator has an additional carpal that cannot be seen from this view.

TABLE 10-3 Comparison of Skeletal Elements of Manus and Pes

MANUS*	PES, WITH SYNONYMS	
Radiale	Tibiale	Talus or astragalus†
Intermedium	Intermedium	
Ulnare	Fibulare	Calcaneus
Pisiform		
Centralia (0 to 4)	Centralia (0 to 4)	Navicular
Distal carpal 1	Distal tarsal 1	Entocuneiform
Distal carpal 2	Distal tarsal 2	Mesocuneiform
Distal carpal 3	Distal tarsal 3	Ectocuneiform
Distal carpal 4 } Hamate	Distal tarsal 4 }	Cuboid
Distal carpal 5 } Hamate	Distal tarsal 5 }	Cuboid
Metacarpals (1 to 5)	Metatarsals (1 to 5)	
Digits (I to V)	Digits (I to V)	

*For synonyms, see Table 10-2.
†Often incorporates the intermedium and a centrale.

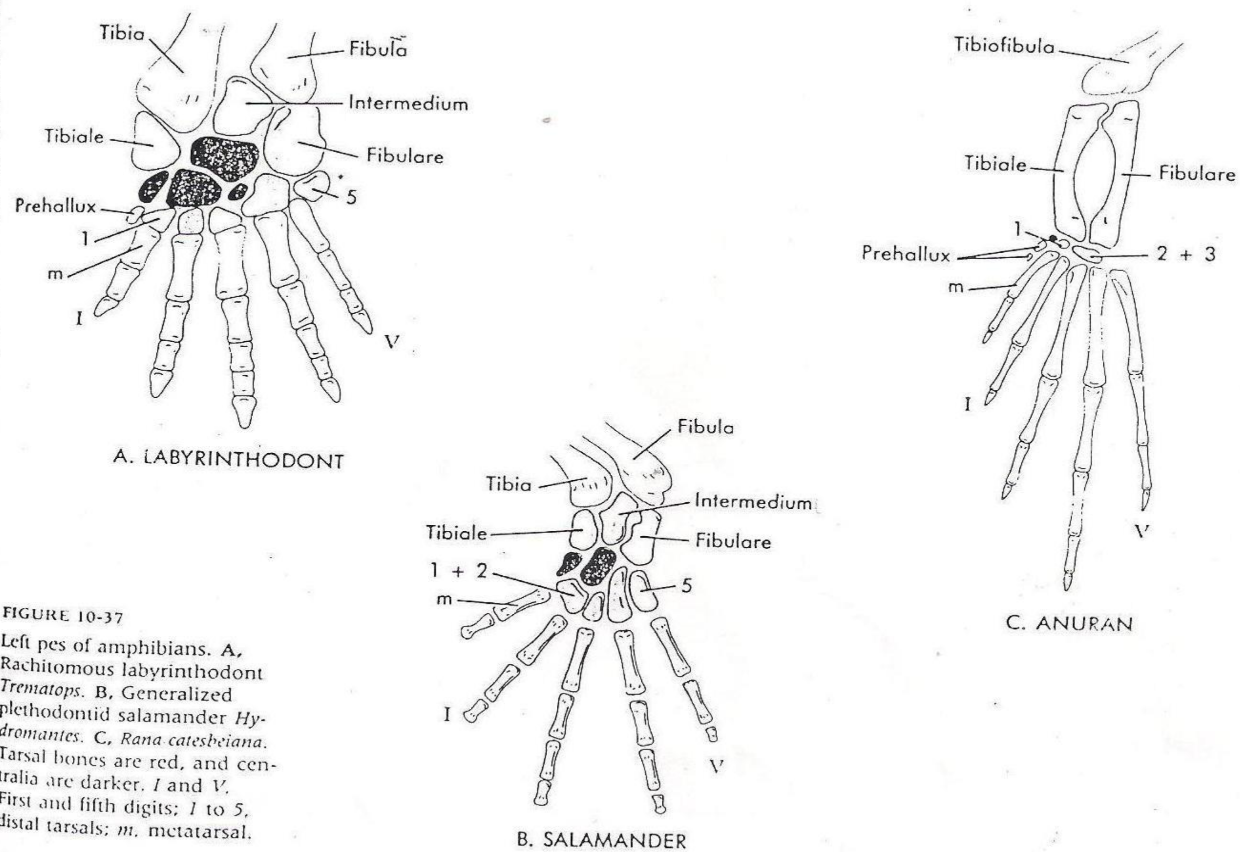
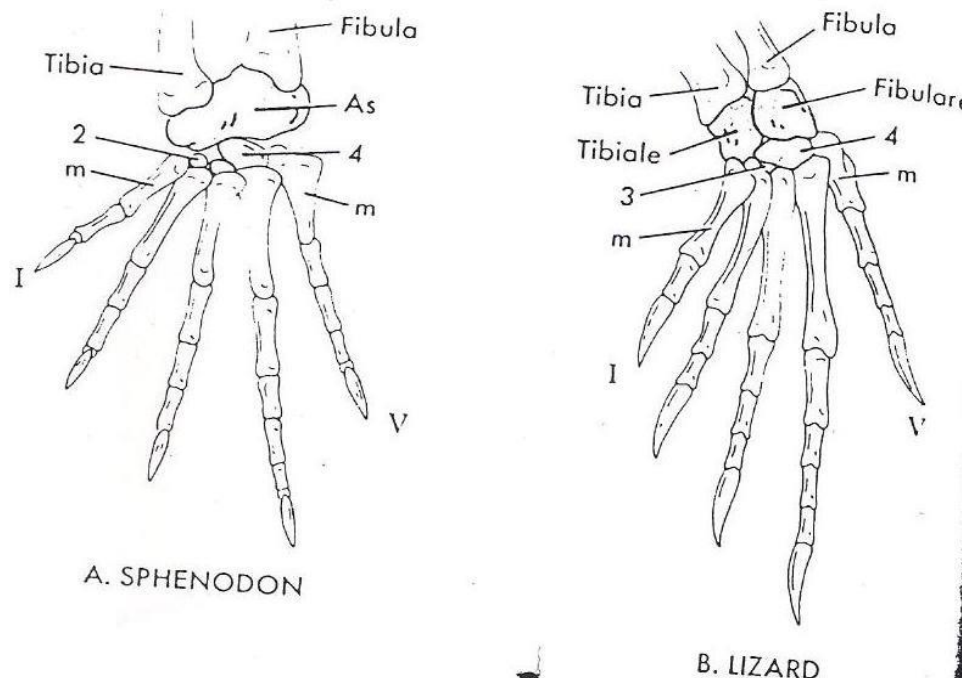


FIGURE 10-37
Left pes of amphibians. A, Rachitomous labyrinthodont *Trematops*. B, Generalized plethodontid salamander *Hydromantes*. C, *Rana catesbeiana*. Tarsal bones are red, and centralia are darker. *I* and *V*, First and fifth digits; *1* to *5*, distal tarsals; *m*, metatarsal.

FIGURE 10-38

Left pes of *Sphenodon* and the lizard *Uromastix*. *I* and *V*, First and fifth digits; *2* to *4*, distal tarsals; *As*, astragalocalcaneus; *m*, metatarsal.



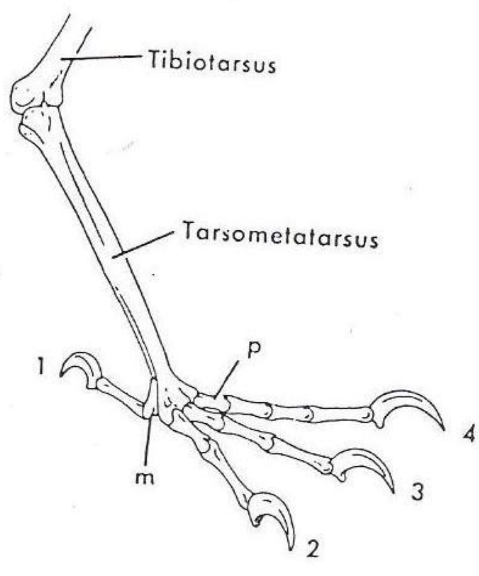
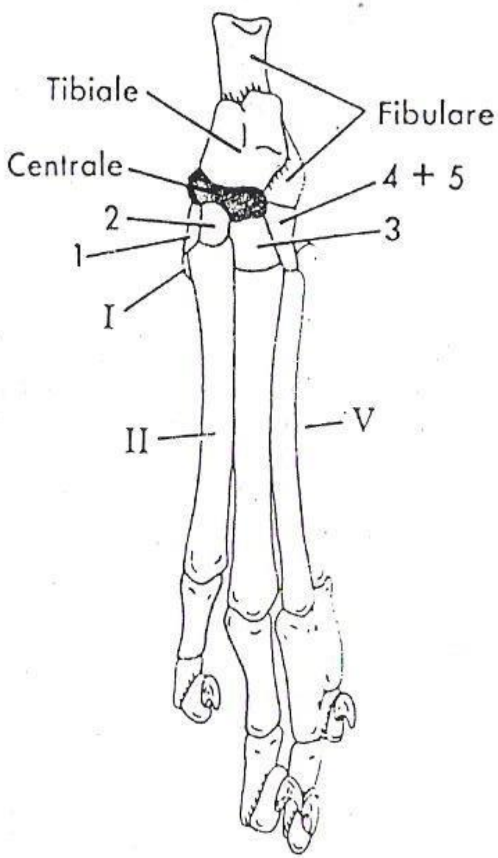
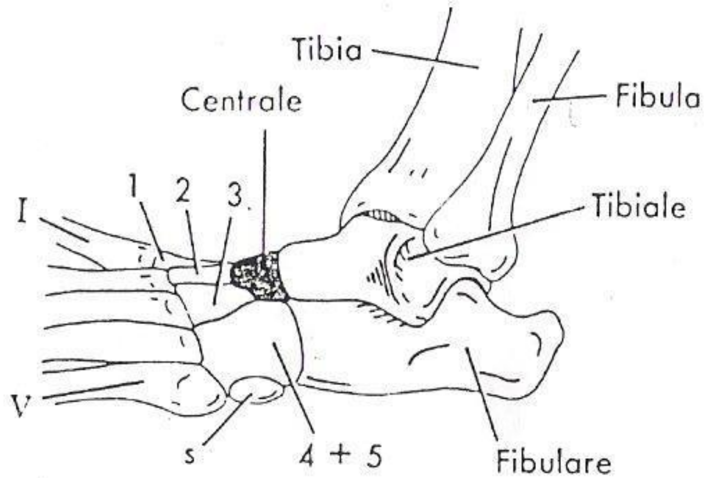


FIGURE 10-39

Left ankle and digits of a passerine bird, medial view, head to the right. *1* to *4*, Digits; *m*, first metatarsal; *p*, phalanx. The claws obscure the terminal phalanges. Note the intratarsal joint between tibiotarsus and tarsometatarsus.



A. CAT



B. RHESUS MONKEY

FIGURE 10-40

A, Left pes of cat, anterior view. The phalangeal formula is 0-3-3-3-3. B, Left ankle and associated bones of rhesus monkey, lateral view. *1* to *5*, Distal tarsals; *I*, *II*, and *V*, metatarsals; *s*, sesamoid in the peroneus longus muscle. For synonyms for mammalian ankle bones *(red)* see Table 10-3.

- There is an ulnar carpal (ulnare) at the end of the ulna and an intermediale between the two.
- The middle row of carpals consists of centralia.
- The distal row is made up of 5 carpals.
- The metacarpals are the skeleton of the palm.
- Primitive pentadactyl limb may have had as many distal carpals and metacarpals as digits.
- Each digit consists of phalanges.
- The early phalangeal formula was 2-3-4-5-3, but has become 2-3-3-3-3

Adaptation for swift-footedness

- Mammals with pentadactyl limbs are plantigrade i.e the wrist, ankles and the digits all rest on the ground eg primates, marsupials etc.
- This is a primitive feature that is not associated with swiftness.
- Mammals in which only the first digit has been reduced or lost tend to be digitigrade.
- The weight is borne on digital arches with the wrist and ankle elevated eg. Rabbits, rodents carnivores.

- The extreme modification of reducing the number of digits is seen in the ungulates.
- Unguligrade mammals walk on 4, 3, 2 or even 1 digit, with the wrist and ankle elevated well above the ground.
- The claws have become hoofs that bear the weight and protect the living tissues of the toes from the abrasive action of the substrate.
- Among the ungulates, there are 2 lines of progression:

1. **Artiodactyls** (deer, carmel)

The weight of the body is distributed equally between digits II and IV.

- Thus arose the cloven hoof, said to be paraxonic because the weight is borne on parallel axes.
- Artiodactyls have an even number of digits.

2. **Perissodactyl** (horse, rhinoceros)

The body weight is borne on digit III

- The other digits are reduced or lost
- This is the mesaxonic foot.
- Perissodactyls have the odd number of digits.

The hind foot/Pes

- The hind foot is comparable with the manus bone for bone.
- Primitive tetrapods have 4 centralia in the pes.
- In Anurans, the 2 proximal tarsals – the tibiale and fibulare are united at each end.
- Articulating with these distally are 3 distal tarsals
- The metatarsals are long with five webbed digits

Reptiles

- Reptiles display a loss and fusion of the ankle bones
- The proximal row of tarsals is reduced by fusion to form a single bone known as **astragalo-calcaneus**

in some lizards.

- Most reptiles have 5 toes (alligators and some lizards have 4, whilst some freshwater turtles have 3)
- The phalangeal formula for reptiles is 2-3-4-5-4, but alligator and turtles have 2-3-4-4-0

Birds

- In birds the proximal tarsals are united with the lower end of the tibia to form a tibiotarsus.
- The distal tarsals are united with the upper ends of the three fused metatarsals to form a long rigid tarsometatarsus.

- There is an intratarsal joint between the tibiotarsus and the tarsometatarsus.
- There is a joint between the tarsometatarsus and the toes.
- Most birds have 4 toes, a few have 3, ostriches have 2.
- Usually 3 toes are directed forward, whilst 1 comes off the back of the foot.
- A few birds like the woodpecker and parrot have 2 toes pointing backwards forming an X (zygodactyly)

Mammals

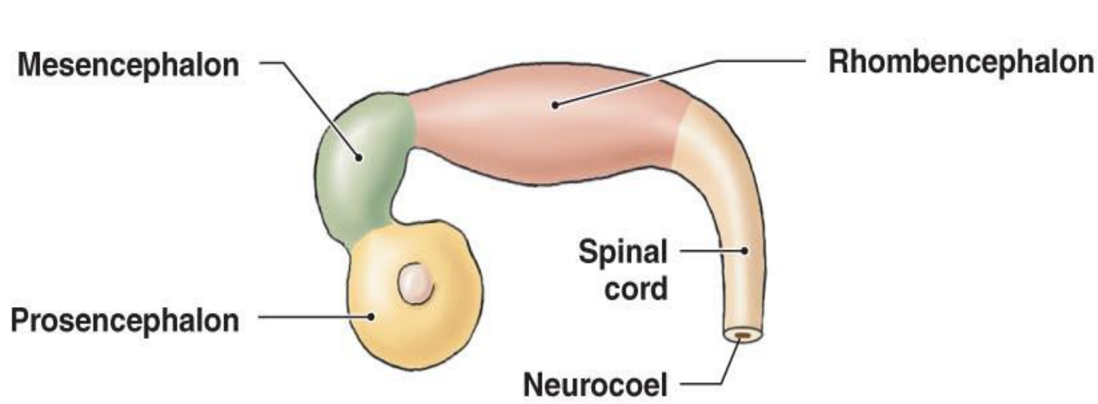
- Mammals lack an intratarsal joint but have a large hinge joint where the tibia and fibula meet the ankle
- The tibiale is the principal weight-bearing bone of the ankle.
- The other proximal tarsal, the fibulare is elongated backwards in plantigrade mammals and upwards in digitigrade mammals.
- This forms the heelbone of plantigrade mammals.
- The phalangeal formula for the pes is 2-3-3-3-3

NERVOUS SYSTEM

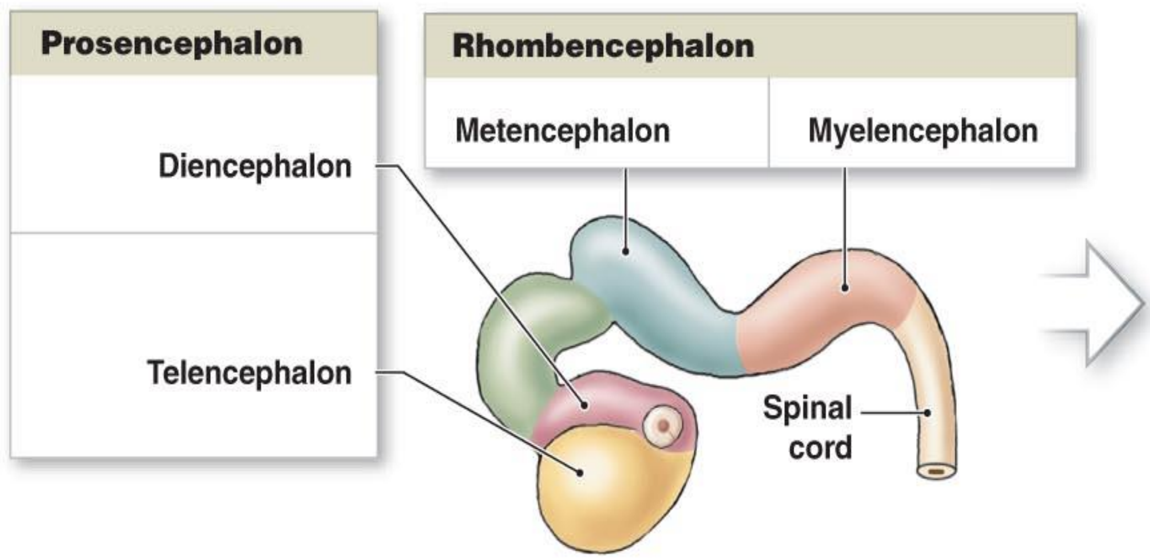
- The nervous system is formed from the ectoderm.
- By the latter stages of neurulation, the future brain is already greater in diameter than the spinal cord.
- After neurulation, the developing brain expands and three brain vesicles are formed, separated from each other by constrictions.
- The three brain vesicles are forebrain (prosencephalon), midbrain (mesencephalon) and hindbrain (rhombencephalon).
- The prosencephalon lies anterior to the notochord.
- Other vesicles are dorsal to the notochord.

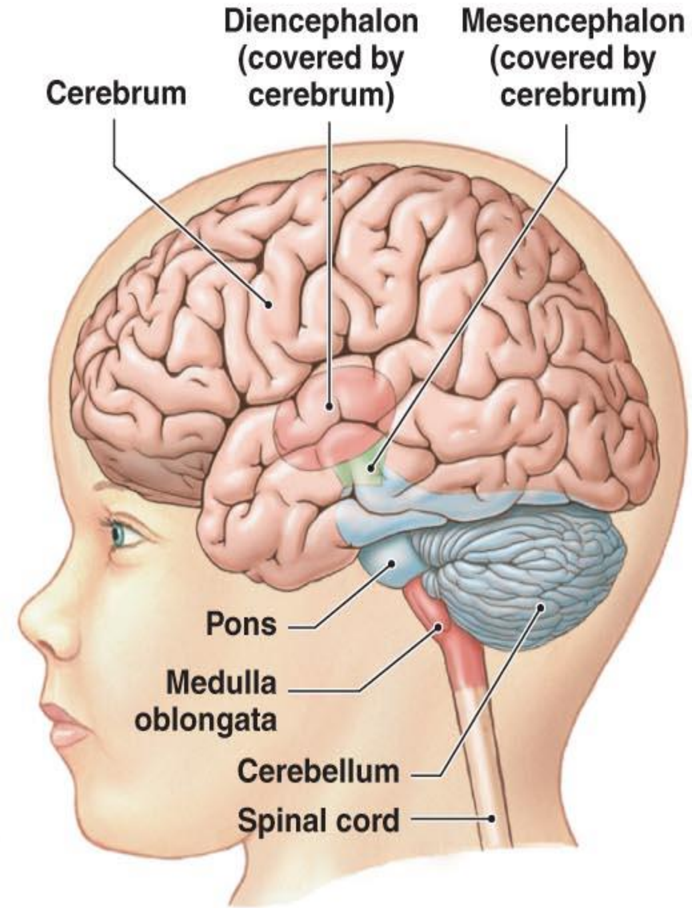
- At the next stage of development, additional constrictions divide the initial three brain vesicles into 5 secondary vesicles.
- The anterior part of the prosencephalon becomes the telencephalon, through expansions of its lateral walls.
- These expansions will later on form the cerebral hemispheres of the adult brain.
- The posterior part becomes the diencephalon.
- The rhombencephalon forms an anterior metencephalon (forming the adult cerebellum) and posterior myelencephalon.

A lateral view of the brain of an embryo after 4 weeks of development showing the neural tube



A lateral view of the brain of a 5-week-old embryo





Brain development in a child, showing the cerebrum covering other portions of the brain

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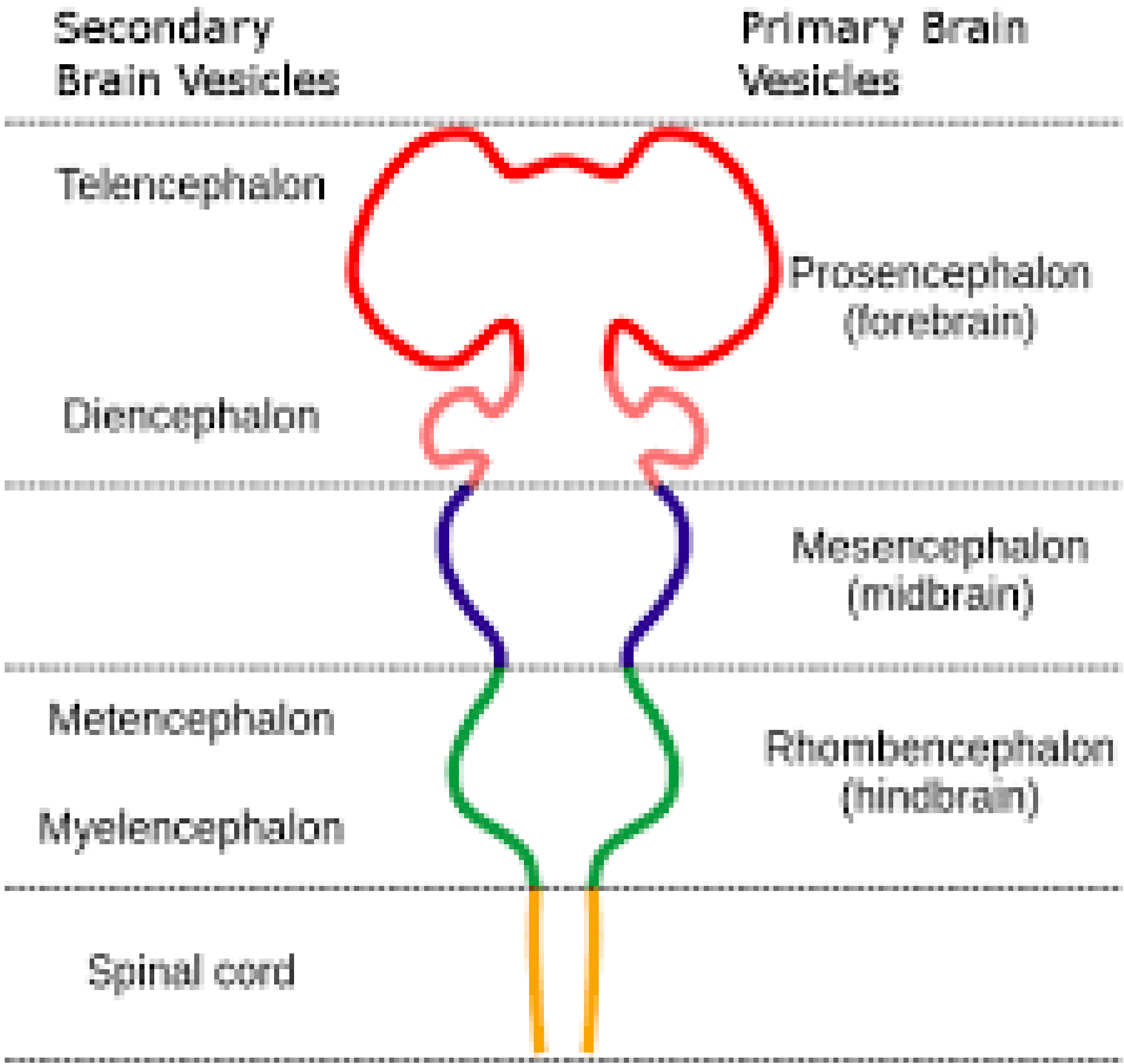

Secondary Brain Vesicles
Primary Brain Vesicles
Telencephalon
Prosencephalon (forebrain)
Diencephalon
Mesencephalon (midbrain)
Metencephalon
Rhombencephalon (hindbrain)
Myelencephalon
Spinal cord

- The embryonic neurocoel is larger in the brain than in the spinal cord.
- In the brain vesicles, the neurocoel forms expansions called ventricles.
- The lateral ventricles (1st and 2nd ventricles) occupy the cerebral hemispheres.
- The 3rd ventricle is in the diencephalon.
- The neural canal expands within the mesencephalon of most vertebrates, but in mammals it is relatively restricted and tube-like.
- This is known as **cerebral aqueduct**.
- The 4th ventricle is in the myelencephalon and metencephalon.

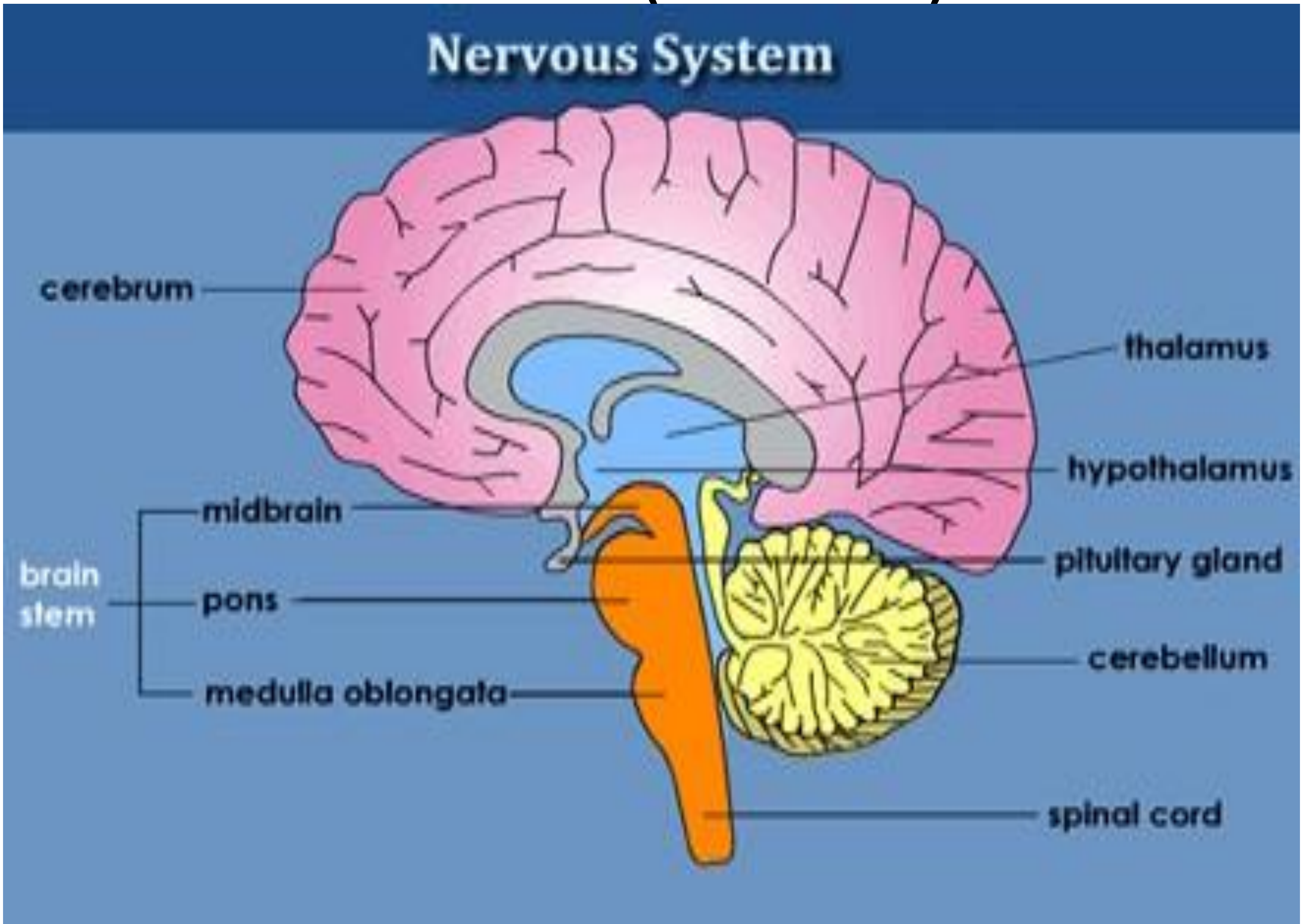
- Most brains have nearly straight axes.
- The brains of birds and mammals acquire 3 flexures in the embryo.

1. Cephalic flexure is located in the mesencephalon.
2. Pontine flexure is located in the part of the metencephalon called the pons.
3. The cervical flexure is located within the posterior part of the myelencephalon.

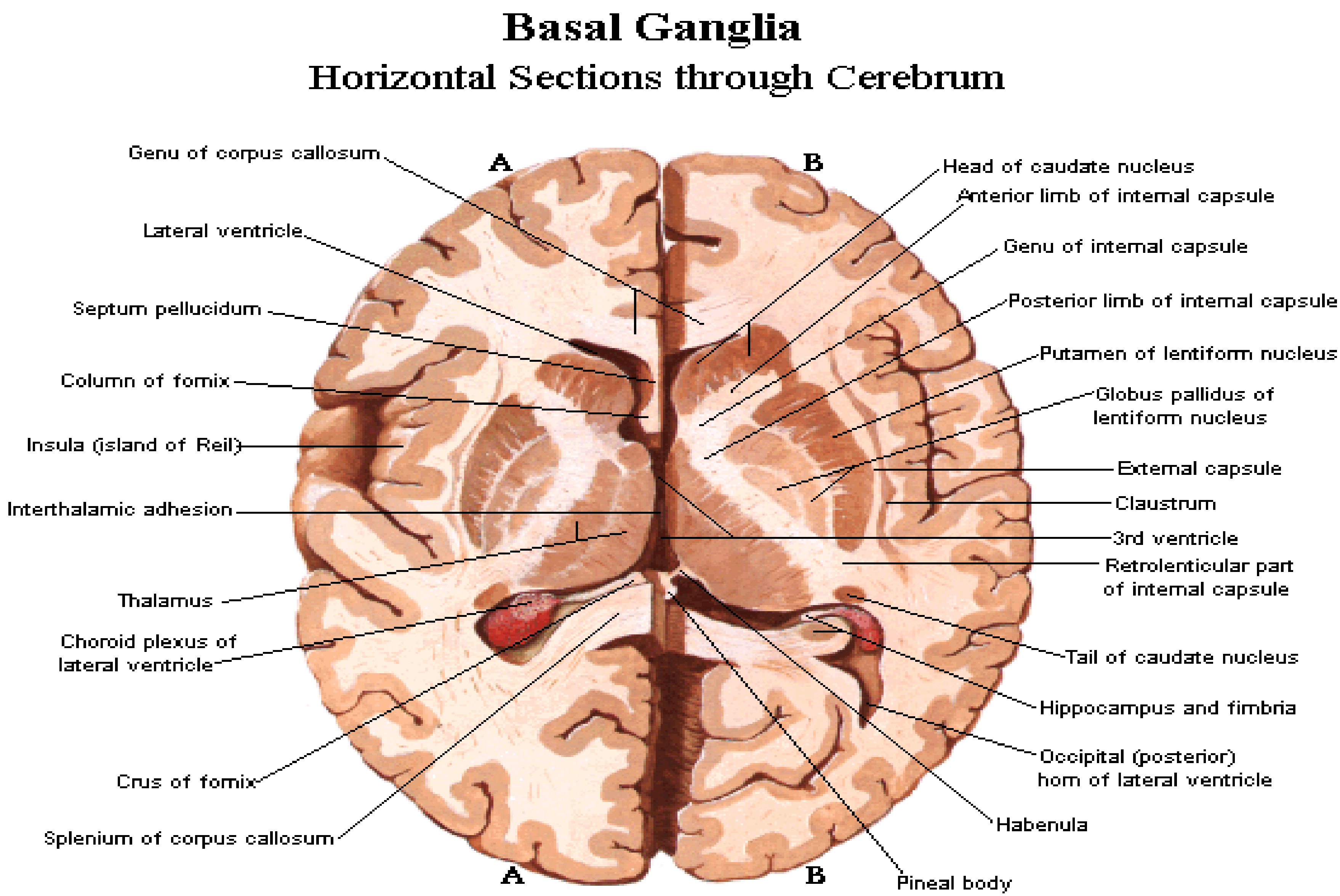
- The brain can also be divided into the following: **Brainstem**, **Cerebrum** and **Cerebellum**
- The central axis of the brain is the brainstem and the first to be formed during ontogeny.

- It is the least variable and the one that is most similar to the spinal cord in structure.
- Part of the metencephalon, all of the diencephalon, mesencephalon and myelencephalon are included in the brainstem.
- Adult mesencephalon is the midbrain, adult myelencephalon is the medulla oblongata.
- The cerebellum and the pons are adult derivatives of the metencephalon.
- The cerebrum is the adult derivative of the telencephalon.

The Brain(Human)



Brain


Basal Ganglia
Horizontal Sections through Cerebrum
A
B
A
B
Genu of corpus callosum
Lateral ventricle
Septum pellucidum
Column of fornix
Insula (island of Reil)
Interthalamic adhesion
Thalamus
Choroid plexus of lateral ventricle
Crus of fornix
Splenium of corpus callosum
Head of caudate nucleus
Anterior limb of internal capsule
Genu of internal capsule
Posterior limb of internal capsule
Putamen of lentiform nucleus
Globus pallidus of lentiform nucleus
External capsule
Claustrum
3rd ventricle
Retrolenticular part of internal capsule
Tail of caudate nucleus
Hippocampus and fimbria
Occipital (posterior) horn of lateral ventricle
Habenula
Pineal body

Diencephalon

- The dorsal part of the diencephalon is the epithalamus.
- The most anterior part is the anterior choroid plexus of the 3rd ventricle.
- Posterior to the plexus is an invagination (the paraphysis) does not mature in man.
- Next is a pair of elevated thickenings, the habernular nuclei.
- Behind the harbenulae are 2 evaginations, the parietal organ and the pineal body.

- The lateral wall of the diencephalon is the thalamus.
- The 2 thalami are separated from one another by the 3rd ventricle and partly boarded by the lateral ventricles.
- Each thalamus is a compact oblong mass of many nuclei.
- Ventral cluster of nuclei project motor fibres posteriorly in the brain.
- The dorsal cluster of nuclei projects sensory pathways to the cerebrum.

- The **hypothalamus** is the ventral part of the diencephalon.
- It contains about a dozen pairs of nuclei which control **autonomic** functions of the body eg. Water balance, temperature regulation, appetite digestion etc.
- On the ventral side of the hypothalamus is the optic chiasma.
- Here optic nerves converge, with partial decussation before continuing as optic tract.

The Hindbrain-metencephalon and myelencephalon

- The myelencephalon is represented by the medulla oblongata.
- It merges with the spinal cord.

Cerebellum

- The cerebellum is the most conspicuous feature of the hindbrain.
- Function: controls motor coordination and maintenance of equilibrium.
- It does not initiate motor activities, but processes those initiated in other parts of the body.

- The size of the cerebellum is coordinated with the activities of the striated muscles.
- It is relatively larger in fishes because of their swimming activities.
- In primitive vertebrates, the cerebellum has 2 parts:

1. Archicerebellum, whose inputs come from the ear and lateral line system.

2. Paleocerebellum, whose inputs come from proprioceptors (muscle sense)organs of the trunk and limbs.

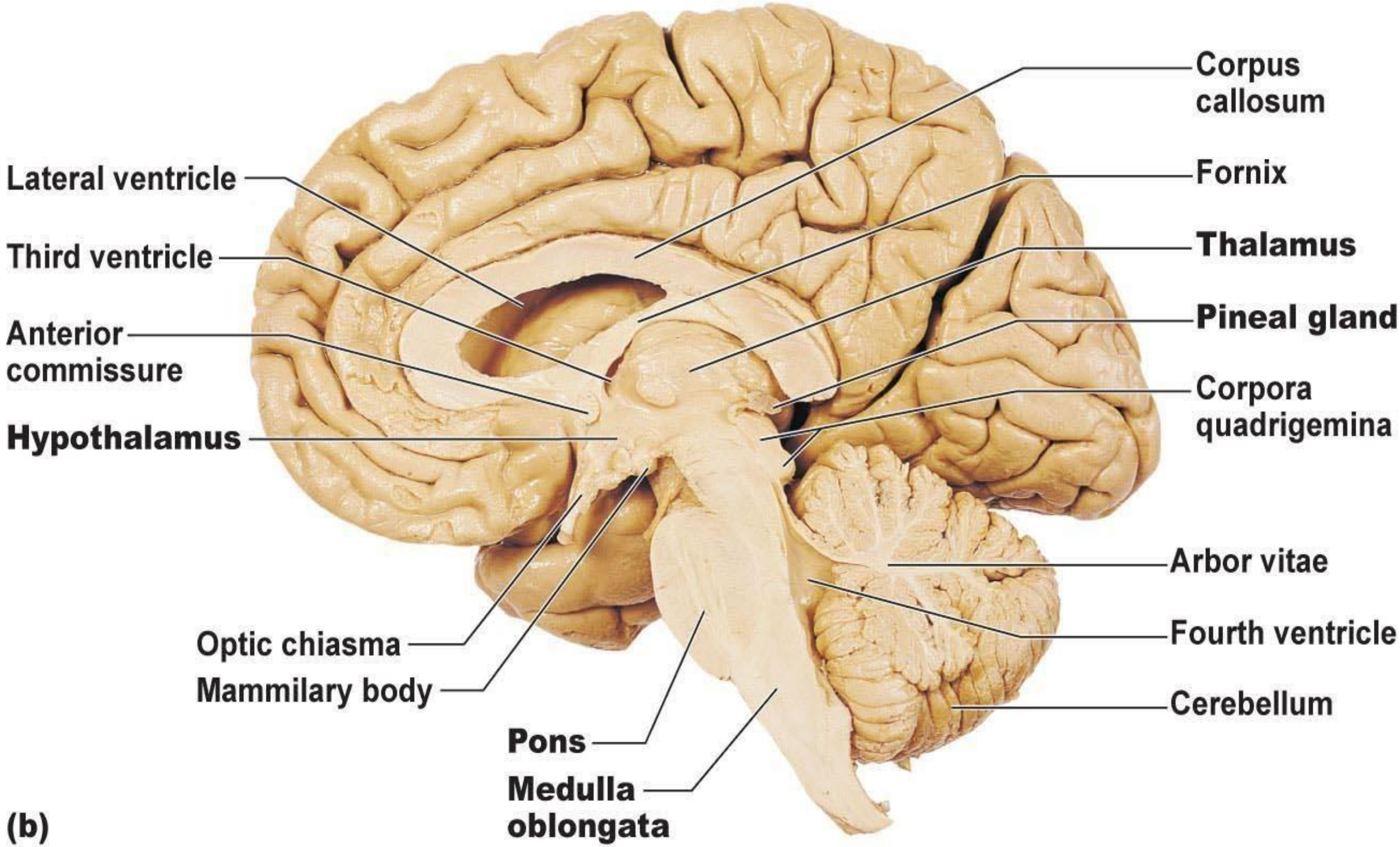
- This part of the cerebellum is important for the maintenance of posture.

- With the evolution of amniotes, the appendicular muscles became more prominent.
- The cerebral cortex became larger and the cerebellum responded by evolving a neocerebellum.
- This pushed the paleocerebellum to the side, where in mammals it formed the hemispheres.

Mesencephalon

- The roof of the mesencephalon has a pair of prominent optic lobes in all vertebrates.
- These receive impulses from the retina.
- It is large in birds that rely on visual stimuli for information about their environment.

- A pair of auditory lobes lie posterior to the optic lobes.
- The four lobes jointly constitute the **corpora quadrigemina.**
- The ventricle in the midbrain is large in fishes and amphibians.
- In these animals, the ventricle extends into the optic lobes as the optocoel.
- In higher vertebrates, the optic lobes are not hollow.
- The midbrain ventricle is constricted to a narrow canal known as the cerebral aqueduct or aqueduct of Sylvius.



(b)

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Telencephalon

- This consists of the cerebral hemipheres and the rhinencephalon i.e olfactory bulbs, tracts and the lobes.
- In fishes the olfactory lobes are as prominent as the cerebral hemispheres.
- The cerebral hemispheres of reptiles and birds are larger than those of lower vertebrates.
- In mammals they have grown forwards over the rhinencephalon.
- The large size of the hemisphere goes with their dominant role in mammalian behaviour.

- With the exception of actinopterygians, the neurocoel of the telencephalon consists of a pair of lateral ventricles.
- Each ventricle is continuous with the 3rd ventricle through an interventricular foramen.
- The rhinencephalon differentiates at the anterior end of the telencephalon.
- It consists of olfactory bulbs, olfactory tracts and olfactory lobes.
- It is rudimentary or regressed in many marine mammals and poorly developed in many birds

Cerebral Hemispheres

- The anterior end of each hemisphere is the olfactory bulb which receives the olfactory nerves.
- The remainder of the hemisphere is divided into 2 parts: the **corpus striatum-** ventral in position and the **pallium** which forms the roof and sidewalls of the cerebrum.

The corpus striatum has 3 principal parts:

1. Archistriatum 2. Paleostriatum 3. Neostriatum

2. Pallium – made up of 3parts:

Paleopallium, Neopallium, Archipallium

- Except in actynopterygians and mammals, the paleopallium is lateral to the ventricle.
- Achipallium is dorsal or median to the ventricle.
- Neopallium may be between the other parts or ventral or lateral to the ventricle.

Comparative anatomy of the Brain

- In cyclostomes, the brain is primitive, the anterior part is short.
- The olfactory bulbs are separated by a shallow constriction from the cerebral hemisphere.
- Parietal organ, pineal body and harbenular are visible in the roof of the diencephalon.

- Optic lobes are evident in lampreys and hagfishes
- Cerebellum is rudimentary, as would be expected in these sluggish parasitic animals.
- In elasmobranchs, the brain is much advanced than that of the cyclostomes.
- Olfactory bulbs are large, widely separated and enclose an extension of lateral ventricles.
- The cerebral hemispheres are joined in the midline and share a common ventricle.
- Corpus striatum and palium are well developed.
- In the diencephalon are pineal body, harbenular, choroid plexus, thalamus and hypothalamus.

- In fishes the optic lobes are prominent and surround an expansion of the midbrain ventricle.
- The cerebellum tends to be large in active species and contains an expansion of the 4^{th} ventricle.
- Archicerebellum and paleocerebellum are clearly distinguished.

Amphibians

- The brains of amphibians is more advanced than that of fishes.
- Cerebral hemispheres are more separated from one another than in fishes and so they share little common ventricle. The corpus striatum is small

- The epithalamus is like that of fishes except that the pineal body is well developed in anurans
- The dorsal thalamus is beginning to enlarge
- The optic lobes are of moderate size in anurans and small in the Urodela
- The cerebellum is rudimentary

Reptiles

- The brain is long, narrow, almost straight
- Olfactory bulbs tend to be smaller than that of fishes
- The cerebrum is large due to the expansion of the corpus striatum and neopalium
- The parietal organ is functional in lizards

- The dorsal thalamus is larger and more complex than in lower classes of vertebrates
- The ventral thalamus has all the nuclei that are recognized in mammals
- The optic lobes are large, giving the reptiles excellent vision
- The midbrain still encloses a ventricle
- The cerebellum is present and is largest in the swimmers and rudimentary in the snakes

Birds

- Birds have relatively large, short and broad brain
- The olfactory bulbs and tracts are prominent in the scavengers, but generally they are smaller than in other vertebrates
- The cerebral hemisphere is surpassed in size only by that of some mammals
- The dorsal thalamus is even more developed than in reptiles
- Optic nerves, chiasma and tracts are large and the optic lobes are particularly large
- They have connections to all sense organs and with the cerebrum

- The cerebellum is larger than in other vertebrates except in some mammals
- Neocerebellum is very prominent because of its relation to flight
- Related to the marked development of the cerebellum is the appearance of pons under the brainstem

Mammals

- The olfactory bulb and tracts range from large (anteater, aardvark) to very small (primates)
- Corpus striatum is prominent even though it is smaller than that of reptiles and birds

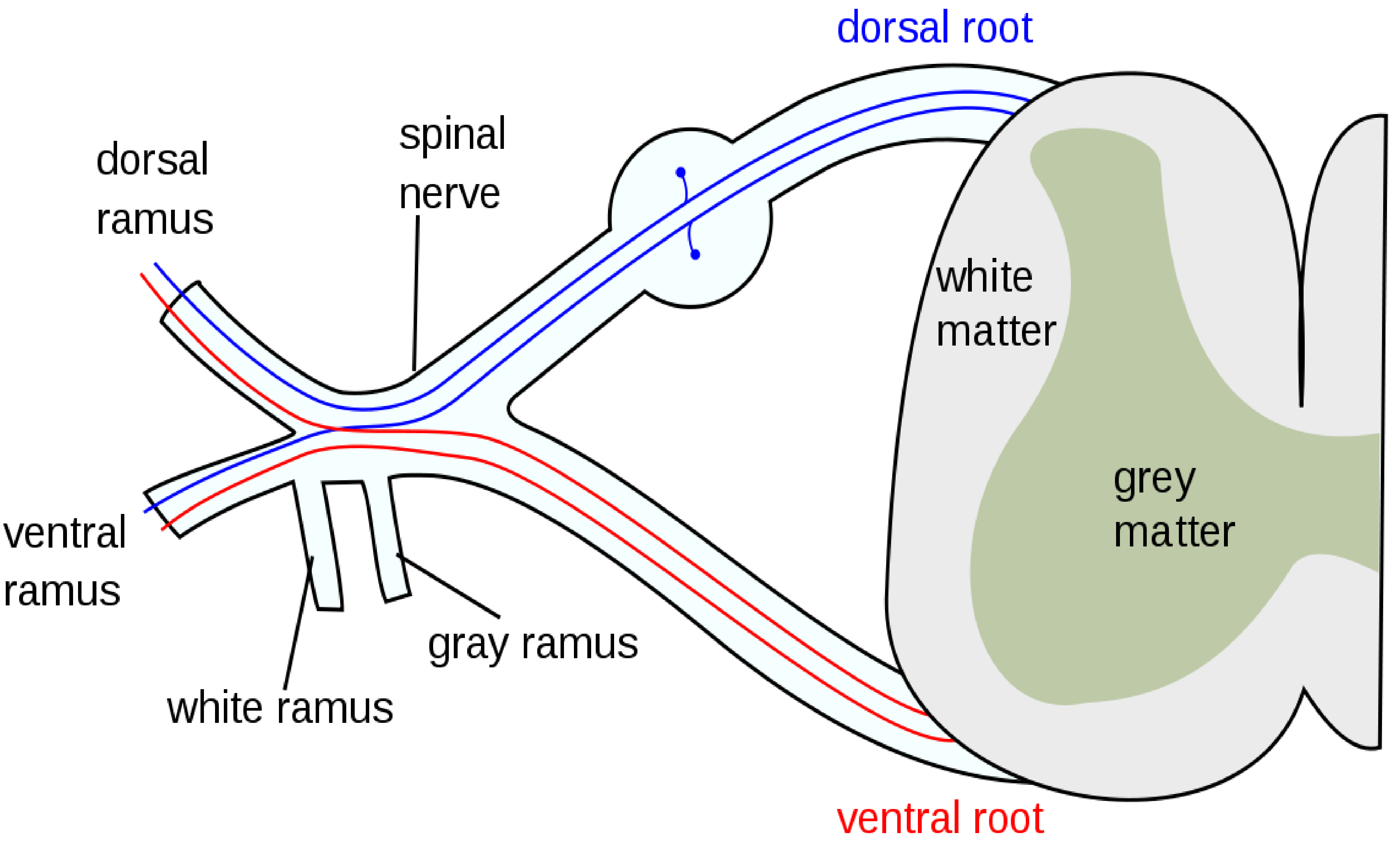
- Neopallium is large and dominates the brain both in structure and function
- The hemispheres are smooth in small mammals and convoluted in most large mammals
- A commissure (tract), the corpus callosum joins the hemispheres of eutherian mammals
- The thalamus and hypothalamus are highly differentiated
- The optic lobes are small because the cerebral cortex has taken over much of their functions
- The ventricle of the midbrain has been reduced to a narrow cerebral aqueduct
- In mammals, the cerebellum is large, much

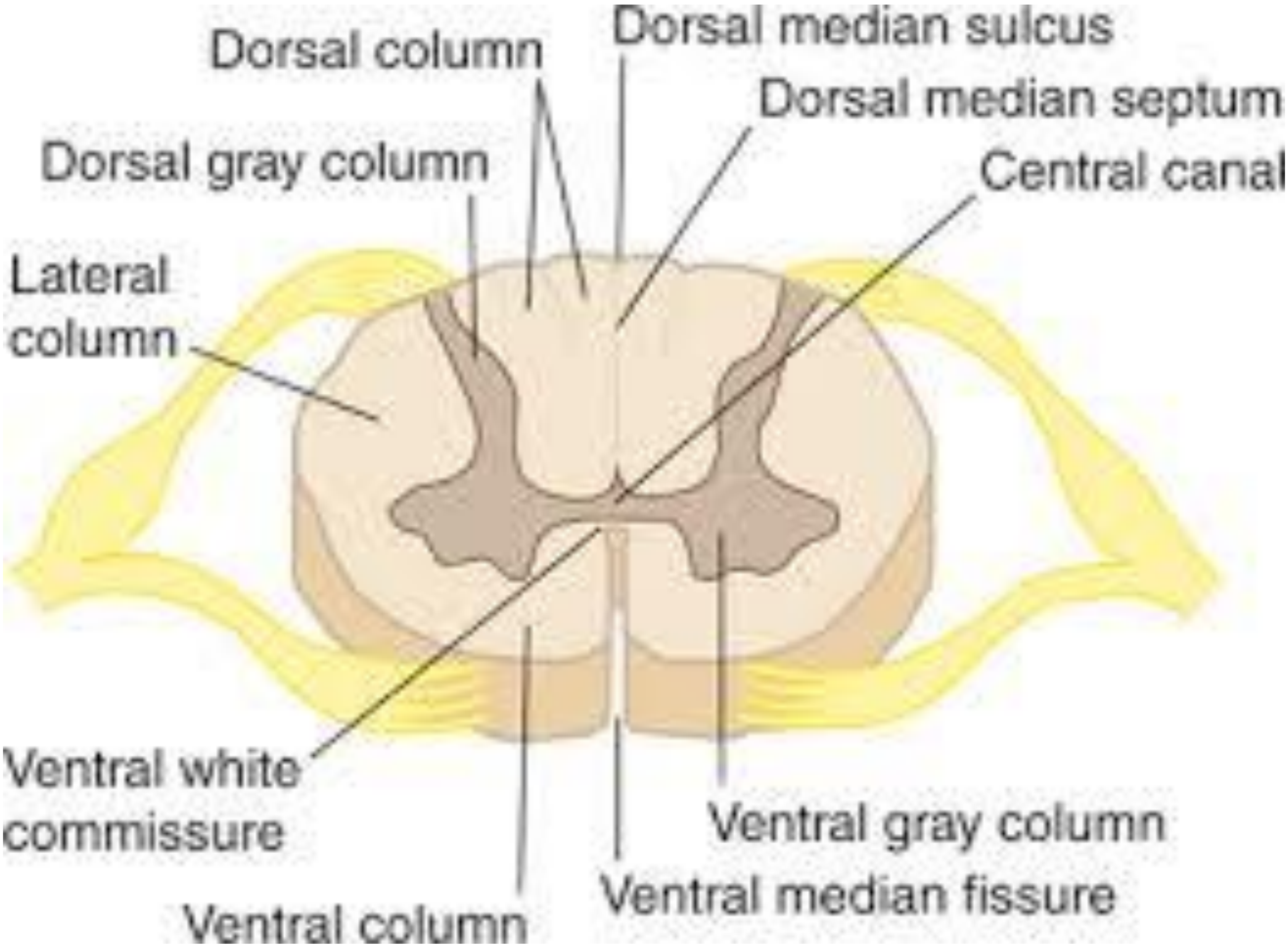
- convoluted and broad
- The neocerebellum has pushed the paleocerebellum to the sides where it forms the lateral hemispheres
- A pons is always present

Spinal cord

- In cross section the embryonic neural tube has 3 layers:
- From the neurocoel outward, ependymal, mantle and marginal areas.
- Some of the cells of the ependymal layer remain in place to become the ciliated lining of the adult central canal.

- Most of the cells however join the mantle cells to form both the neurons and neuroglia.
- These would be the gray matter of the adult cord.
- The marginal layer forms neuroglia and becomes the white matter of the cord.
- As the cord grows in diameter, it enlarges in every place except at the roof and floor of the neurocoel.
- Growth establishes surface grooves at the roof and floor of the neurocoel.
- These are known as dorsal median sulcus (furrow) and ventral median fissure (split)


dorsal root
spinal nerve
dorsal ramus
white matter
grey matter
ventral ramus
gray ramus
white ramus
ventral root


Dorsal column
Dorsal median sulcus
Dorsal median septum
Dorsal gray column
Central canal
Lateral column
Ventral white commissure
Ventral gray column
Ventral median fissure
Ventral column

- The general structure of the cord is best exemplified by a cross section of the cord of an amniote.
- The gray matter is internal, resembles the letter H
- The upper arms of the H are the dorsal gray columns (horns)
- The shorter, broader lower arms are the ventral gray columns (horns)
- The gray commisure, just above and below the central canal makes up the cross arm of H
- It transmits fibres from one side of the cord to the other.

White matter

- This is divided into right and left sides by the dorsal gray median sulcus and ventral median fissure
- Each half is further divided by the gray columns into 3 funiculi
- **The dorsal funiculus** is between the dorsal column and dorsal median sulcus
- **The ventral funiculus** is between the ventral fissure and ventral column
- **The lateral funiculus** is between the dorsal and ventral columns

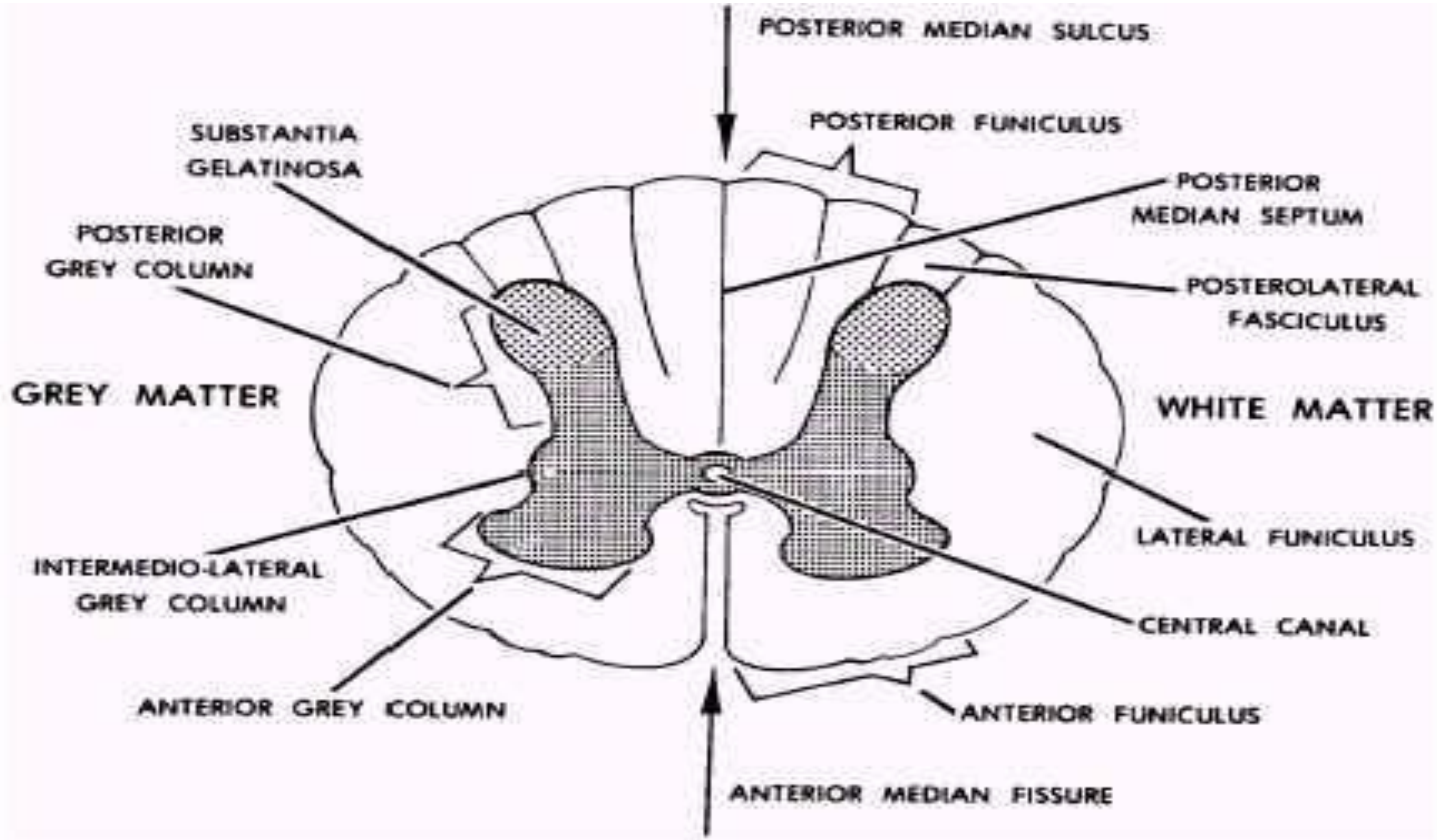


Figure 11-6. A cross-section of the spinal cord.

Comparative A*n*atomy

- In Amphioxus, the spinal cord is primitive because the neural folds do not completely fuse.
- Cyclostomes, like other vertebrates complete the neurulation process to enclose a central canal.
- There is no sharp boundary between the gray matter and the white matter.
- The cord is wide and its ventral surface is concave where it fits against the notochord.
- The spinal cord of other fishes and amphibians is sub circular in cross section with distinct white and gray matter.
- Ventral gray columns are evident.

- Dorsal median sulcus and ventral median fissure are first seen among these animals
- Amniotes have a deep sulcus and fissure.
- The cord enlarges opposite the appendages.
- The cervical enlargement is large if the pectoral appendages are large (bats, apes)
- The lumbar enlargement is more pronounced if the pelvic appendages are large.
- In cross section the gray matter is shaped like the letter H, with thick arms.
- The spinal cord of mammals have dorso-lateral and ventro-lateral sulci.

CIRCULATORY SYSTEM

- The circulatory system is the first of all the organ systems to become functional during ontogenic development.
- The first indication of the formation of the circulatory system is the appearance on the yolk sac of isolated masses of mesoderm called blood islands.
- The peripheral cells of adjacent islands form a network of tiny blood vessels.
- The deeper cells separate from one another to become blood cells.

- The vertebrate circulatory system has two components: 1. a blood vascular system 2. lymphatic system.
- The blood vascular system consists of the heart, blood vessels and blood.
- The blood vessels are arteries, veins and capillaries.
- Arteries distribute blood from the heart to the tissues and veins return blood from the tissues to the heart.
- Arterioles are joined to venules by capillaries which form a network within tissues.
- Capillaries are usually about 1 mm long, scarcely larger in diameter than a single red blood cell.

- Exchange between blood and tissues takes place through their thin walls.
- The blood vascular system is continuously within ducts and is therefore said to be a closed system.
- However, fluid constituents of the blood leak out of the capillaries by diffusion, osmosis and the hydrostatic pressure produced by the heart.
- This forms the tissue fluid which later enter the lymphatic capillaries where they constitute lymph.
- Lymph passes slowly into larger lymphatic vessels until it is discharged into the venous system.
- Lymphatic capillaries in the gut are called lacteals.
- Lacteals absorb digested fats.

- Histologically arteries, veins and capillaries are initially undistinguishable.
- Each tube is formed from thin endothelial cells, loosely covered on the outside in a network of connective tissues (this is the structure of a capillary)
- Arteries and veins have retained these tissues as the **tunica intima** and have added more peripheral tissues as they mature.
- Arteries develop a thick tunica media consisting of smooth muscle fibres.
- In the largest arteries, it consists of yellow elastic fibres

- The structure of arteries is completed by a thinner tunica externa.
- Veins are usually larger in diameter and thin-walled than arteries.
- The tunica media is thin and may not be distinct.
- The tunica externa, by contrast is as thick or thicker than that of arteries.
- Lymphatic capillaries resemble blood capillaries but they are larger, more irregular and more permeable.
- Their endothelial cells are relatively large.
- Lymphatic vessels are constructed like veins, but three layers are less distinct.

- The embryonic heart when first established has 2 layers; an internal endocardium and a thicker outer epimyocardium
- The endocardium corresponds to the tunica interna of an artery or vein, but the mature heart has a thicker layer of elastic connective tissue under the endothelial layer.
- The epimyocardium matures into a myocardium and an epicardium.
- The myocardium or the heart muscle is an enlargement of the tunica media of arteries.
- The epicardium corresponds to the tunica externa but differs in being a serous membrane.

- The heart muscle (cardiac muscle) resembles skeletal muscle in being organized into fibres which have striated myofibrils.
- It however differs from skeletal muscle because the fibres branch and recombine, the nuclei are central rather than peripheral and have intercalated discs which interrupt the myofibrils, dividing the fibres into cell areas.
- Other characteristics of cardiac muscle are its ability to beat and conduct stimulus on its own.
- In the adult heart the beat is initiated at a locus called the ‘pacemaker’
- The beat is conducted to all the chambers in a

co-ordinated sequence by stimulation fibres (Purkinje fibres)

- In the adult heart the beat is also influenced by the autonomic nervous system. **888**

Evolution of the Heart

- Amphioxus has no heart, instead it has a pulsating vessel in the position where the heart evolved in the vertebrates.
- This vessel is similar to the embryonic primordium of the vertebrate heart and is homologous.
- The structure of the adult ancestral vertebrate heart can be inferred from the structure of embryonic heart of descendants.

- It is nearly a straight tube with four chambers.
- There is a thin-walled sinus venosus which receives blood from the great veins.
- It empties it through a sinuatrial valve into the atrium.
- The atrium, also thin walled but muscular pumps blood through the atrioventricular valves into a large thick-walled ventricle which pumps blood into the cornus, which is lined with several rows of semilunar valves.

Single and double circuit Hearts

- In fishes, blood passes from the heart to the gills and from there directly to all parts of the body, after which it is returned to the heart.
- Therefore blood makes a single circuit during which it is pumped, oxygenated, distributed and returned to the pump.
- No blood escapes oxygenation and none fails to enter capillary bed, where oxygen can be released for use by the tissues.
- In species that breathe with lungs rather than gills, a pulmonary circuit carries blood from the heart to the lung and brings back oxygenated blood, after which

a systemic circuit carries the oxygenated blood to all parts of the body and returns oxygen-depleted blood to the heart.

Comparative anatomy

- The heart of cyclostomes and fishes other than Dipnoans vary in structure, but depart little from the general ancestral plan.
- The heart is far forward in front of the pectoral girdle and under the posterior gills
- The sinus venosus ranges from large (most sharks) to small (Cyclostomes)
- It is often irregular in shape

- The heart muscle may be smooth instead of cardiac muscle
- The atrium is relatively large and usually dorsal to the ventricle.
- The inner layer of the ventricle is exceedingly spongy.
- The heart is made up of four chambers: sinus venosus, atruim, ventricle and cornus arteriosus
- Blood flows through these chambers in sequence.
- The heart of sharks is typical of jawed fishes in general.
- The sinus venosus has thin wall, little muscle but much fibrous tissue

- The sinus is capable of contracting, but it is mainly a collecting chamber of venous blood returning from all parts of the body.
- It is filled by suction each time the ventricle contracts and relaxes.
- Blood from the sinus moves through the sinoatrial aperture into the atrium between two one-way valves, as soon as the atrium begins to relax after emptying.
- The atrium is a large thin-walled muscular sac that is a storing area for blood about to enter the ventricle to be taken to the gills.

- From, the atrium, blood passes into the ventricle though the artrioventricular aperture that is guarded by a pair of one-way valves.
- These prevent ventricular blood from being pumped back into the atrium when the ventricle contracts.
- The ventricle has very thick muscular walls and is the actual pumping portion of the heart.
- The anterior end of the ventricle is prolonged as a muscular tube of small diameter, the cornus arteriosus.
- This extends to the extreme cephalic end of the pericardial cavity and continuous with the ventral aorta.

- A series of semilunar valves prevent the backflow of blood into the ventricle.
- Because of its elasticity, it expands with each delivery of ventricular blood and then slowly constricts to maintain a steardy arterial pressure in the ventral aorta so that the flow of blood through the gill capillaries is steardy despite the rhythmicity of the ventricular beat.
- In Teleosts, the cornus is short and has only one set of valves.
- The function of maintaining a steardy flow of blood through the gills is assumed by the bulbous arteriosus which is a muscular expansion of the

- ventral aorta

Transition to double Circuit Pump

- The hearts of Dipnoans (lung fishes) amphibians and reptiles are transitional between single and double circuit pumps
- These animals can survive with such pumps because they are less active than birds or mammals and for most the lungs are not the only respiratory organ
- Some of these animals can adjust the circulation , according to the circumstance to approach either single or double circuit condition

- The modification of the hearts of lungfishes and amphibians are correlated with aerial respiration by means of swimbladders or lungs
- The first modification is that the atrium is partly divided (Dipnoans and Urodeles) or completely divided (Anurans).
- Pulmonary blood from the lungs enters the left chamber whilst systemic blood from the rest of the body enters the sinus venosus which joins the right chamber
- The ventricle is partly divided in Dipnoans and undivided in Amphibians

- Even though the ventricle is single, the spongy nature of its walls reduces mixing of blood
- The cornus is large and no longer contractile
- It is partly divided by the semilunar valves (Anurans) or by a spiral valve which reduces mixing and deflects the two streams of blood into different vessels
- Oxygen-poor blood into aortic arches leading to the gills and oxygenated blood into arches that supply blood to other parts of the body
- A second modification is the formation of a partial interventricular septum in lungfishes or ventricular trabeculae in amphibians that maintain a separation

- of oxygenated and deoxygenated blood from the left and right atria.
- A third modification is the formation of spiral valve in the cornus arteriosus in many Dipnoans and Anurans
- The valves direct oxygen-poor blood into aortic arches leading to the gills or lungs and they direct oxygenated blood into arches that supply other parts of the body
- A fourth modification shortened the ventral aorta in dipnoans and anurans so that it becomes non existence as embryonic development progresses
- As a result, oxygenated and deoxygenated blood,

- kept separate in the heart by the septa, trabeculae or spiral valves moves directly from the cornus arteriosus into appropriate vessels

The Hearts of Amnoites (Double Circuit pumps)

- Adult birds and mammals have completely double circulation:
- A low pressure pulmonary circuit involving the right side of the heart
- A high pressure systemic circuit involving the left side
- The sinus venosus is vestigial in birds and absent in adult mammals, the embryonic sinus having merged with the right atrium

- Thereafter, the vessels that emptied into the sinus venosus empty directly into the right atrium
- The embryonic location of the sinus venosus is marked in adults by a sinoatrial node of neuromuscular tissues
- The right and left atria are completely separated by an interatrial septum
- Nevertheless they are connected during embryonic development through an interatrial foramen called foramen ovale
- This foramen closes at the time of hatching or birth

- The site of the closed foramen is marked in adult mammalian heart by a depression, the fossa ovale
- The right atrium in reptiles receives blood from the sinus venosus
- That of birds and mammals receives blood that earlier in phylogeny and during embryonic development emptied first into the sinus venosus
- The left atrium receives blood from the pulmonary veins
- The two ventricles are completely separated in crocodilians, birds and mammals
- In turtles and squamates, however, the interventricular septum is incomplete, but a special

- Chamber, the cavum venosum minimises or prevents the mixing of oxygenated and deoxygenated blood in the heart
- The ventricular linings of mammals has columns of muscle tissues, the trabeculae carneae that strenghen the walls of the ventricles
- One-way valves guard the passageway from the atria into the ventricles of vertebrates. In Amniotes, each valve consists of one or more fibrous flaps of cusps
- In mammals these flaps are connected by chordae tendineae to papillary muscles that project from the ventricular walls

- During ventricular contraction, the cusps are forced upwards into the atrioventricular passageway preventing the reflux of blood into the atria
- Each valve has one or two cusps in reptiles and birds
- In most mammals, the left valve has two cusps (bicuspid or mitral valve) and right one has three (tricuspid)
- Semilunar valves at the exits of the ventricles into the pulmonary and aortic trunks prevent the backflow of blood into the ventricles as they relax

Lymph and lymphatic System

- Lymph and lymph channels are found in all vertebrates
- The lymphatic system consists of thin-walled lymph channels, lymph hearts, lymph nodes and lymph nodules, the largest of which is the spleen
- In contrast to blood, lymph moves in one direction only i.e from the tissues towards the heart
- The lymphatic system commences in lymph capillaries, whose walls are single layered endothelial tubes or in lymph sinusoids
- The capillaries are branching tubes of slightly greater diameter than blood capillaries

- There are constrictions and expansions rather than being of standard diameter
- Capillaries or sinusoids penetrate most of the soft tissues of the body other than the liver and the vernous system
- They are not present in skeletal tissues
- Sinusoids and capillaries collect interstitial fluid
- Once inside the tubes, the fluid is colourless or pale yellow and is called lymph
- This fluid passes from one endothelial lined channel to the next and finally into a vein
- There are valves at the exits to prevent the influx of venous blood into the lymph channels

- In higher vertebrates, the lymphatics in the small intestine collect absorbed fats after a meal
- In a particularly fatty meal, the lymph in these vessels has a milky appearance, called lacteals and the lymph within is called chyle