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Department of Biology

Theoretical
Comparative Anatomy of Chordata
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المرحلة الرابعة ـ الدراستين الصباحية والمسائية
الفصل الدراسي الثاني

تدريسي المادة :

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The vertebrate body

Comparative anatomy today is the study of structure, of the functional significance of structure, and of the range of variation in structure and function in different species. Its methods are descriptive and experimental. The data are employed partly to attempt to deduce the history of the different species on our planet and the environmental conditions under which they rose, flourished, and became extinct. The data also help to satisfy the curiosity of the human mind. Like other scientific disciplines, comparative anatomy has its roots in philosophy, and its aim is enlightenment.

A study of comparative vertebrate anatomy is, in a sense, a study of history. It is the history of the struggle of vertebrate animals for compatibility with an ever changing environment. It is the history of the extermination of the unfit and the invasion of a new territory by those best equipped for survival. It is a study of history, just as is the study of man's conquests, political fortunes, and social evolution

General body plan:

- **Head**
- **Trunk**
- **Tail**
- **Appendages**
- **Bilateral symmetry**
- **Vertebrate characteristics the big four:** Notochord and vertebral, column, Pharynx, and Dorsal, hollow central nervous system
- **Satellite characteristics**
- **Skin**
- **Metamerism**
- **Respiratory mechanisms**

- **Coelom**
- **Digestive organs**
- **Urinogenital organs**
- **Circulatory system**
- **Sense organs**

The big four Chordate characteristics:

Vertebrates constitute a subphylum (Vertebrata, or Craniata) in the phylum Chor- data. They exhibit four definitive structural characteristics:

1. **The presence of a notochord, at least in the embryo**
2. **The occurrence of a dorsal, tubular nervous system**
3. **The presence of a pharynx with pouches or slits in its wall, at least in the embryo**
4. **post-anal tail**

These are chordate characteristics and are found also in protochordates. Other features associated with vertebrates but not necessarily unique among them will be discussed as secondary characteristics.

1-The notochord and vertebral column:

The notochord is the first skeletal structure to appear in vertebrate embryos. At its peak of development it is a rod of living cells located immediately ventral to the central nervous system and dorsal to the alimentary canal extending from the midbrain to the tip of the tail (Fig. 1). During later development the part of the notochord in the head becomes incorporated in the floor of the skull, and, except in agnathans, the part in the trunk 'and tail becomes surrounded by cartilaginous or bony rings called vertebrae. These provide more rigid support for the body than does a notochord alone. A typical vertebra consists of a centrum that is deposited around and within the notochord, a neural arch that forms over the spinal cord, and various processes. In the tail a hemal arch may surround the caudal artery and vein (Figure 2).

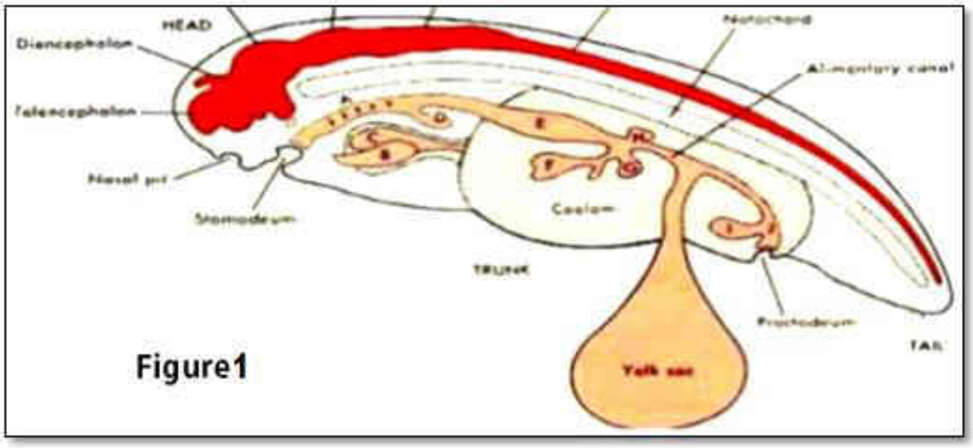


Figure1

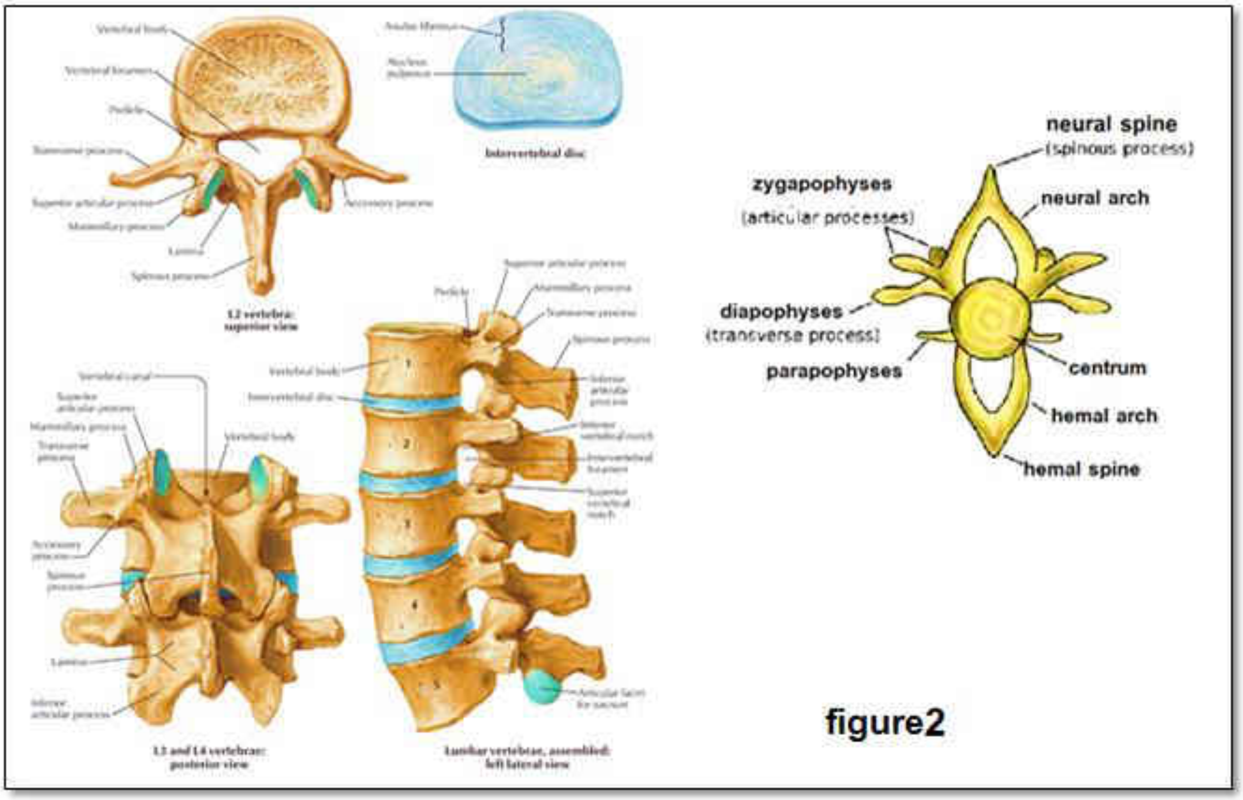


figure2

The fate of the notochord in adult vertebrates is variable. In almost all fishes it persists the length of the trunk and tail, although usually constricted within each centrum (Fig. 3). The same is true in many urodeles and some primitive lizards.

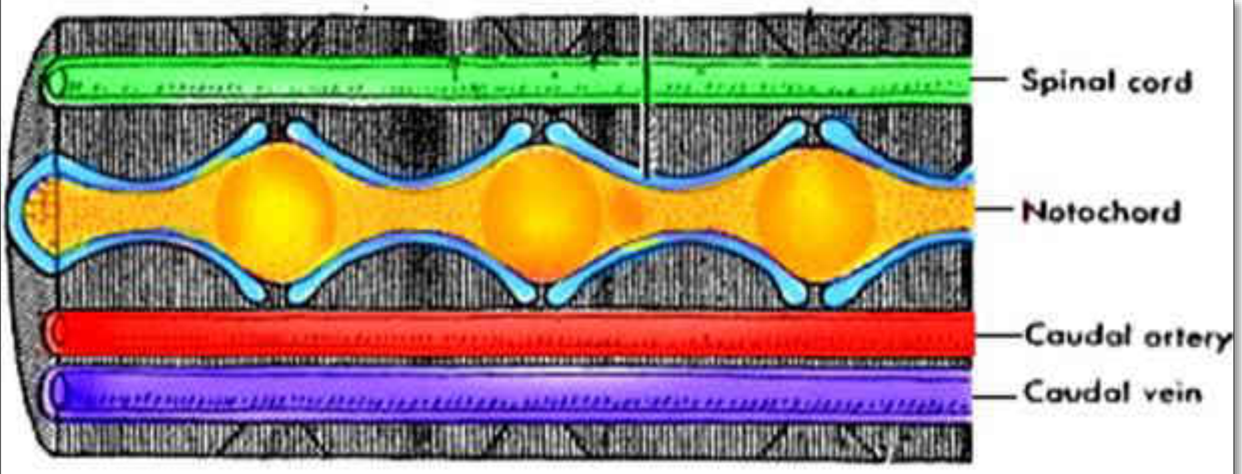
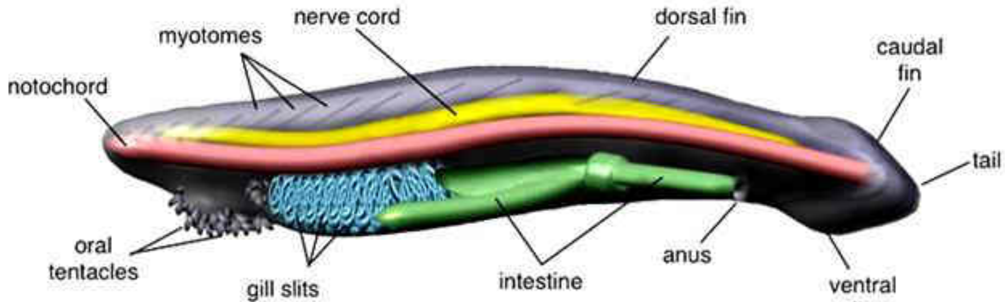


figure3

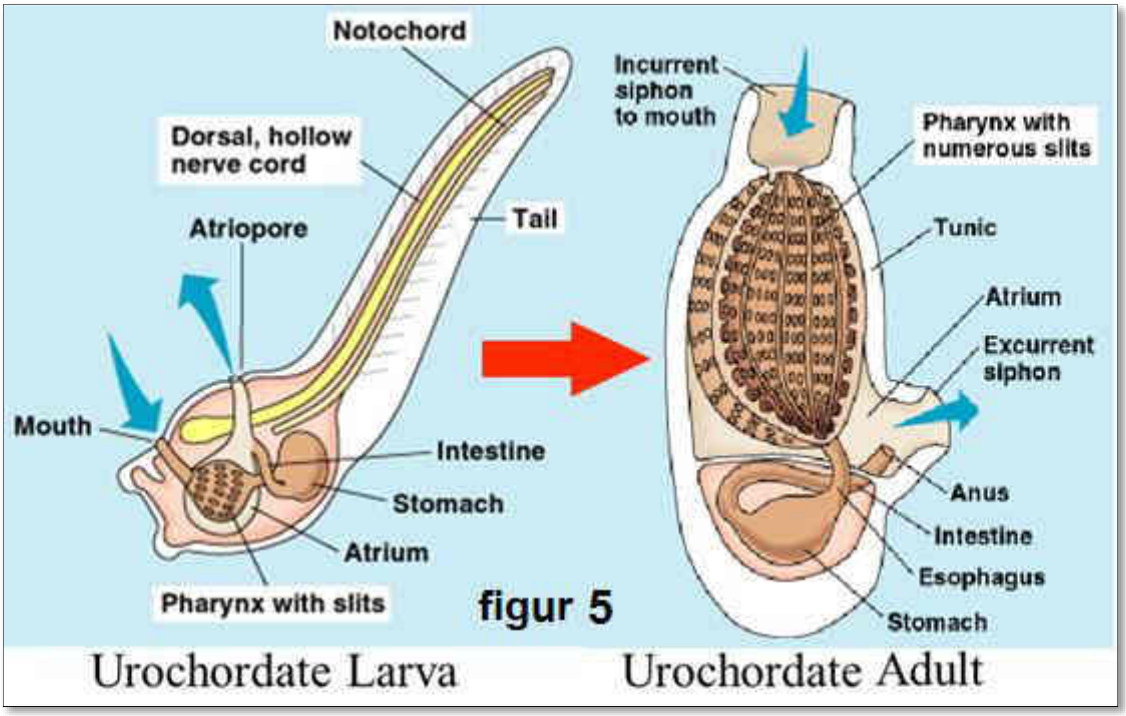
However, in modern reptiles, birds, and mammals the notochord is almost obliterated during development. A vestige remains in mammals within the intervertebral discs separating successive centra (Fig. 2). The vestige consists of a soft spherical mass of connective tissue called the pulpy nucleus. Modern reptiles and birds lack even this vestige.

In protochordates and agnathans the notochord has a different fate. In an amphioxus it continues to grow as the animal grows and never becomes surrounded by vertebrae. Therefore it remains throughout life as the chief axial skeleton (Figure 4).



figur 4

In urochordates the notochord is confined to the tail, and disappears at metamorphosis when the tail is resorbed (Figure 5).



figur 5

In agnathans the notochord grows long with the animal, but paired lateral neural cartilages are perched on the notorchord lateral to the spinal cord (Fig. 6).When a notochord persists as an important part of the adult axial skeleton, it develops a strong outer elastic and inner fibrous sheath (Fig. 7). It is apparent that the notochord has been disappearing as an adult structure in recent vertebrates.

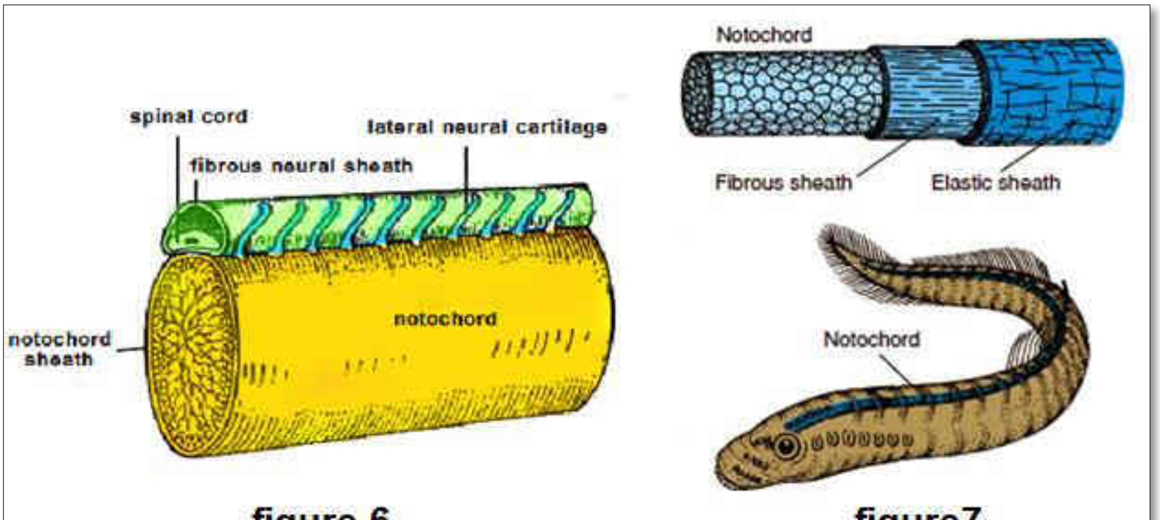


figure 6 figure7

2-Dorsal, hollow central nervous system

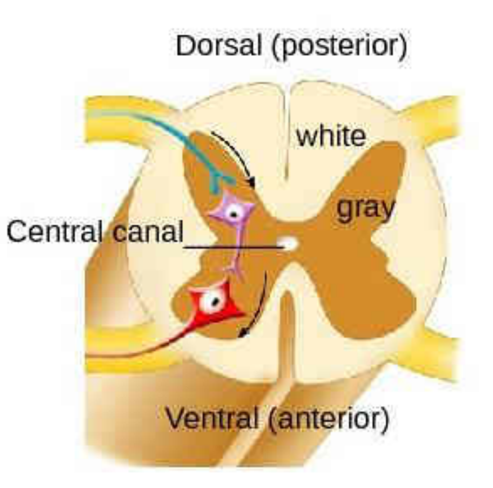


figure 8

The dorsal hollow nerve cord is derived from ectoderm that rolls into a hollow tube during development. **In chordates**, it is located dorsally to the notochord, the nervous system in protostome animal phyla is characterized by solid nerve cords that are located either ventrally and/or laterally to the gut. **In vertebrates**, the neural tube develops into the brain and spinal cord, which together comprise the central nervous system (CNS). The peripheral nervous system (PNS) refers to the peripheral nerves (including the cranial nerves) lying outside of the brain and spinal cord (Figure 8).

3-Pharyngeal slits

The pharynx is the region of the alimentary canal exhibiting pharyngeal pouches in the embryo (Fig. 9& 10). The pouches may rupture to the exterior form pharyngeal slits. These slits may remain throughput life, or they may be temporary. If they remain throughout life, the adult pharynx is the part of the alimentary canal having slits. If the slits are temporary, the adult pharynx is the part of the alimentary canal connecting the oral cavity and esophagus.

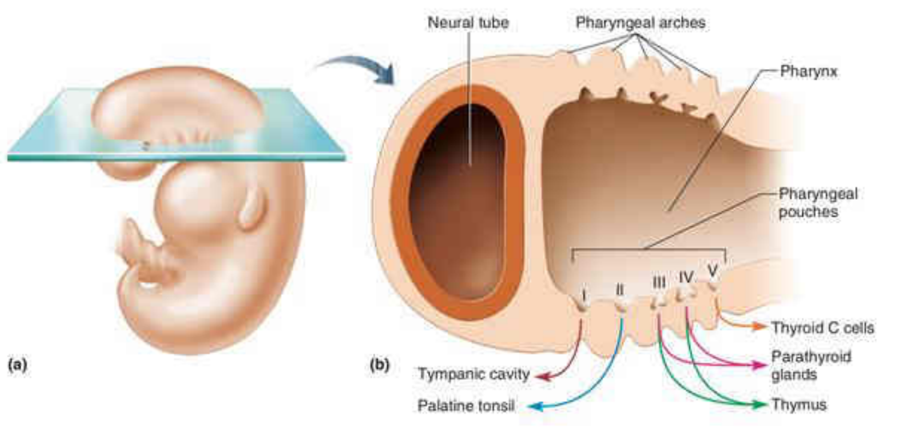
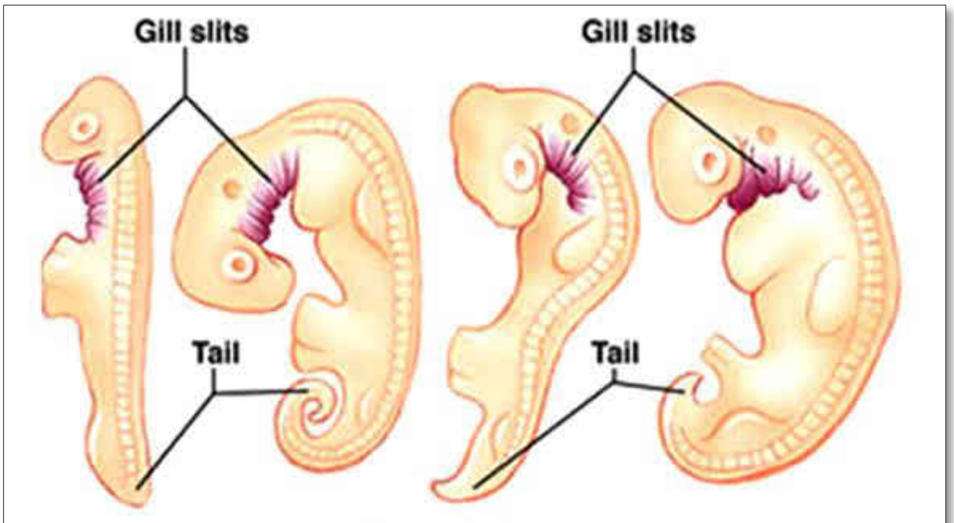


figure 9

4- Post-anal tail

The **post-anal tail** is a posterior elongation of the body, extending beyond the anus. The tail contains skeletal elements and muscles, which provide a source of locomotion in aquatic species, such as fishes. In some terrestrial vertebrates, the tail also helps with balance, courting, and signaling when danger is near. In humans and other great apes, the post-anal tail is reduced to a vestigial coccyx ("tail bone") that aids in balance during sitting (Fig.10).



figere 10

Secondary characteristics:

1-Respiratory mechanisms

Most vertebrates carry on external respiration (exchange of respiratory gases between animal and environment) by means of highly vascularized membranes derived chiefly from the pharyngeal wall or floor. Internal gills are situated in gill pouches opening to the exterior via gill slits. External gills develop as outgrowths from a pharyngeal arch (Fig. 11). Lungs arise from a midventral evagination of the pharyngeal floor. The evagination, called a lung bud, pushes into the coelomic cavity but remains connected with the pharynx by an air duct.

Vertebrates sometimes carry on respiration by other devices such as skin, the buccopharyngeal lining, and (during embryonic life) special extraembryonic membranes that lie just under an eggshell or in contact with the mother's uterus.

2-Coelom

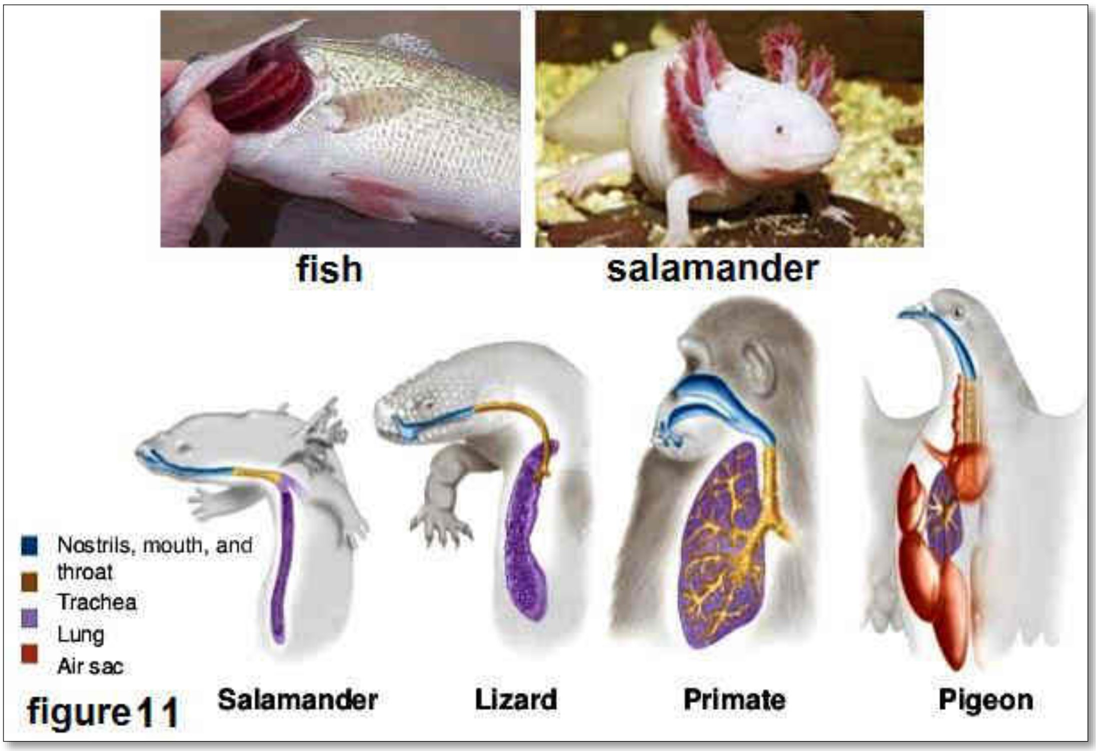


figure 11

Like many invertebrates, vertebrates are built like a "tube within a tube," having a coelom between body wall and digestive tube. The coelom is subdivided in fishes, amphibians, and many reptiles into a pericardial cavity housing the heart and a pleuroperitoneal cavity housing most of the other viscera, including the lungs (Fig. 12). The pericardial and pleuroperitoneal cavities are separated by a fibrous transverse septum. In some reptiles and in birds and mammals the lungs become isolated in separate pleural cavities. The transverse septum is then supplemented by other septa, which may be muscular. In many male mammals, caudal out pocketing of the coelom a fourth subdivision of the coelom.

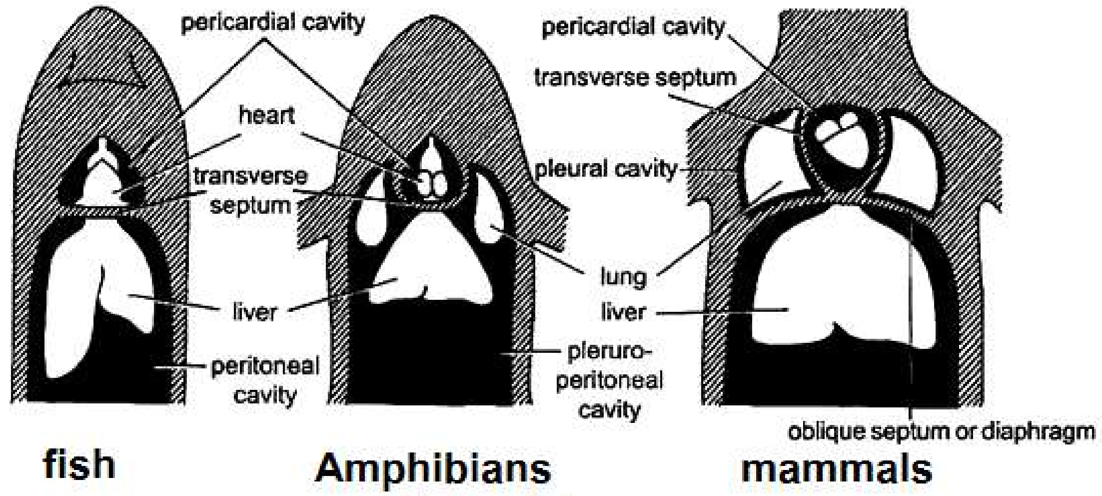

pericardial cavity
heart
transverse septum
liver
peritoneal cavity
fish
Amphibians
lung
pleuro-peritoneal cavity
pericardial cavity
transverse septum
pleural cavity
liver
oblique septum or diaphragm
mammals

figure 12

Integument system (Skin)

Skin is a composite organ - composed of and outer layer or layers of epithelium (the epidermis), and a much thicker inner layer (the dermis) composed of closely packed fibrous connective tissue. The epidermis arises from the single cell layer of the ectoderm while the dermis arises firm the mesoderm of the dermatome. Modifications of the epidermis and dermis involve:

- The relative number and complexity of skin glands
- The extent of differentiation and specialization of the most superficial layer (stratum corneum) of the epidermis.
- The extent to which bone develops in the dermis.
- The skin of an amphioxus exhibits epidermis and dermis, but the epidermis is only one cell thick.

THE EPIDERMIS

The epidermis of most fishes and aquatic amphibians has many skin glands, chiefly mucous, and few .keratinized cells on the surface. Entirely terrestrial vertebrates, on the contrary, have few mucous glands and a thick layer of keratinized cells that constitute a prominent stratum corneum. These conditions minimize the loss of water through the skin. The epidermis has no blood vessels and is nourished by capillaries in the dermis.

Integument in Different Classes of Chordates

1- Protochordata:

In Branchiostoma the skin is simple without keratin. The epidermis is single layered made of tall or columnar cells. Epidermis has numerous unicellular gland cells which secrete a thin cuticle. Dermis (corium) is gelatinous in Amphioxus (Fig.13).

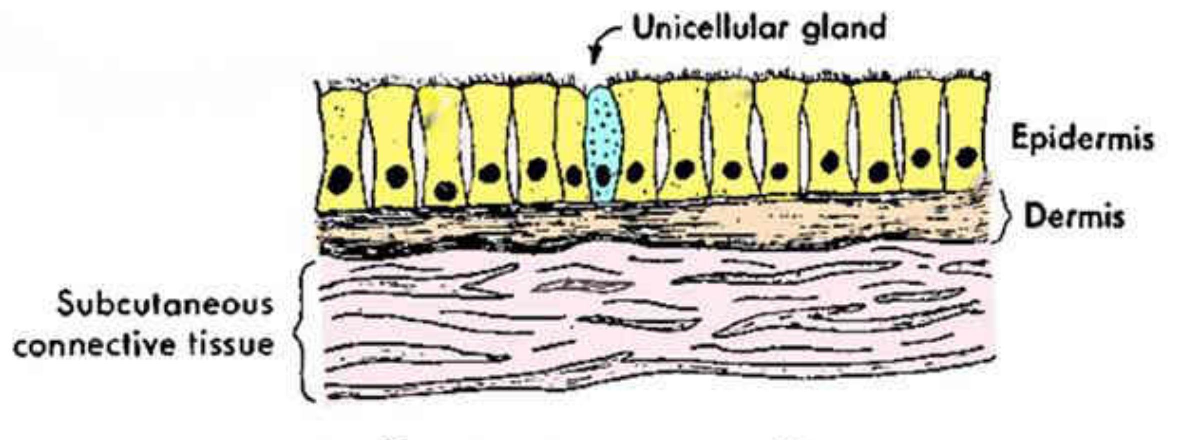


Fig. 13 Skin of a young amphioxus.

2. Cyclostomata:

Epidermis is multilayered (stratified) but has no keratin. It has three types of unicellular gland cells- mucous glands secrete mucous, club cells probably scab-forming cells, and granular cells are of unknown function. Mucous glands are especially advantageous to aquatic species that spend time out of water. Below the epidermis is the cutis formed of collagen and elastic fibers. Star-shaped pigment cells are also present in the cutis. localized areas of the skin sometimes develop cornified structures, although these are relatively few. Conical horny epidermal spines and teeth develop in the buccal funnel and on the tongue of cyclostomes (Fig. 14). These rasping structures are periodically shed.

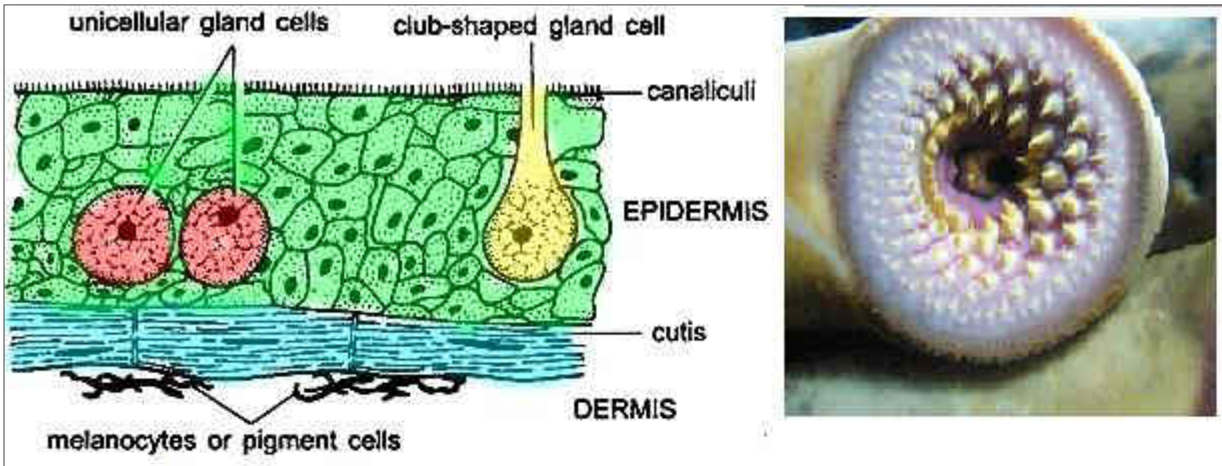


figure 14

3. Pisces:

The epidermis has several layers of simple and thin cells, but there is no dead stratum corneum. The outermost cells are nucleated and living. The stratum Malpighii replenishes the outer layers of cells which have some keratin. Unicellular goblet or mucous gland cells are found in the epidermis, as in all aquatic animals (Fig.15).

The mucus makes the skin slimy reducing friction between body surface and water, protects the skin from bacteria and fungi, and assists in the control of osmosis. Multicellular epidermal glands like poison glands and light producing organs (photophores) may also be found. The epidermis rests on a delicate basement membrane.

The lung fish ***Protopterus*** secretes a cocoon of mucus that it inhabits during the annual dry season, and some teleost mothers secrete nutritious mucus that is eaten by the young offspring.

The dermis contains connective tissue, smooth muscles, blood vessels, nerves, lymph vessels, and collagen fibres. The connective tissue fibres are generally not arranged at right angles, but run parallel to the surface. Scales are embedded in the dermis and projected above the epidermal surface.

Many bony fishes show more brilliant colours than any other group of animals. The colours of fishes are due to chromatophores and iridocytes.

- **Chromatophores:** in the dermis are derived from neural crest cells. They contain pigments which not only produce colours but also cause variations of colours. Chromatophores containing brown or black pigment are known as melanophores and those containing red, yellow, or orange pigment are collectively called lipophores.

Iridocytes or guanophores: are reflecting cells. They have no pigment but contain crystals of guanin. They lie in the dermis and cause irides-cence. Iridocytes reflect light from guanin crystals to produce white or silvery colours if the iridocytes are below the scales, if the iridocytes are above the scales they cause iridescent hues. ByCombinations of chromatophores and iridocytes various colours are produced, e.g., blue is produced by reflection from iridocytes, the blue combines with yellow pigment to produce green.

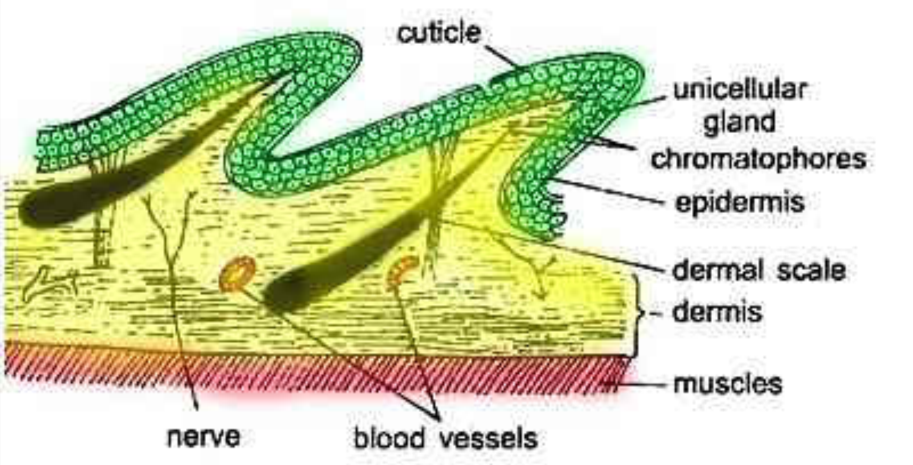


figure 15

4. Amphibia:

The epidermis is multilayered; the outermost layer is a stratum corneum made of flattened, highly keratinised cells. Such a dead layer appears first in amphibians, and is best formed in those which spend a considerable time on land. The stratum corneum is an adaptation to terrestrial life; it not only protects the body but prevents any excessive loss of moisture.

In ecdysis, the stratum corneum is cast off in fragments or as a whole in some. The dermis is relatively thin, it is made of two layers, an upper loose stratum spongiosum and a lower dense and compact stratum compactum. Connective tissue fibres run both vertically and horizontally (Figure 16).

There are two kinds of glands, they are multicellular mucous glands and poison glands in the dermis, but they are derivatives of the epidermis.

- The mucous glands produce mucus which not only forms a slimy protective covering but also helps in respiration.

- The poison glands found in toads as parotid glands produce a mild but unpleasant poison which is protective, keep the enemies away.

In the upper part of the dermis are chromatophores which have black melanophores and yellow lipophores, these produce the colour of the skin.

The ability of the skin for changing colour to blend with the environment is well developed. Skin of labyrinthodontia, the stem Amphibia had an armour of dermal seales. Bony dermal scales are found embedded in the skin of some Gymnophiona (Apoda) and a few tropical toads. These scales are absent in modern Amphibia.

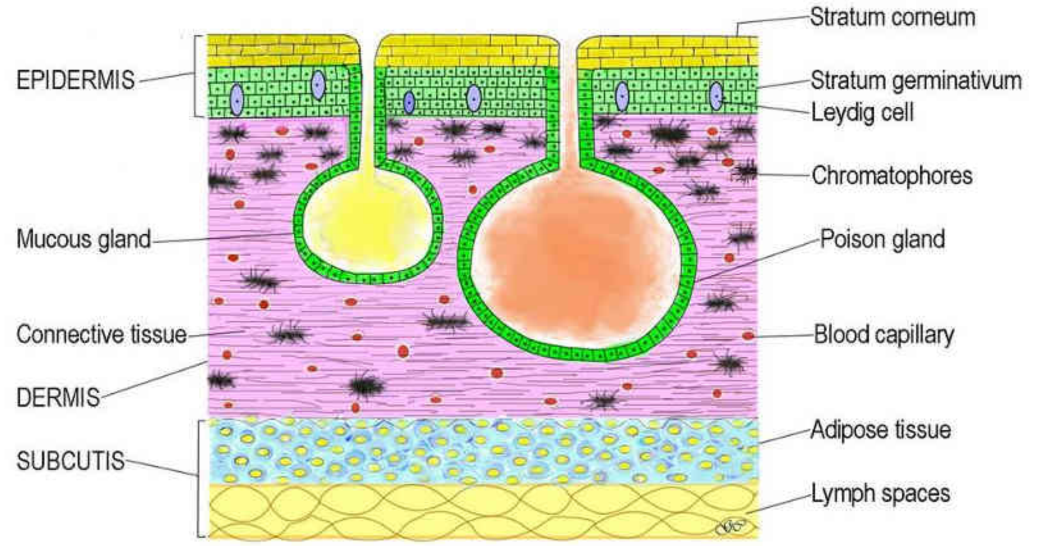


figure 16

4- Reptiles

The integument (Fig. 17) is thick and dry. It prevents any loss of water. It has almost no glands, this is an adaptation to prevent evaporation of water. The epidermis has a well-developed stratum corneum which makes the skin dry and prevents any loss of body moisture, thus, well adapted to a terrestrial life. The epidermis produces horny scales. Scales are shed periodically in fragments or cast in a single slough, as in snakes and some lizards.

The scales often form spines or crests. Below the epidermal scales are dermal bony plates or osteoderms in tortoises, crocodiles, and some lizards (Heloderma). These are retained for life and are not shed off. These may form dermal bones in the skull lying superficially or they may be found in the dermis.

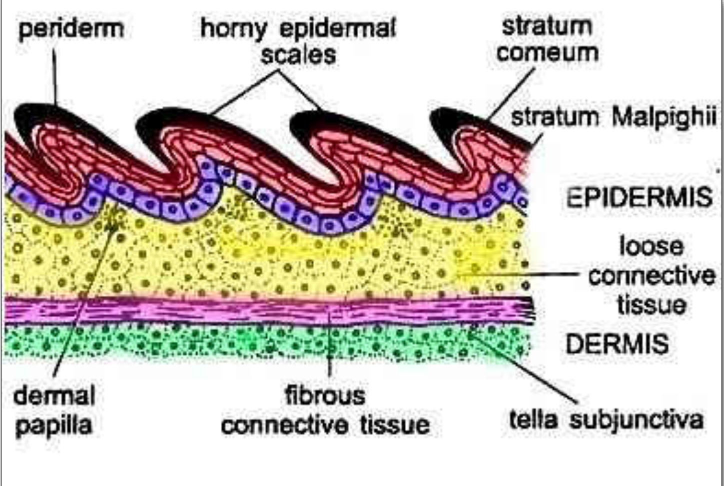


figure17

The dermis is thick and has an upper loose connective tissue layer and a lower layer tella subjunctiva and separating the two is a horizontal layer of fibrous connective tissue. The upper layer has an abundance of chromatophores in snakes and lizards like fishes and amphibians. Leather of high commercial value is made from the skin of lizards, snakes, and crocodiles.

Reptiles essentially lack skin glands. Many lizards have glands near the cloaca. Their openings called femoral or pre-anal pores are generally smaller in female and found only in the male in some species. They are most active in the breeding season. Musk glands in the throat and cloacal opening of crocodilians function during courtship. Generation glands found recently are associated with periodic shedding of the skin.

6. Bird (Aves):

The integument (Fig. 18) is thin, loose, and dry and devoid of glands except an uropygial gland at the base of the tail whose secreted oil is used for preening the feathers, especially in aquatic birds. The stratified epidermis is delicate, except on shanks and feet where it is thick and forms epidermal scales. The claws, spurs and horny sheaths of beaks are also the modifications of stratum corneum of epidermis.

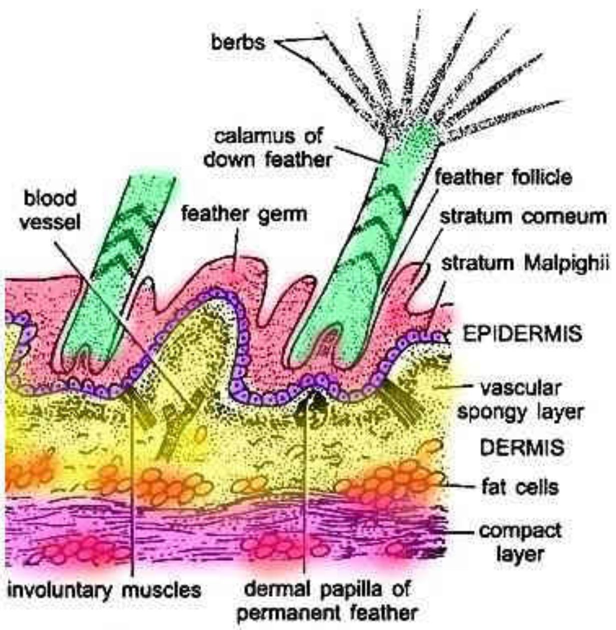


figure 18

The dermis is thin and has interlacing connective tissue fibers, abundant muscle fibers for moving feathers, blood vessels and nerves. The dermis forms an upper vascular and spongy layer and a lower compact layer.

7. Mammals

The skin (Fig.19) is elastic and waterproof and is much thicker than in other vertebrates, especially the dermis is very thick and tough and is used for making leather. The epidermis is thickest in mammals and is differentiated into five layers:

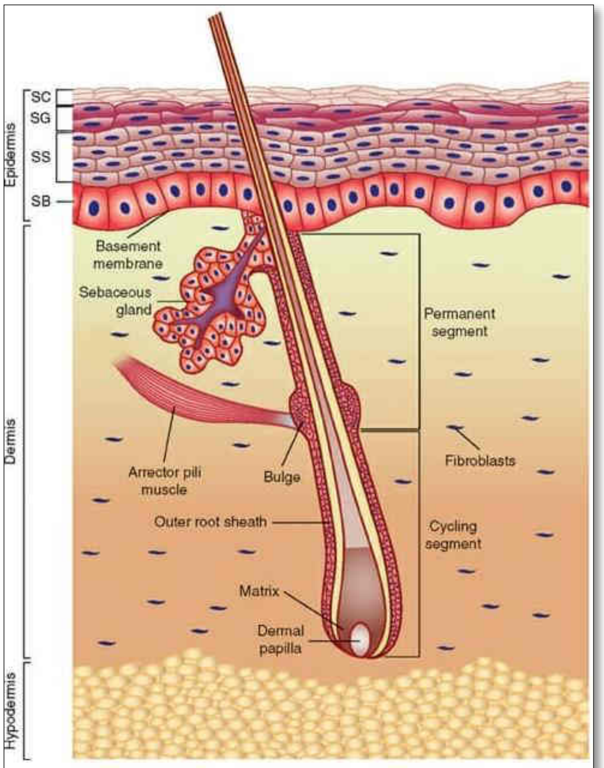


Figure.19

- stratum corneum
- stratum lucidum
- stratum granulosum
- stratum spinosum
- Stratum germinativum or Malpighian layer.

The outer layer of stratum corneum containing keratin, its cells lose their nuclei, but the cells are not dead as believed before. They secrete several hormones, one of which represses the mitotic activities of the Malpighian layer. In places of friction, such as soles and palms, the stratum corneum is very thick.

The dermis is best developed in mammals. The upper part of the dermis in contact with the epidermis is the papillary layer which is made of elastic and collagen fibers with capillaries in between. It is thrown into folds to form rows of dermal papillae, especially in areas of friction. The greater lower part of the dermis is a reticular layer having elastic and collagen fibers.

In both layers there are blood vessels, nerves, smooth muscles, certain glands, tactile corpuscles, and connective tissue fibres extending in all directions. Below the dermis the subcutaneous tissue has a layer of fat cells forming adipose tissue which helps to maintain body heat. In making leather only the dermis is used. Dermal scales are not found in mammals except armadillos.

Glands of skin in Mammals

Mammals have a wide variety of skin glands, but all seem to be variations of two major groups, sudoriferous (sweat) and sebaceous (oil) glands. The types of glands are:

1. Mammary glands

Mammary glands appear to be modified sebaceous glands. Mammary glands arise in both sexes from a pair of elevated ribbons of ectoderm, called **milk lines**, which extend along the ventrolateral body wall of the fetus from the axilla to the groin. Patches of undifferentiated mammary tissue develop along the milk lines, invade the dermis (Fig.20), and then spread under it in the superficial fascia. As development progresses, a nipple forms above each patch. Further development of mammary tissue usually occurs in a circular patch beneath each nipple. As the female mammal approaches sexual maturity (adolescence in primates), rising titers of female sex hormones cause the juvenile duct system to spread and branch.

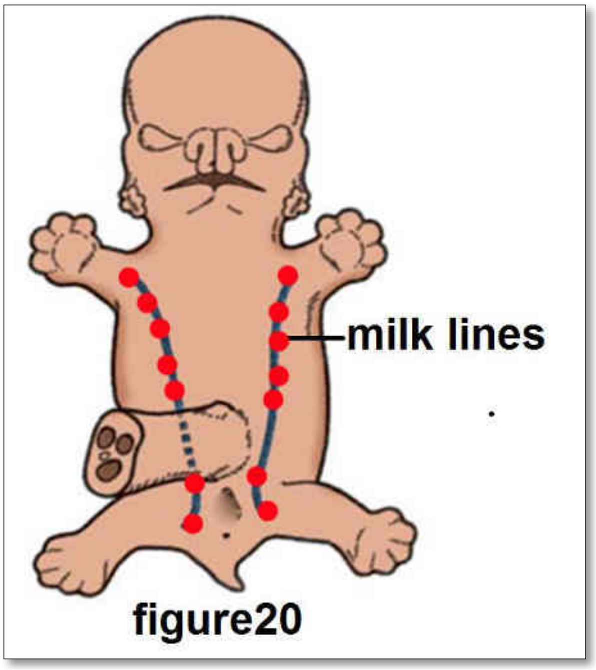


figure20

The distribution and number of mammary:

The distribution and number of mammary glands and nipples vary with the species:

- A single pair of thoracic nipples occurs in apes and man.
- Bats also have thoracic nipples.
- Insectivores and some lemurs have one pair of thoracic and one pair of inguinal nipples. Male lemurs have a nipple on each shoulder
- Flying lemurs and marmosets have a single pair in the armpit (axillary nipples).
- In Cetacea nipples occur near the groin (inguinal nipples), and the baby porpoise or whale holds onto the nipple as the mother swims about in the sea.
- Nutrias have four on the back so that the babies are able to ride along on the mother's back above water while nursing.
- In pigs, dogs, edentates, and many other mammals, a series of axillary, thoracic, abdominal, and inguinal nipples is scattered all along the milk line.

Supernumerary nipples may occur in any mammal, including man. In general, there are sufficient nipples for the number of young in a litter and these are in locations appropriate to the habits of the species.

The teats:

- In true teats (Fig. 21, man) all ducts open at the tip of the nipple as a result of the elevation of the duct-bearing area during development.
- In false teats (Fig. 21, ungulate) the skin around the duct openings becomes elevated, and all ducts empty into one cistern. Suckling young are not concerned about the terminology as long as the teats are provident.
- Monotremes do not develop typical mammary glands or nipples. Instead, in both sexes modified sweat glands produce a nutritious secretion, which is lapped off a convenient tuft of hairs by the young (Fig. 21, monotreme).
- Teats would probably be useless in the duckbill, since it appears doubtful whether the young, hindered by horny beaks and lacking muscular cheeks and lips, could nurse.

- Except during lactation, the teats of the opossum are hygienically stored in expressions within the skin.

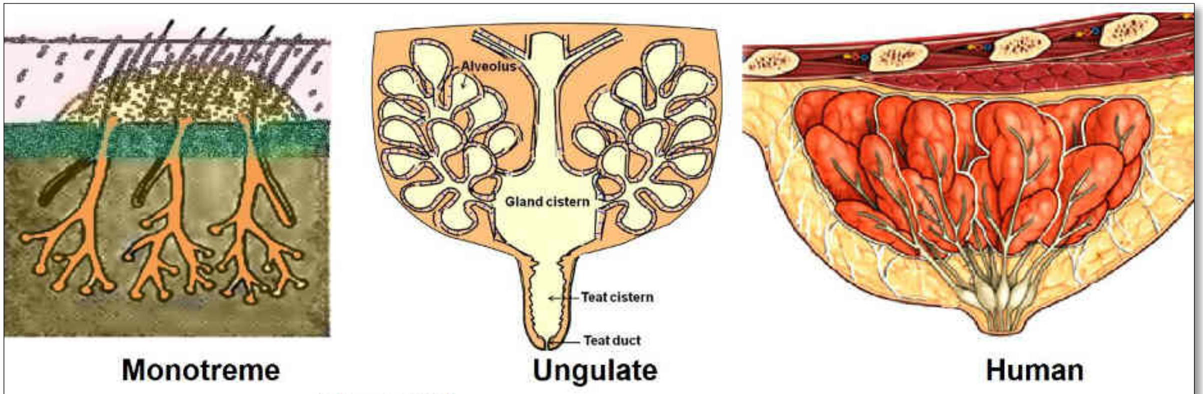


figure21

2-Sudoriferous (sweat) glands:

Sudoriferous (sweat) glands are long, slender, coiled tubes of epidermal cells extending deep into the dermis (Fig.22). Their secretions ooze onto the surface of the skin through tortuous channels that perforate the stratum corneum and open as pores. Sweat glands are widespread among mammals, but they may be absent, as in scaly anteaters and marine mammals. They may occur only on the soles of the feet (cats and mice) or on the toes, lips, ears, back, or head. Man, covered with less hair, has the greatest number of sweat glands per square inch of body surface. The ciliary glands, which open into the hair follicles of the eyelashes and along the margins of the eyelids, are modified sudoriferous glands

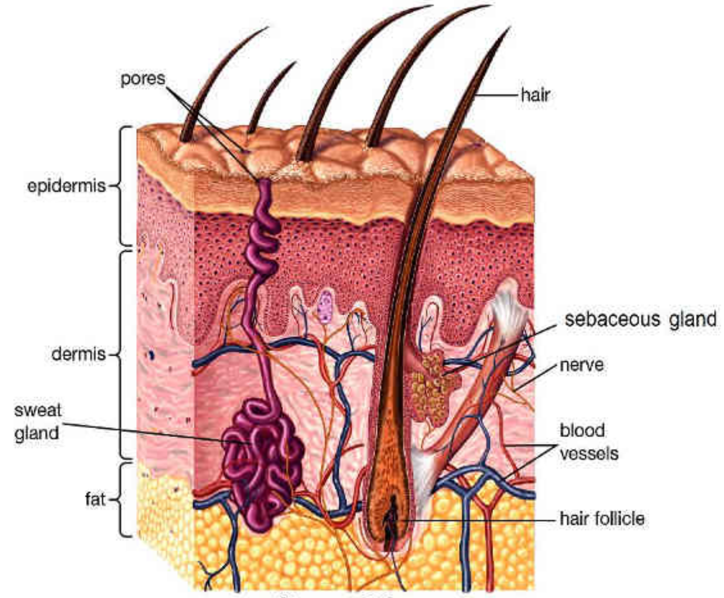


figure22

3. Sebaceous glands

Sebaceous glands secrete an oily exudate, sebum, into the hair follicles (Fig. 22). The oil lubricates the skin. Fur (including human hair) glistens after brushing because of the oil on the hairs. Usually several lands open in association with one follicle, but in some areas they open directly onto the surface of the skin. Marine mammals are practically devoid of hair and do not have sebaceous glands.

4. Ceruminous glands

In the outer ear canal of mammals modified sebaceous glands (ceruminous glands) secrete cerumen (Fig.23), waxy grease. The hairs and the wax trap insects that may otherwise wander deep into the canal and touch the highly sensitive eardrum.

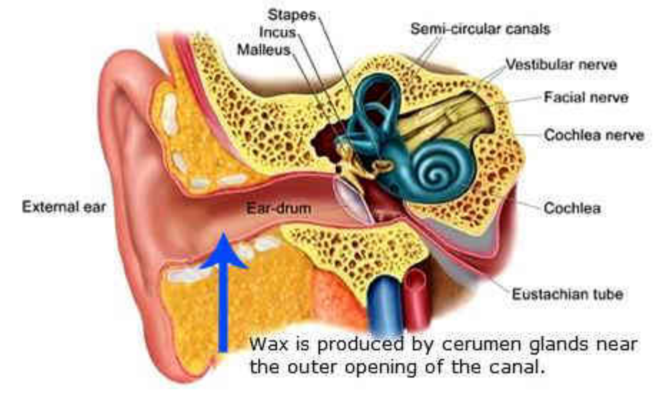


figure23

5. Tarsal (meibomian) glands

Meibomian glands are modified sebaceous glands that are arranged vertically within the tarsal plate. Tarsal (meibomian) glands secrete oil onto the conjunctiva of the eyeball. They are embedded in a dense connective tissue plate, the tarsus, in each eyelid (Fig.24).

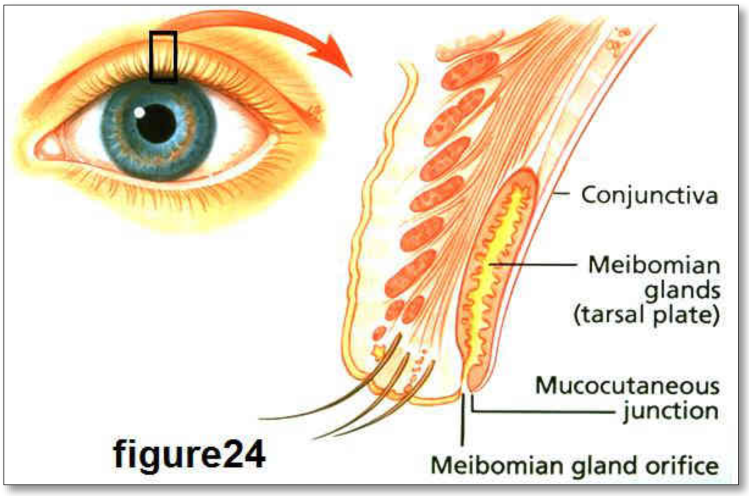


figure24

6. Scent glands

Scent glands are exocrine glands. Mammals have a variety of scent glands (sebaceous and sudoriferous). They produce semi-viscous secretions which contain pheromones (carry a message to other members of the species or to the other sex) and other semiochemical compounds. These odor-messengers indicate information such as status, territorial marking, mood, and sexual power.

- Scent glands develop on the feet in goats and rhinoceros, and callus-like growths on the feet of horses appear to be remnants of similar glands.
- Kangaroo rats have sebaceous scent glands along the middorsal line in the most el-posed area of the arched back.
- (Grisons South American rodents) emit such a pungent odor at all times that it would be unthinkable to remain in a closed room with these animals for more than a few minute.
- Male elephants have a temporal gland that swells during the breeding season and secretes a sticky, brown fluid. At this time the male elephant is very dangerous.
- A gland above the eye of the peccary looks like navel and secretes a watery fluid.
- The male lemur in some species has a hardened of spiny skin on the forearm, under which lies a gland the size of an almond.
- Bats have many glands in the skin of the face and head.
- Anal glands of skunks represented scent gland, the spray from glands considered defensive weapons.
- All of the foregoing appears to be modifications either of sebaceous or sudoriferous glands. Many of the odors of the mammalian zoo are caused by scent glands, not by unhygienic conditions in the pens and cages.

Epidermal Derivatives of the Integument

Terrestrial vertebrates have a stratum corneum that varies in thickness among species and on different parts of the body. The most generalized cornified structures are epidermal scales. Specializations include claws, nails, hoofs, feathers, hair, and horns.

1. Epidermal scales:Epidermal scales are regular overlapping thickenings of the stratum corneum found only in amniotes.

Reptiles are almost completely covered with them (Fig. 25), and in these animals epidermal scales reach an evolutionary peak. The scales on the head of snakes exhibit a characteristic number and arrangement for the species and are often named for underlying bones (Fig. 26). The large quadrilateral scales that come in contact with the ground are scutes. The broad scales on the surface of a turtle's shell are identified by name (Fig. 27), but their arrangement does not coincide with that of the under lying bones of the shell. Warty or home outgrowths replace scales in some parts of the body, particularly in lizards (Figs. 28).

Lizards and snakes have a double layer of stratum corneum, the inner layer having the same structure as the entire epidermis of amphibians (Fig. 29). The outer layer is shed periodically. In lizards it flakes oft in large patches, but in snakes the outer layer of the entire body including the transparent covering (spectacle) of is shed in one piece.

The stratum corneum is impervious to water. The double layer in lizards and snakes and the tough corneum of turtles and crocodilians result in very slow loss of water in dry air.

In **birds** and **mammals** epidermal scales are confined to restricted regions of the body such as legs and feet (Fig.30), the base of the beak, and the tail, as in rodents.

Armadillos (Fig. 31) and pangolins (Fig.32) are exceptions in that they are almost completely covered with epidermal scales.

figure 25

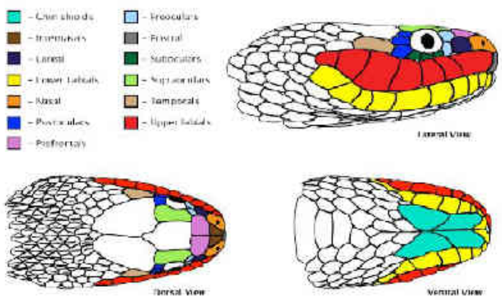


figure 26

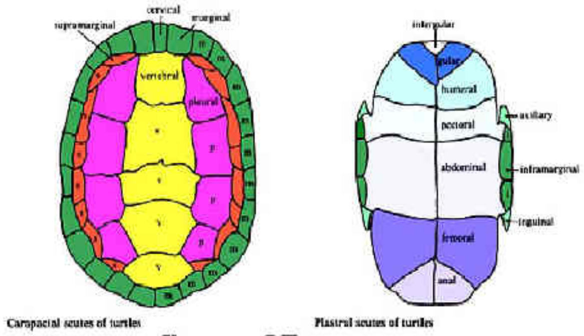


figure 27

figure 28

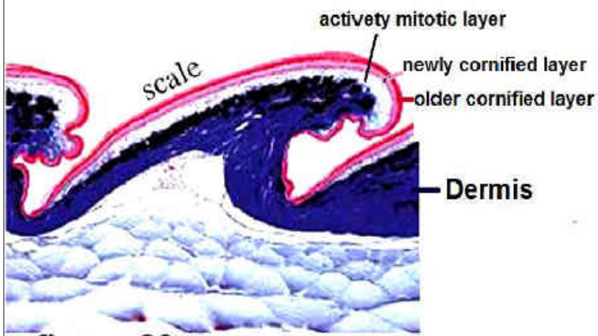


figure 29

figure 30

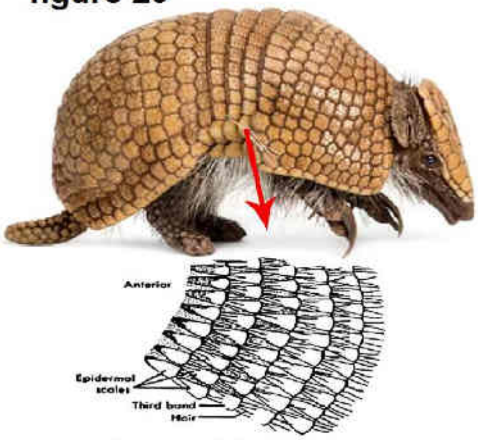


figure 31

figure 32

2. Claws, nails, and hoofs

Claws, nails, and hoofs are modifications of the stratum corneum at the ends of digits. Claws first appeared in reptiles, and have persisted in birds and most mammals. Claws evolved into nails in primates and into hoofs in ungulates. Claws, nails, and hoofs have the same basic structure. They consist of two curved parts, a horny dorsal plate, the unguis, and a softer ventral plate, the subunguis (Fig. 33).

- **Claw:** A claw is a curved, pointed appendage found at the end of a toe or finger in most amniotes (mammals, reptiles, birds). It composes of a scale-like plate (unguis, there is better developed) which takes the dorsal position. Another plate (subunguis), lies beneath or ventral to the unguis; the sub-unguis is reduced in size and is almost continuous with the torus or pad at the end of the digit (Fig. 33).
- **Nail:** Nails are evolved forms of claws, which is a covering on tips of fingers and toes in primates and some mammals. In nails the unguis is better developed and has become flattened, and the subunguis is much reduced. As a result, nails cover only the dorsal surfaces of digits. The 'root' of the nail is called nail groove or sulcus unguis. Beneath the nail and its root lies the nail bed, which is made up of three distinct regions: proximal (or matrix it is concerned with the development of the nail, in man may be seen as a crescent- shaped area, called lunula.), middle and distal(Fig. 33).
- **Hoof:** Hoofs are characteristics of ungulates. They consist of two curved parts, a hornydorsal plate, the unguis, and a softer ventral plate, the sub-unguis (Fig. 33). The two plates wrap partially around the terminal phalanx, which is usually blunt when associated with a hoof.

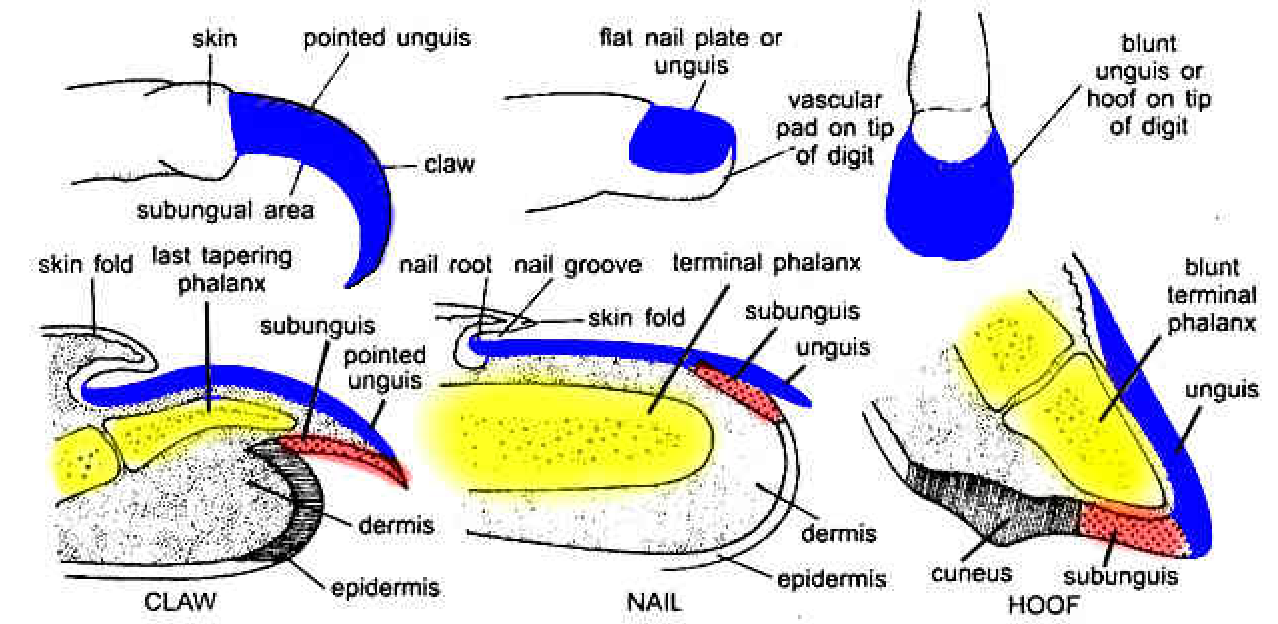


figure 33 Relation between claw (eagle), nail (human) and hoof (horse). Digital tips show complete above and in sagittal section below.

3. Feathers

Feathers are remarkably complicated cornified outgrowths of the epidermis. Feather Function: Flight, Insulation, Downy feathers, nesting material, Heat absorption, Mate attraction, Camouflage, and Protection from elements. The typical feather consists of a central shaft (**rachis**), with serial paired branches (**barbs**) forming a flattened, usually curved surface the vane. The barbs possess further branches the barbules and the barbules of adjacent barbs are attached to one another by hooks, stiffening the vane. In many birds, some or all of the feathers lack the barbules or the hooks, and the plumage has a loose, hair-like appearance (Fig. 34).

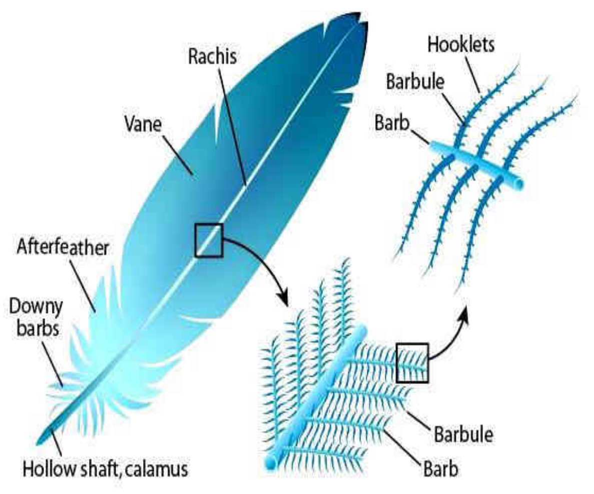


figure 34

Feathers come in many different shapes, but all of them can be classified into many different types of feathers: (Fig. 35).

1. **Flight feathers**: are found two places on birds: the wings and tail. Flight feathers are long, and on the wings, have one side of the vane wider than the other. They also have stronger barbules which give them more strength for flight.
2. **Contour feathers:** give shape and color to the bird. They are found everywhere except the beak, legs, and feet. Contour feathers are colored only at the ends. At its base, a contour feather becomes downy which helps insulate the bird.
3. **Down feathers**: have little or no shaft. They are soft and fluffy. Down feathers help insulate birds by trapping air. Some birds, such as herons, have special down feathers called powder down which breaks up into a fine powder. The bird then spreads this fine powder all over its body to act as a water repellent. **Semiplume feathers:** are a cross between down and contour feathers. Unlike down, they do have a well formed shaft. However, they do not have well developed barbicels which make them soft. Semiplume feathers are found underneath contour feathers and are used for insulation
4. **Filoplume feathers** are incredibly small. They have a tuft of barbs at the end of the shaft. Unlike other feathers which are attached to muscle for movement, filoplume feathers are attached to nerve endings. These feathers send messages to the brain that give information about the placement of feathers for flight, insulation, and preening.
5. **Bristle feathers** are very stiff with only a few barbs found at the base. Bristle feathers are found around the mouth of insect eating birds where they act as a funnel. They can also be found around the eyes where they work like eyelashes.

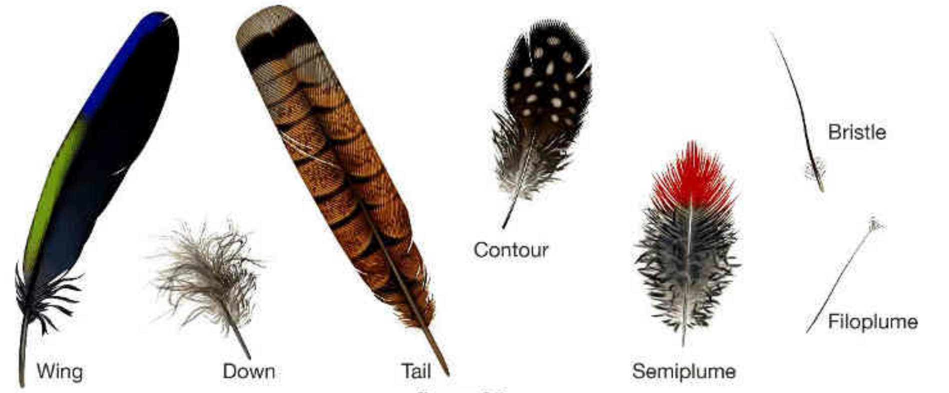


figure 35

Development of feathers:

Exaptation many stages of feather development (Fig. 36).

1. Epidermal cells grow, and form an elongated tube called the feather sheath.
2. Epidermal cells at the base of the sheath grow downward, creating a ring-like follicle that grows into the dermis.
3. Epidermal cells that line the sheath form the barbs of the feather.
4. The feather emerges and a tube-like structure called the calamus forms at the base.
5. Barbules stem from barbs. Barbules develop hooklets that interlock adjacent barbs, asymmetrical shape in flight feathers.

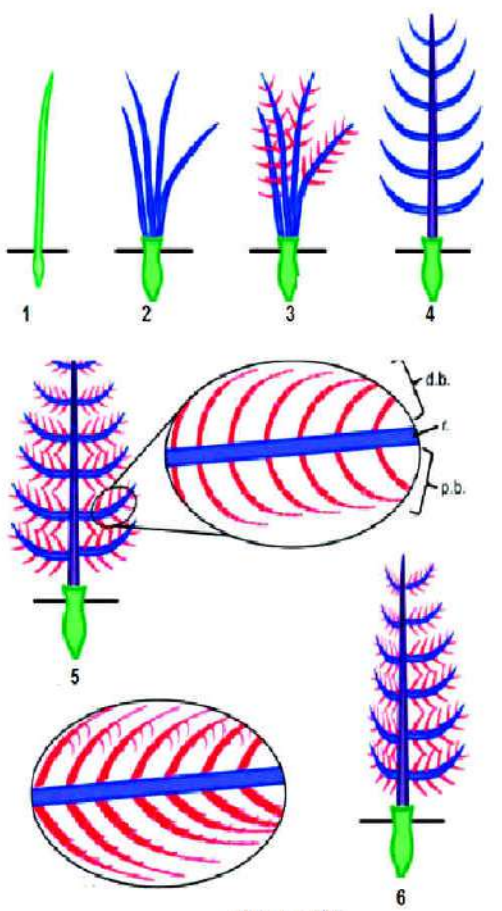


figure 36

4. Hair

Hairs are much like feathers but are far less complex. They may form a dense, furry covering over the entire body, or there may be only one or two bristles on the upper lip, as in some whales.

The fur of mammals has many uses: protection, sensory purposes, waterproofing, and camouflaging, with the primary usage being thermoregulation. The types of hair include:

- Definitive, which may be shed after reaching a certain length.
- Vibrissae, which are sensory hairs and are most commonly whiskers.
- Pelage, which consists of guard hairs, under-fur, and awn hair.
- Spines, which are a type of stiff guard hair used for defense in, for example, porcupines.
- Bristles, which are long hairs usually used in visual signals, such as the mane of a lion.
- Villi, often called "down fur," which insulates newborn mammals.
- Wool, which is long, soft, and often curly.
- The horns of rhinoceros

Anatomy of hair (Fig. 37):

A. Hair follicle: Determines the characteristics of the hair (A live)

- ✓ Sac of skin tissue buried deep in the scalp with a bulb at the bottom.
- ✓ Sebaceous gland is attached to the follicle and gives hair its shine by producing sebum oils
- ✓ Nerve and Capillaries supply nutrients to the follicle
- ✓ Tiny smooth muscle, the arrector pili, When the muscle contract, the hairs are drawn toward a vertical position.

Hair follicle is divided into 2 regions:

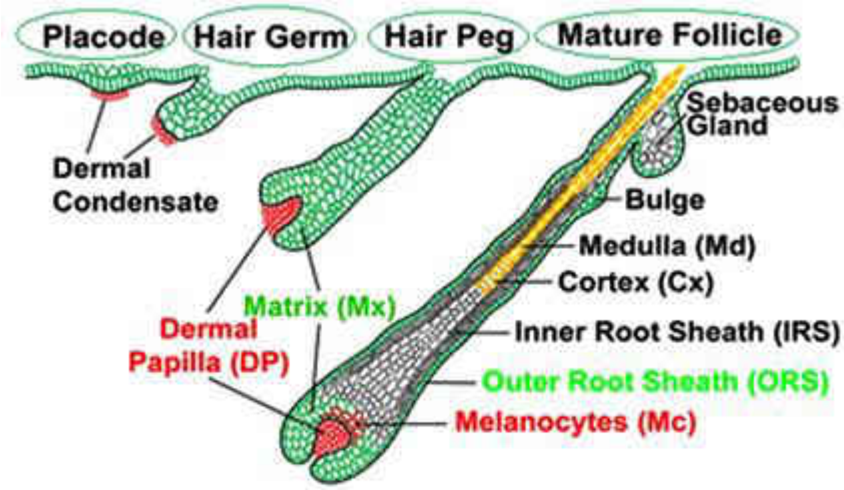
1. **Hair Bulb**: Located inside of the hair follicle. Houses actively growing cells. As new cells produce, continually push the cells upward and arrange into layers
    - Outer layers are the lining of the hair follicle
    - Inner layers are the actual hair
    - Cells in hair bulb also produce the pigment (melanin)
2. **Mid-follicle**: Growing cells die and form into what we know as hair

B. Hair shaft: Hair that is seen above the scalp (Dead) - Hair that is seen above scalp- These are the dead cells that turned into keratins - The hair is lubricated by sebum oils

The hair's shift structure can be divided into 3 distinct parts:

1. Medulla: innermost layer of the hair shaft, composed of an amorphous, soft, oily substance
2. Cortex: main component of the hair, containing long keratin chains that add elasticity, suppleness and resistance to the hair. The cells of the cortex are joined together by an intercellular cement rich in lipids and proteins. Each cell is composed of bundles that lie in the direction of the hair length: these are macrofibrils which are made up of microfibrils, which in turn contain protofibrils.
3. Cuticle: thin protective outer layer that contains the nourishing portion essential to hair growth. It is highly keratinized, composed of cells shaped like scales that are layered one over the other, measuring about 60 micrometers long and about 6 micrometers wide (Fig. 37). Development of hairs

Hair follicles first develop as cylindrical ingrowths of the epidermis into the dermis. Beneath the epidermal ingrowth and indenting its base, a dermal papilla organizes. With continued proliferation of epidermal cells, the hair primordium grows deeper and deeper into the dermis, nourished by vessels within the papilla. When the bulb at the base of the primordium is sufficiently differentiated, cornified cells start to appear, and a hair shaft begins to rise out of the follicle (Fig.38).



Figurev 38: Development of hairs.

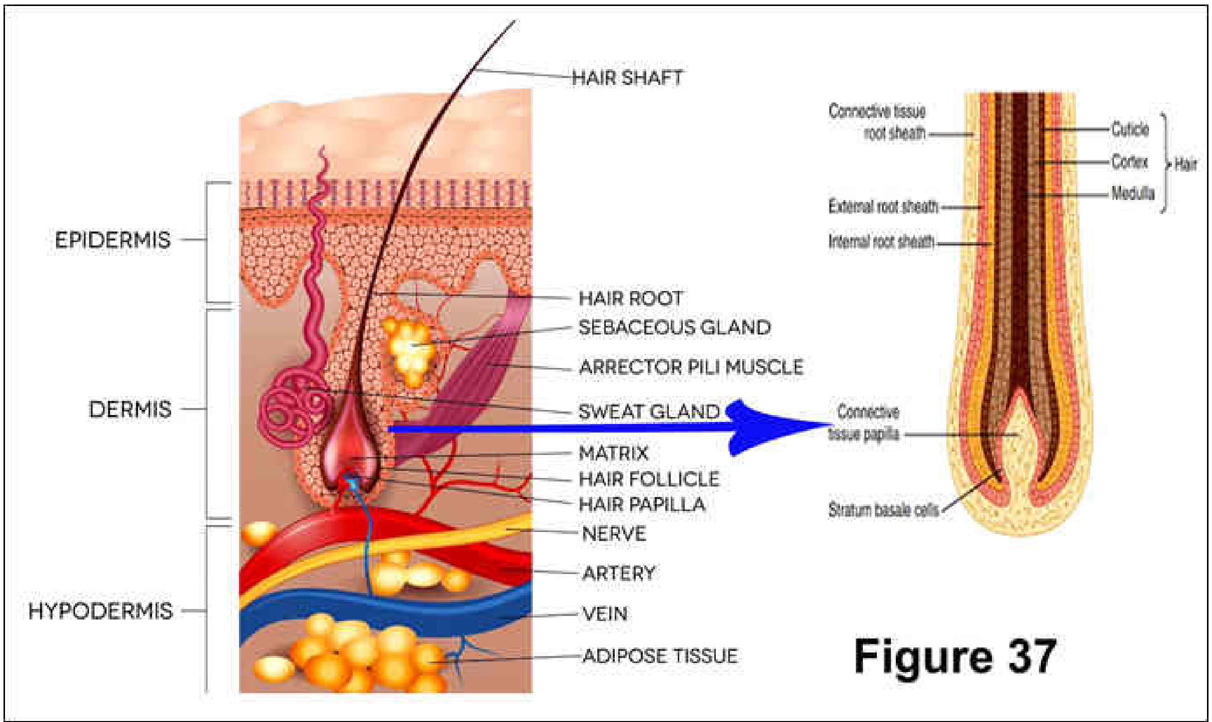


Figure 37

5. Horn and Antlers:

A horn is a permanent pointed projection on the head of various animals that consists of a covering of keratin surrounding a core of live bone. Their Functions are: enable males to carry out combat in competition for mates, secondarily used for display, indicators of social status, antipredator defense.

- **True Horns** occur in males of all species of Bovidae, and females often bear them too. Horns are never branched, but they do vary from species to species in shape and size. Extension of frontal bone, Inner bony core covered with a sheath of keratin, no parts are shed. Single pair in all but one living bovid (four-horned, Tetracerus) (Fig.39,1).
- **Antlers** are one of the most easily recognized characteristics of the family Cervidae. They are present only in males, entirely bony when fully developed, extension of frontal bone, shed periodically (usually annually in temperate zones), during growth covered with velvet (highly vascularized). Their morphology varies among species(Fig.39,2).
- **Pronghorn antelope**, in family Antilocapridae, have distinctive upright horns. They differ from the horns of bovid in two important respects. First, they are branched, each has a short, posteriorly-directed branch near the base, and a short, anteriorly-directed hook near the tip. Second, the horny sheaths are shed annually(Fig.39,3).
- **Giraffe horns** are paired, short, unbranched, permanent, bony processes that are covered with skin and hair. They do not project from the frontal bones, but lie over the sutures between the frontal and parietal bones. Horns are present in both sexes of giraffes and even on newborns (Fig.39,4).
- **Rhino Horns** differ from true horns because these horns have no core or sheath. Non-bony, solid mass of hardened epidermal cells formed from cluster of long dermal papillae resulting fibers hair-like, but grow differently from true hairs, not attached to underlying nasal bones. In species that have two horns, the second horn lies over the frontal bones. Rhino horns commonly curve posteriorly(Fig.39,5).

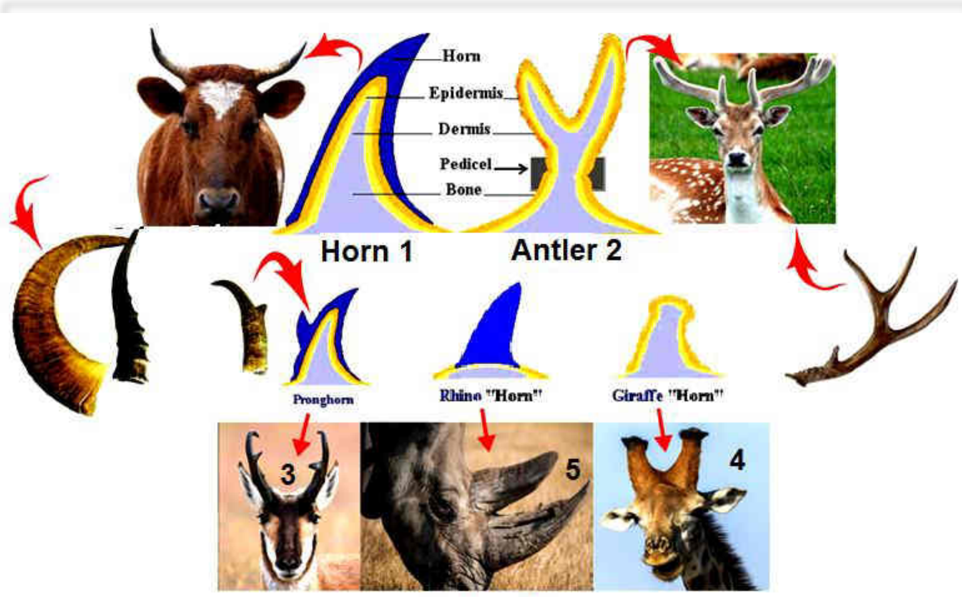


figure 39

6. Other cornified structures of Amniotes

Rattlesnake rattles are rings of horny stratum corneum that remain attached to the tail after each molt (Fig. 40,1). Beaks are covered with a horny sheath, and roosters' combs are covered with a thick (Fig. 40,2), warty stratum corneum. Monkeys and apes sit on thick ischial callosities, and camels kneel on knee pads. Tori are epidermal pads that most mammals other than ungulates walk on. Cats "pussyfoot" by retracting their claws and walking stealthily on tori. At the ends of digits tori are called apical pads. Corns and calluses are temporary thickenings of the stratum corneum that develop where the skin has been subjected to unusual friction(Fig. 40: 3;4;5;6;7).Toothless whales have great frayed horny sheets of oral epithelium called baleen hanging from the roof of the mouth. As many as 370 of these sheets have been counted in one whale. The apparatus serves as a massive strainer of food (Fig. 40,8). They are among the many cornified structures that develop from the skin.

figure 40: **Cornified structures of Amniotes**

The dermis

The basic component of dermis, whether fish or man, is collagenous connective tissue. Collagen is a proteinaceous fibril demonstrable by electron microscopy, 'which aggregates with other collagen fibrils to form dense bundles of collagenous connective tissue visible by light microscopy.

Reticular and elastic tissue bundles also form in the dermis. Capillaries supply the dermis and, by diffusion, the epidermis, since the latter lacks vessels. Dermal papillae become exceptionally vascular because much nourishment and oxygen are needed to maintain the rapid mitosis taking place in the basal layer of the epidermis at that location.

A variety of bulbous (encapsulated) general sense receptors are found in tire dermis, particularly in birds and mammals. Nerves invade the dermis, lymphatics enter, and pigment cells migrate in from neural crests, multiply, and become established close to the epidermis. Smooth muscle, including erectors of feathers and hairs, form in birds and mammals, and mesenchyme cells become adipose for storage of fat.

Bony dermis of fishes

Ancient dermal armor varied in detail, but a basic structural pattern is evident. It consisted of four basic: Lamellar bone, Vascular or spongy bone, Dentine (dermis) and is always associated with enamel, and Acellular enamel (epidermis). The armor was disposed either as broad, flat plates or as smaller bony scales. In either case, it covered the entire body in the oldest species. Presumably, this armor was protective, but it may also have served as a storage site for calcium and phosphates (Fig.41&42).

Cyclostomes, catfishes, eels, and some other recent fishes have lost the ability to form scales. Nevertheless, scale anlagen form transitorily in teleost embryos.

Fish scales are also called dermal scales since they are derived mainly from the dermis. The types of scales are:

- **Cosmoid Scales**: Found in Placoderms (extinct) as plates, and also typical of the Lobe Finned Fishes or Sarcopterygii, (Choanichthyes). Extinct fish had scales of enamel, cosmine and bone with pulp cavities. Modern ones, like Coelocanth and the lung fish have calcified fibers so this type of scale is almost extinct. No specimens available (Fig. 41,1).

- **Ganoid Scales**: Ganoid scales are dimond-shaped scales found in lower order fishes such as Bowfin (Amia calva), gars (Lepisosteidae), and sturgeons (Acipenseridae). ganoid scales are comprised of bone. They have a bony basal layer, a layer of dentin (also found in human teeth), and an outer layer of ganoine which is the inorganic bone salt for which these scales are named(Fig. 41,2).

- **Placoid Scales**: are found on elasmobranchsa and dogfish. Made of enamel (epidermal) and the dermal derivatives, dentine and bone with a pulp core. They are typical of cartilaginous fishes. Placoid scales are responsible for the rough feeling of dogfish skin (Fig. 41,3).

- **Cycloid scales:** are smooth-edged scales predominately found in lower order teleost fishes, such as salmon, carp and other soft fin rayed fish. Similar to ctenoid scales, they are overlapping which allow for greater flexibility in movement than other types of scales. The surface layer of the scale is comprised of calcium-based salts and the inner layer is predominately collagen. As a fish grows, its scales grow, adding concentric layers, similar to tree rings. For certain species, these rings can be counted to estimate the age of a fish(Fig. 41,4).

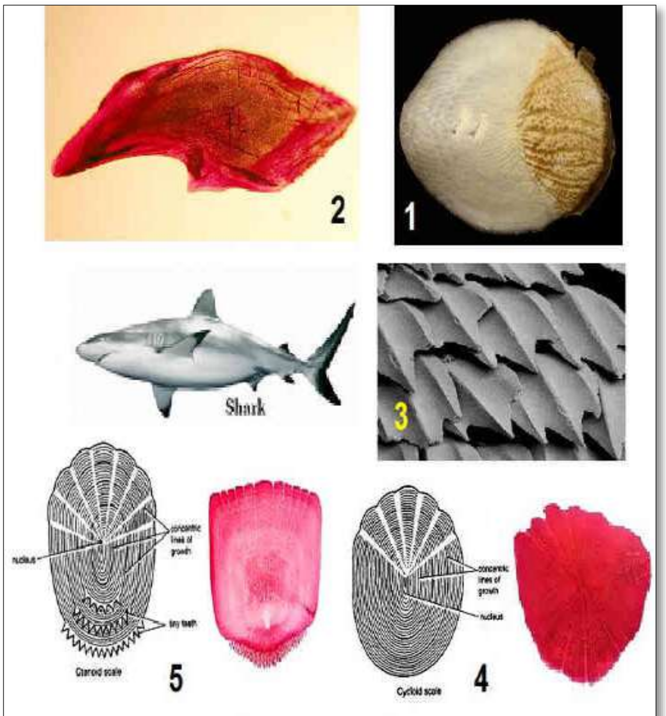


figure 41

- **Ctenoid scales** are scales with comb-like edge found in higher order teleost fishes, such as perch and sunfish. Cteni are the tiny teeth on the posterior margin of the scale. The surface layer of the scale is comprised of calcium-based salts and the inner layer is predominately collagen(Fig. 41,5).

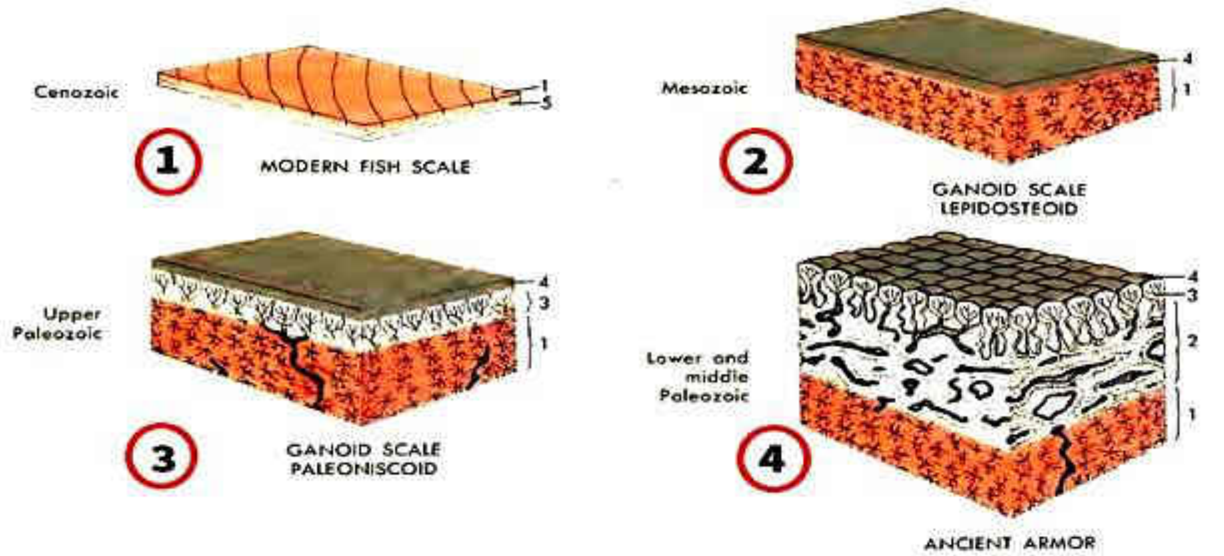


figure42 Dermal bone and dermal scales through the ages, diagrammatic. 1, Lamellar bone; 2, spongy bone; 3, dentin; 4, enameloid of one kind or another, including ganoin; 5, fibrous plate characteristic of modern fish scales. The surface elevations in ancient armor are "denticles" consisting of layers 3 and 4. The lamellar bone in modern fish scales is acellular. Cosmoid scales (not illustrated) resemble ancient armor.

Dermal ossification in tetrapods

Bony dermal scales, often called osteoderms in tetrapods, continue to form in some amphibians, most reptiles, and a few mammals. Only among birds are there no dermal scales. Their loss was certainly no disadvantage in flight.

- **Apodans** and some tropical toads have dermal scales. In apodans the scales are microscopic between the furrows of the skin(Fig. 43,1).
- **Crocodilians** have large oval osteoderms in the dermis, especially along the back (Fig. 5-35) where they are often associated with epidermal crests that give the animal an awesome appearance. A few lizards have similar but smaller bony scales(Fig. 43,2).
- **Turtles** are truly armored vertebrates. The armor, or shell, consists of large bony plates that meet in immovable sutures (Fig. 43,3). The arched carapace and ventral, flattened

plastron are united by bony lateral bridge's that must be sawed through to expose the internal organs. Leatherback turtles have leathery shells because the dense collage¬ nous tissue of the dermis does not become ossified.

- **Among mammals**, only armadillos have dermal armor (Fig. 43,4), and it lies beneath epidermal scales. Dermal scales in mammals and, perhaps, in some other tetrapods may well represent a reacquisition of bone that was once lost, rather than being a vestige of the past.

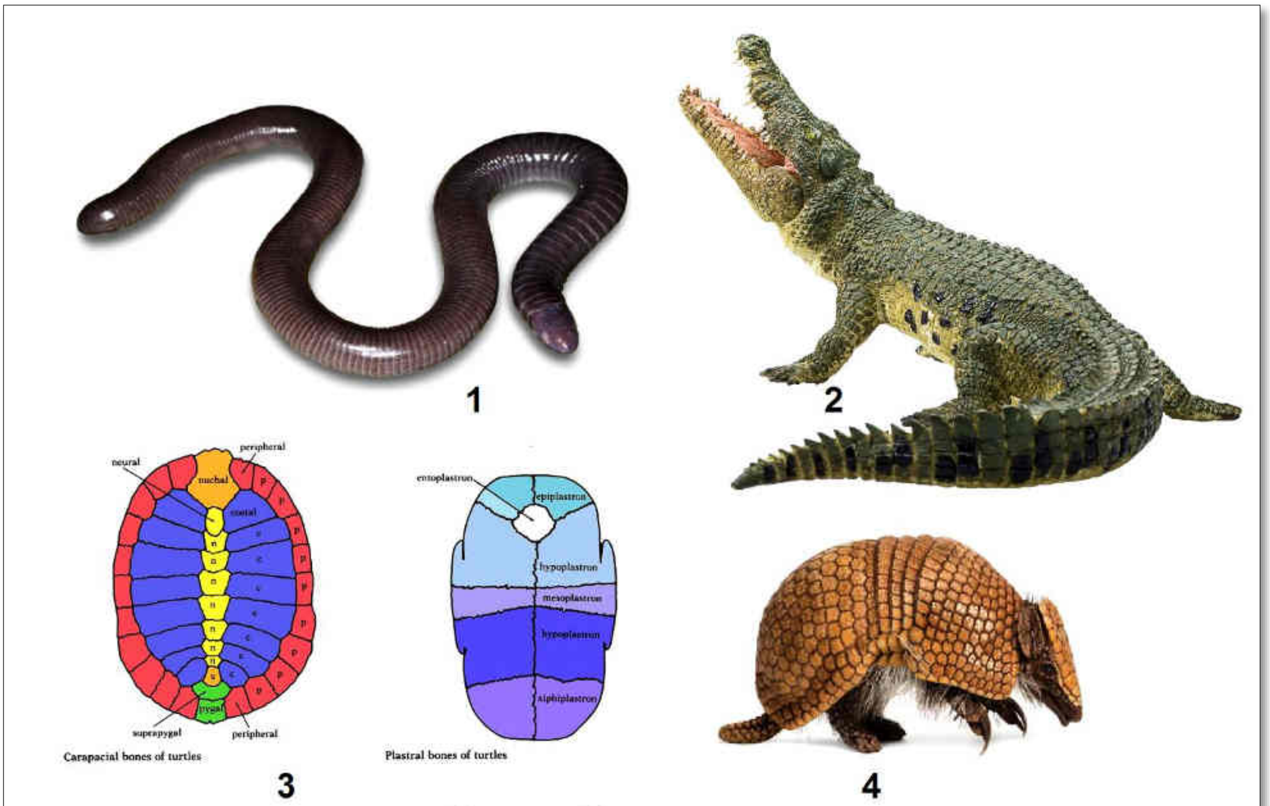


figure 43

Integument pigment

Color is due to pigments or to anatomical structures that absorb or reflect light. The position of it within the cells of skin layer, it represents special cells like chromatophores and Melanophores etc.

- **Chromatophores** are cells that produce color, of which many types are pigment containing cells, or groups of cells, found in a wide range of animals including amphibians, fish, and reptile that largely responsible for generating skin and eye color in ectothermic animals.

Chromatophores are generated in the neural crest during embryonic development.

- **Melanophores** are a type of chromatophore that produce and store melanin, which are varying shades of brown. It is found in the epidermal layer, and associated with the pigmentation of hair and skin. This type of melanophore is common in mammals and birds. It is also referred to as melanocyte that contains melanin granules (melanosomes).
- **Lipophores** are a type of cells, that produce pigmented granules are soluble in lipid solvents, which divided in two types: Xanthophores contain yellow granules and erythrophores contain red.
- **Iridophores and leucophores** contain a prismatic substance, guanine, which reflects and disperses light, producing silvery or iridescent skin.

Dermal chromatophores are responsible for rapid color changes (physiological color changes occur only in ectotherms such as are seen in chameleons Fig.44).The color change results from the dispersal of granules in processes of pigment cells or aggregation of granules to a position close to the nuclei. Dispersal of granules forms a cover that masks underlying pigments, not all varieties of chromatophores respond alike to the same stimulus, various color is result.

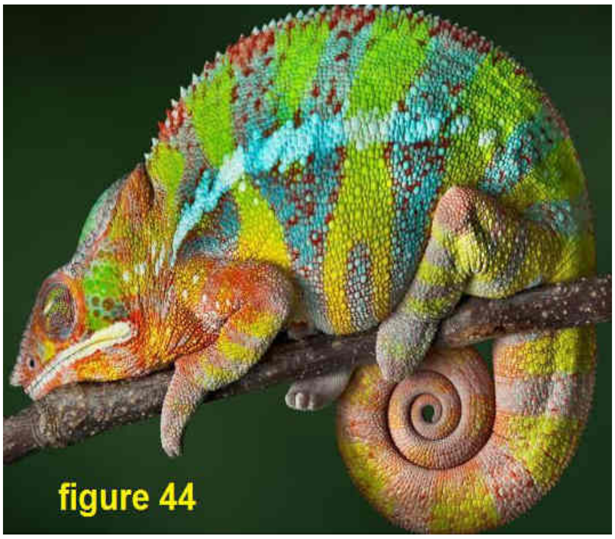


figure 44

Birds and mammals have epidermal as well as dermal pigment cells, but their skin cannot change color reflex because the granules within the cells cannot aggregate and disperse. These animals change color only as pigment granules are synthesized in response to longtime stimuli such as exposure to sunlight (“getting a tan,” for example) or when hairs, feathers, or epidermis is shed and replaced with new hairs, feathers, or epidermis with different color combinations or densities.

Feathers receive brown, yellow, and red pigments. blue feathers, have no blue granules, When viewed under a microscope by transmitted light, the “blue” feather is seen to be brown, the color of the melanin granules beneath the prismatic layer. The blue color observed in reflected light is a dispersion phenomenon, like the blue of the sky. The iridescence of feathers is also a dispersion phenomenon.

Some function of skin

1. Dermal armor provides protection from attack and, since it is usually heaviest in the head, it protects the brain and special sense organs from mechanical injury. Even in the absence of armor a leathery dermis provides some protection against penetration of foreign objects.
2. Skin glands secrete obnoxious or poisonous substances that ward off enemies. If the enemy lives through the first encounter, it may not seek another. Some glands keep skin moist and the conjunctiva of the eye free of irritants.
3. Integumentary pigments provide protective coloration and, in naked skin, absorb excess solar radiation.
4. The bristling coat of an angry mammal and the ruffled plumage of a frightened bird make them ominous. Claws, nails, horns, spines, barbs, needles all confer advantages in the struggle for existence.
5. Temperature regulation is effected largely by the skin. Fur and feathers insulate against heat and cold, sweat cools through evaporation, and dilation of blood vessels within the dermis increases heat loss by radiation. When heat conservation is necessary, the vessels constrict. Fat deposits insulate deep tissues from icy waters or frigid air, or provide energy stores for hibernation, migration, or periods of seasonal famine.
6. The skin assists in maintaining homeostasis. Bony scales are reservoirs for calcium and phosphate storage. Chloride-secreting glands and sweat glands excrete salts and water. Heavy layers of stratum corneum conserve water. Aquatic amphibians excrete carbon dioxide through the skin.

7. Mammary glands provide nourishment to newborn mammals.
8. Adhesive pads and claws assist in climbing.
9. Feathers provide an airfoil for aerial locomotion.
10. The distribution of pigment and the pheromonal secretions of scent glands often signal species and sex of the bearer.
11. Nerve endings in skin alert vertebrates against inimical forces.
12. Brood pouches under the skin house developing young.
13. Vitamin D is synthesized in some skin. You will probably be able to think of other roles that the integument performs.

Comparative Anatomy of digestive system:

The adult digestive system includes the digestive tract and accessory digestive glands. The **digestive tract** is a tubular passageway that extends through the body from the lips of the mouth to the anus or cloacal opening. Glands embedded in the walls lining the tract release secretions directly into the lumen. On the basis of histological differences among these intrinsic **luminal glands** and differences in size, shape, and embryonic derivation, three regions of the digestive tract are recognized: the **buccal cavity**, or mouth; the **pharynx**; and the **alimentary canal**. From histological differences in the luminal wall of the alimentary canal, up to four regions are identified: **esophagus, stomach, small intestine,** and **large intestine.**

Functions:

- ✓ mechanical breakdown - big lumps of food to small
- ✓ chemical breakdown - digestion → monomers
- ✓ absorption of monomers
- ✓ compact waste → feces, extract water → eliminate

Common features:

- ✓ longitudinal tube through body
- ✓ regional specializations along length
- ✓ basic wall plan common to all vertebrate groups

Components of the Digestive System

- **Oral cavity**
- **Pharynx**
- **Esophagus**
- **Stomach**
- **Small & large intestine**
- **Rectum**
- **Anus or cloaca**

1. **Oral cavity**

Mouth & lips

- ✓ Mouth is the anterior opening of the alimentary canal ,which may be terminal , ventral or slightly dorsally directed.
- ✓ It is guarded by suckers in cyclostomes and by jaws and teeth in gnathostomes.
- ✓ Lips are horny in fishes but fleshy and suctorial in mammals .Birds and turtles possess horny beak in place of lips.

Oral cavity (Fig. 45)

- This is the anterior most chamber of alimentary canal meant for handling food.
- Depending upon the kind and size of food ,its size is highly variable and it contains three important organs for handling food material ,namely ,oral glands ,tongue and teeth
- Oral Cavity Begins at mouth, ends at pharynx Tongue in floor of cavity

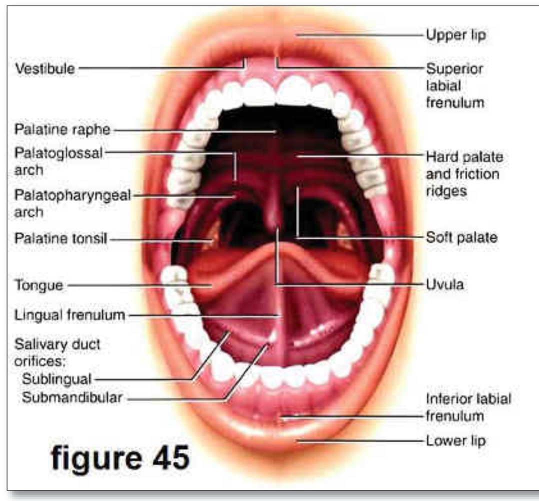


figure 45

- Palate in roof of cavity
- Primary palate
- Secondary palate
- Teeth

Oral glands

- Cyclostomes possess mucous glands in oral cavity but Petromyzon also has salivary glands that secrete an anticoagulant enzyme.
- Fishes have no particular oral glands except simple mucous glands.
- In tailed amphibian and apoda, oral glands are almost nonexistent but in anura there are.
- Oral glands are poorly developed in turtles and crocodiles but well developed in lizards and snakes .Poison glands of snakes are modified labial glands.
- Birds possess sublingual glands that open into the floor of the oral cavity.

- Mammalia oral cavity is very wet as it contains two types of glands salivary glands and mucous glands.
- The submandibular glands lie in the posterior part of the lower Jaw.
- Sublingual glands are smaller than the other two salivary glands .Molar glands are mucous glands that are well developed in herbivores and open near the upper molars.
- Another kind of mucous glands are Orbital glands which occur in cat and dog family

Tongue

Tongue is a fleshy and highly mobile organ in the oral cavity that is used in various ways in vertebrate groups (Fig 46):

1. Cyclostomes (lamprey) possess a thick and fleshy primary tongue on the floor of the oral cavity.
2. In fishes ,the tongue is primary and merely a fleshy fold on the floor of anterior end of pharynx supported by the extension of hyoid arch.
3. In urodeles such as *Necturus*, tongue is similar to fishes and is not put too much use .Frogs and toads having a predilection for insectivorous diet are gifted with a highly flexible tongue that consists of a basal primary tongue and the anterior glandular and musculr secondary tongue.
4. Turtle and crocodiles being amphibious in nature have a small non-protruibl tongue but snakes and lizards possess a highly movable tongue that is bifurcated at the apex and supplied with olfactory cells.
5. Bird tongue is short and hard and practically lacks muscles and lateral lingual swellings . Such incapable tongue is of no handicap to these beaked creatures as the food does not stay in the mouth for longer duration .However ,some birds are gifted with long and flexible tongue such as woodpeckers.
6. Mammalian tongue is the best developed of all vertebrates .It is derived from5 portions paired **fleshy ridges** of hyoid arch ,a median secondary tongue called **tubuerculum impar** and paired **lateral lingual swellings** ,which provide it extraordinary mobility and flexibility in the oral cavity.

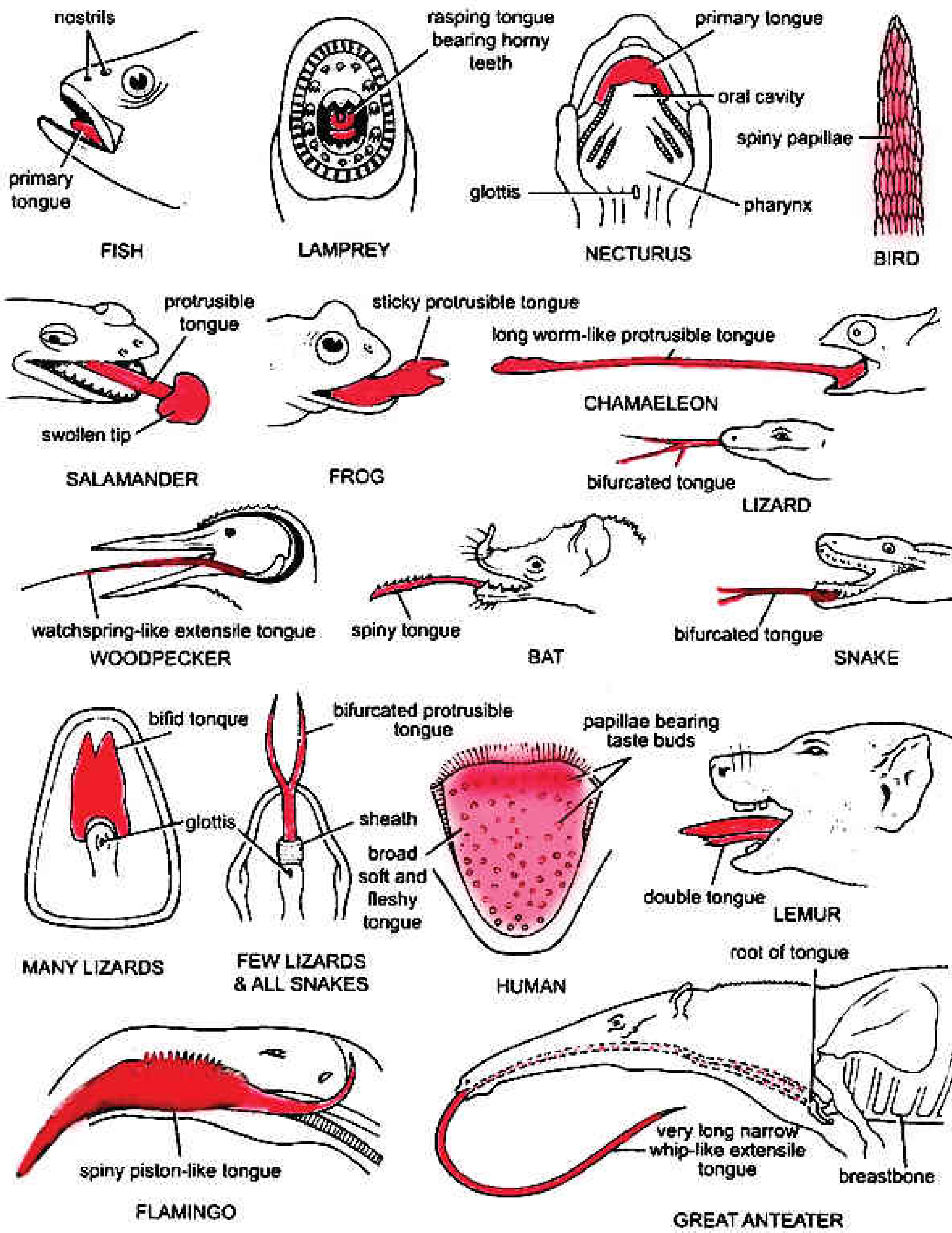


figure46: types of tongous in some vertebrates

Teeth

- Teeth are hard bony structures in the oral cavity that are variously modified to capture , tear ,cut or grind food material before it is swallowed.
- Epidermal teeth are hard comified epidermal structures of rare occurrence, as in the buccal funnel of cyclostomes and on the edges of tadpole jaws.

figure 47: horney teeth of cyclostoma

Types of teeth

1. **Polyphyodont** dentition involves replacement of teeth from time to time several times in lifetime so that jaws are never left without teeth such as toothed fish
2. **Diphyodont** dentition is a characteristic of mammals in which **milk teeth** appear in the young ones but as they grow and jaw becomes larger ,milk teeth are replaced by larger **permanent** onesHuman
3. **Monophyodont** Animals having one set of teeth of which none are replaced at a later stage of growth such as: Beluga whale

Based on the type of attachment of teeth on the jaw bone the following three types are found in vertebrates (Fig.48):

1. **Acrodont teeth** are attached on the top surface of the jaw bone as in fish and amphibians.
2. **Pleurodont** teeth are attached on the inner side of the jawbone that brings larger surface area of tooth in contact with jaw bone and hence attachment is stronger ,as in lizards and urodeles.
3. **Thecodont** dentition is found in mammals in which root of the tooth is finely fixed in a socket of the jawbone ,making the attachment strongest than in other vertebrate.

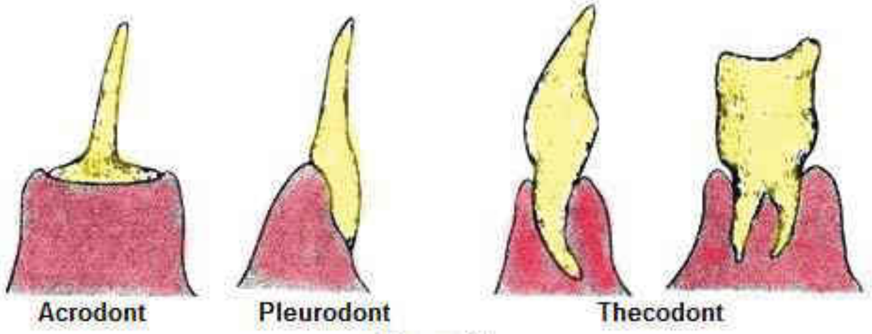


figure 48

Based on the kinds of teeth found there are two types of dentition (Fig.49) :

- **Homodont** dentition is found in the majority of vertebrates such as fish , amphibian and reptiles in which all teeth are same in form and function ,although their size may be variable depending on the location.
- **Heterodont** dentition occurs in mammals in which there are four functionally different types of teeth ,namely ,flat **incisors** for cutting ,long and pointed **canines** for tearing flesh and large and broad **premolars** and **molars** with flat grinding surface.

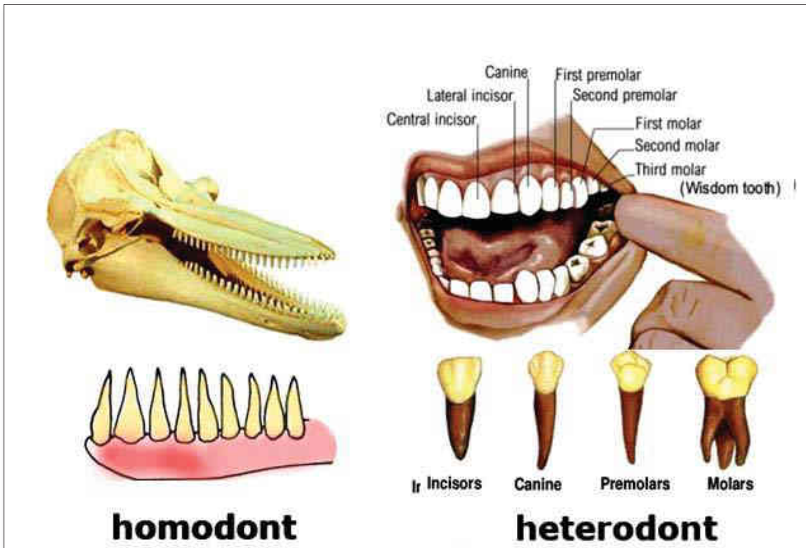


figure 49

2. Pharynx

- Pharynx is part of the alimentary canal between oral cavity and esophagus and is primarily concerned with respiration.
- In fishes, pharynx exhibits paired gill pouches containing gill lamellae and gill slits opening to the exterior, whereas in terrestrial vertebrates trachea opens into the pharynx.

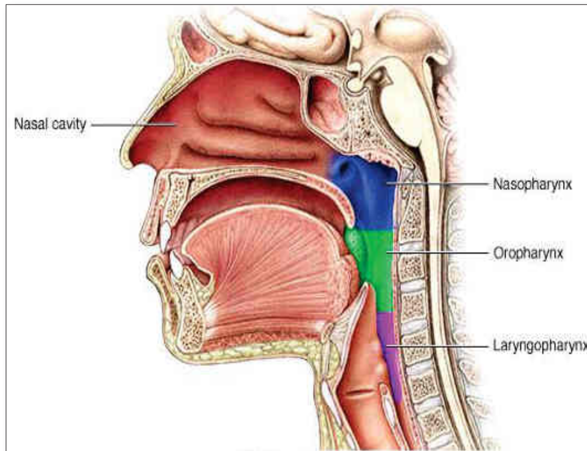


figure 50

- Nasal passage opens into the oral cavity in all other vertebrates except mammals and crocodiles in which nasal passage opens far backwards into the pharynx, allowing the oral cavity to handle food. While breathing can go on uninterrupted(Fig.50).
- At this time, larynx is pulled forward to lie against a flap of tissue called epiglottis, which closes the tracheal opening called glottis. In all other vertebrates except mammals as long as the food remains in the oral cavity breathing has to stop.

3. Esophagus

- Esophagus is a narrow tube that connects pharynx with stomach and is generally as long as the length of neck.
- It has no serous coat and inner mucosa bears longitudinal folds that give it enormous power of distension to allow large food to pass through it by peristalsis.
- Fish esophagus is very short bearing longitudinal folds but in birds and mammals it may be very long as in giraffe where it has to match the whole length of neck.

4. Stomach

Stomach is a muscular chamber or a series of chambers that serves for storage of food swallowed, macerating and churning it into pulp by peristalsis and secrete and mix certain digestive juices with it for digestion of nutrients.

Primary function of stomach continues to be storage of large quantity of food that has been swallowed.

- **Cyclostomes**

  In larval cyclostomes, stomach is ciliated which is quite useful in pushing detrivorous diet backwards on which they feed but in adult lampreys stomach is indistinguishable.

- **Fishes**

  In most of the fishes, stomach continues to be narrow and long inside the elongated body cavity. In elasmobranchs, it is J-shaped and measures about half the length of the entire digestive tract.

- **Amphibia**

  Urodeles have straight stomach with hardly any digestive function assigned to it. In frogs and toads, cardiac end is wide and pyloric small.

- **Reptiles**

  Snakes and lizards have elongated stomachs that fit inside their elongated abdominal cavity but in turtles the stomach is narrow U- shaped tube. Crocodiles have highly specialized stomach that is highly curved. Except for the tortoises, digestive glands are strongly developed in the stomachs of reptiles.

- **Birds**

  Bird stomach is modified greatly into a glandular proventriculus and horny gizzard that is necessary to grind seeds and other types of food that they need to swallow whole in the absence of teeth.

- **Mammals (Fig.51)**

  1. In monotremes, stomach is sack-like but lacks glands and in ungulates and cetaceans the glands occur in pyloric portion only. Stomach is a large sac meant to accommodate large quantity of food that must be swallowed quickly when available before the arrival of predators and competitors.
  2. Ruminant (cud-chewing) mammals have a complex stomach having four parts, namely, **rumen, reticulum** with honey-comb like rough lining, **omasum** and **abomasum**.
  3. Gastric juice is secreted by the lining of abomasums and pylorus for further digestion.
  4. Carnivore stomach is clearly divided into cardiac, fundus and pyloric portions,

of which fundus always remains empty and accommodates gases**(Fig.52)**.

5. The so called hourglass stomach is found in primates and rodents in which cardiac and pyloric parts are divided by a constriction.

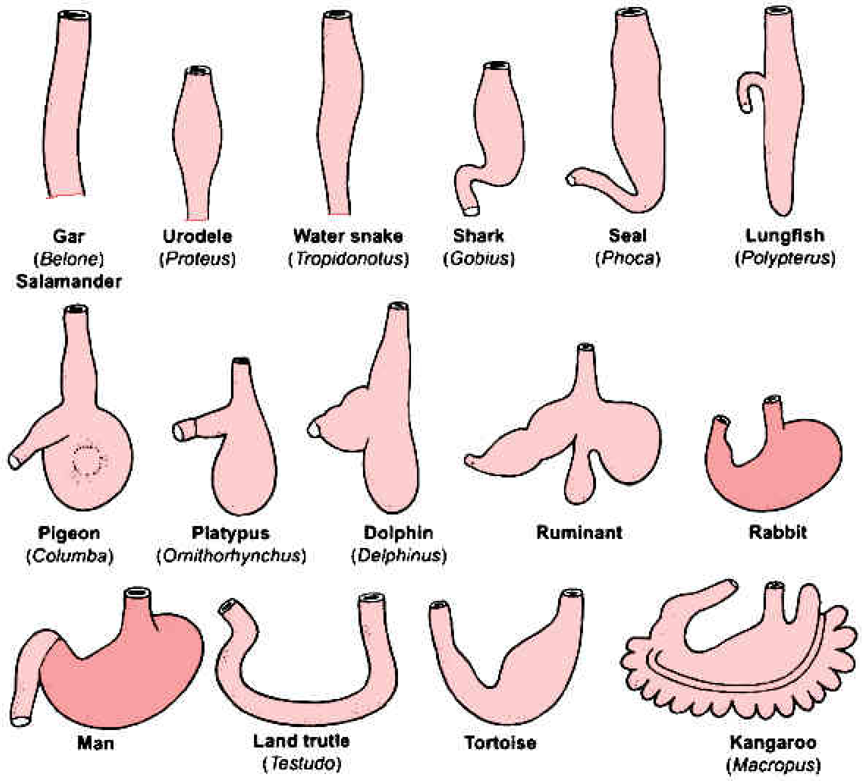


figure 51: Different shapes of vertebrate stomachs including human.

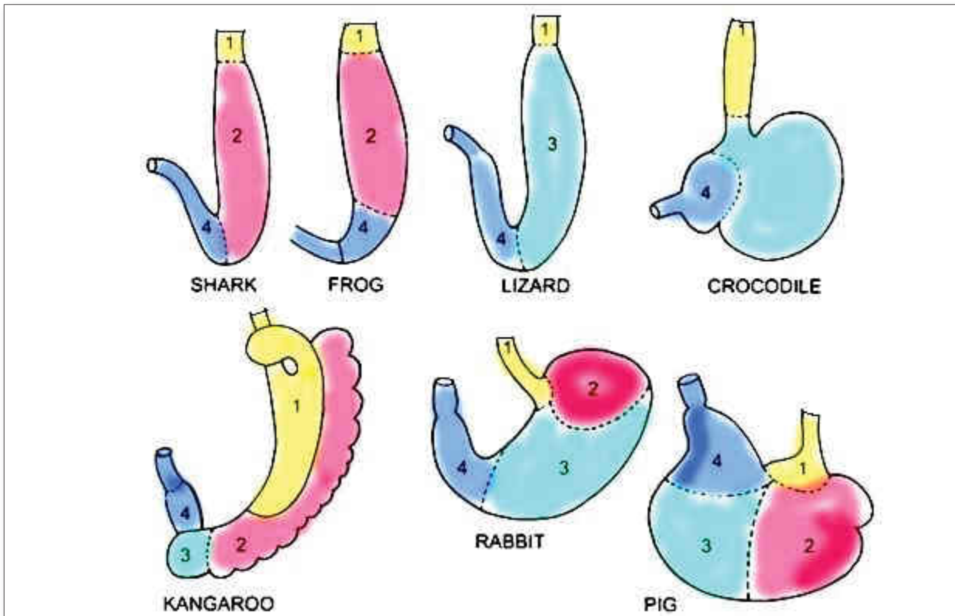
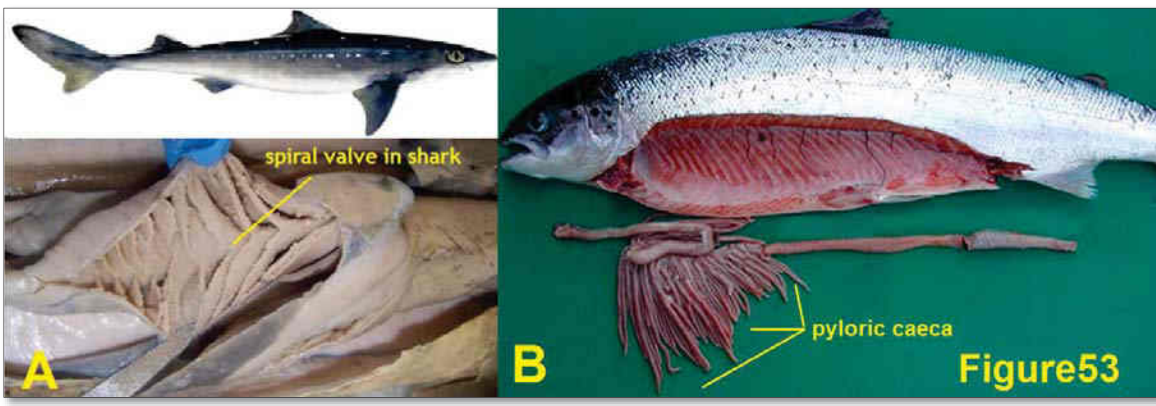


figure 52 Stomachs of some vertebrates showing different glandular regions. 1–oesophagus; 2–cardiac region; 3–fundic region; 4–pyloric region.

Intestine

It is part of the alimentary canal between stomach and cloaca or anus and the primary site of digestion and absorption. Digestion is alkaline as bile and pancreatic juices are released into duodenum which is attached to the pyloric part of stomach.

- **Cyclostomes.** Intestine is straight, slightly enlarged on the posterior side to form rectum and terminates into anus that opens in a cloacal depression.
- Fishes. Intestine of fishes is short, wide and almost straight, although some teleosts possess a spirally twisted intestine. Lungfishes also have a cloacal caecum to increase the absorptive surface area. Bony fishes do not have a spiral valve (Fig 53**A**), but have many hollow finger-like pyloric caeca instead (Fig 53**B**), attached between pyloric stomach and duodenum, which perform the same function of increasing the digestive area of intestine.
- **Amphibia** In limbless amphibians, intestine is almost straight and is not differentiated into



small and large intestine. In urodeles and anurans small intestine is long and coiled but large intestine is short and straight and separated from small intestine by an iliocolic valve.
- **Reptiles**. Small intestine is elongated, coiled and uniform in diameter and large intestine is almost straight. Iliocolic valve is present between the two portions.
- **Birds**. Length of intestine increases in birds but large intestine is short, straight and terminates into cloaca. Most of the birds possess one or two colic caeca that increase the absorptive surface of intestine (Fig.58).
- **Mammals**. Intestine is more elaborate; the small intestine is divided into duodenum, jejunum and ileum and the large intestine differentiated into colon and rectum. Jenjunum (means empty) is about 8 feet long in man and has leaf-like large villi(Fig.54A). Ileum is about 12 feet long and has finger-like one millimeter long villi for aiding absorption.

Carnivore intestine measures only 5-6 times the length of body while in herbivores it is 20-28 times the body length. In carnivores including man caecum is reduced and appendix rudimentary. Rectum is small and opens to the exterior by anal opening, except in monotremes where there is a shallow cloaca.

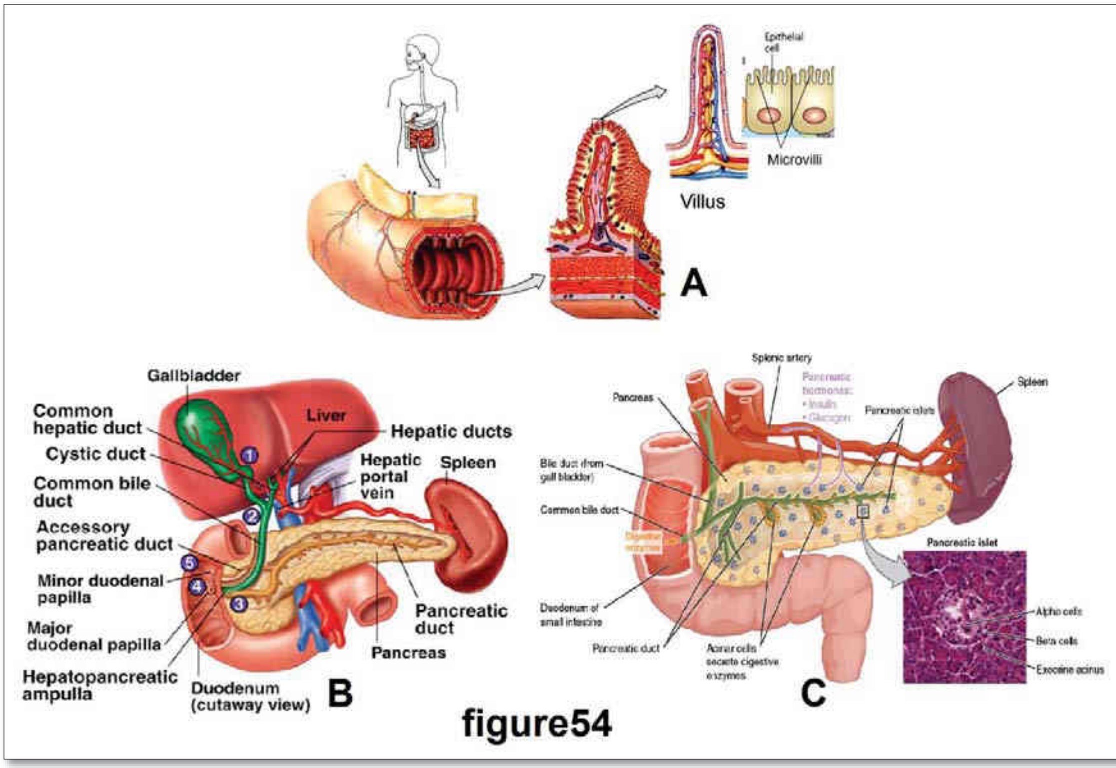


figure54

Liver

The main function of liver is assimilation and treatment of food after it has been digested and absorbed in intestine. New types of proteins and fats are synthesized in liver. But liver also produces bile juice that contains bile pigments. Often a gall bladder that opens by cystic duct into the bile duct for quick release whenever required.

- **Cyclostomes.** Liver is unusually small and single lobed in lampreys but bilobed in hagfishes. Gall bladder is absent in lampreys but present in hagfishes but in larval stages both gall bladder and bile ducts are present in all.
- **Fishe**s. Liver is large and lobed in fishes. Gall bladder is always present except in some sharks.
- **Amphibia**. Liver is large for the body size, lobed and with a gall bladder.
- **Reptiles**. There is no important deviation from amphibians in reptiles. In snakes there is a single elongated lobe. Gall bladder is always present in reptiles.
- **Birds**. Liver is always lobed. Gall bladder is sometimes absent as in pigeon, in which bile ducts open directly.
- **Mammals**. There are many more variations in mammals as compared to other groups. There are two main lobes which are subdivided into as many as 6-7 sub-lobes. Gall bladder is generally absent in those whose diet does not include much fat(Fig.54B).

Pancreas

This is the second largest digestive gland that arises from the endoderm of embryonic gut and can be divided into head, body and tail portions that lie in the loop of duodenum. It performs both exocrine and endocrine functions; the former contributes to about 99% of the secretions that are responsible for the digestion of proteins, fats and carbohydrates in small intestine.

- **Cyclostomes.** There is no well-defined pancreas in adult lampreys but pancreatic tissue is embedded in liver and intestine. Hagfishes possess small pancreas that lies near the bile duct.
- **Fishes.** Cartilaginous fishes have 2-lobed, well-defined pancreas that has a single duct. In lungfishes and some teleosts pancreas is diffused and its endocrine portion is separated.
- **Amphibia, reptiles & Aves.** There is no noteworthy feature in these groups. There is a well-developed pancreas with one or several ducts which may open in duodenum either

directly or may join the bile duct.

- **Mammals.** Generally two pancreatic ducts are present in mammals. Both ducts arefunctional in horse and dog. When bile duct joins the pancreatic duct there is a sphincter of Boyden at the junction. A small sac-like hepatopancreatic ampulla or ampulla or Vater is found in man in which bile duct and pancreatic duct open(Fig.54C).

Overview

Fish digestive system (Fig55)

1. No oral salivary glands - water lubricates food
2. No separate stomach in some species
3. Intestine surface area for absorption increased:
4. Long tube, folded/coiled in coelom
5. Mucosa folded internally

- spiral valve
- Villi

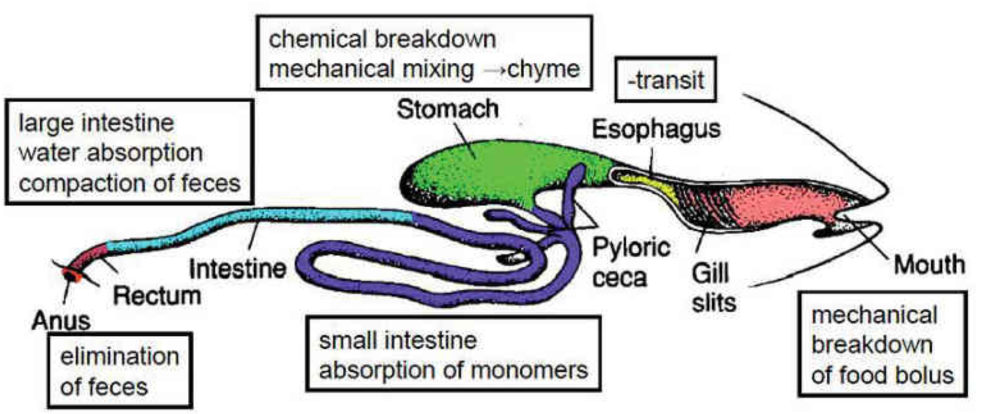


figure55

Amphibian digestive system (Fig.56)

1. ciliated oral epithelium
2. esophagus short, wide, ciliated
3. stomach regions: fundus, pylorus-glands short tubular
4. small intestine coiled -large mucosal villi, no glands
5. large intestine → cloaca

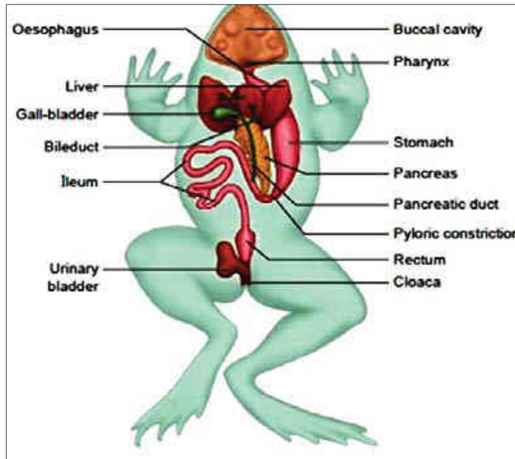


Figure 56 Digestive System of *Rana*

Reptilian digestive system (Fig.57)

1. Regional structure similar to amphibian gut
2. Gizzard: enlarged pylorus - grind food
3. Cecae: pouches off intestine -more time for digestion.
4. Snake feeding on whole prey no mechanical breakdown, all chemical.

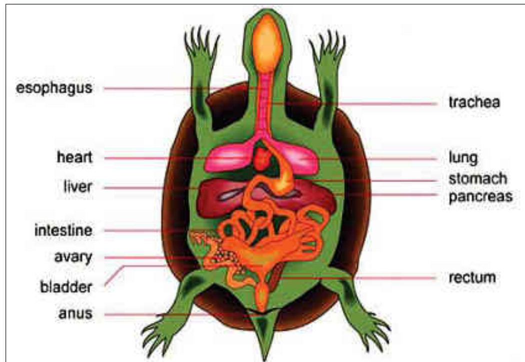


figure 57 INTERNAL ANATOMY OF A TURTLE

Bird digestive system (Fig.58)

1. keratinized beak - no teeth in modern birds
2. keratinized tongue - aids mechanical breakdown
3. Crop: expanded esophagus food reservoir regurgitation for young.
4. Herbivores seed eaters: gizzard mechanical breakdown using stones, grit to grind food.
5. The proventriculus (a glandular type of stomach) secretes acid and enzymes.

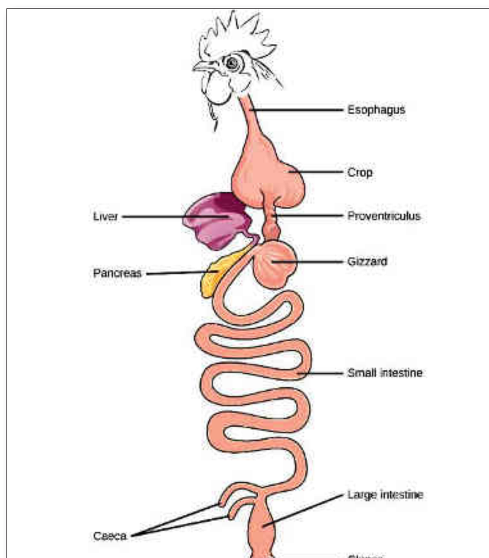


figure 58

Mammalian digestive system (Fig.59)

1. Diet-related specializations:
2. length of gut related to digestion time
3. -carnivores - chemical digestion fast, gut short
4. -herbivores - chemical digestion slow, gut longer
5. keratinized esophagus - rodents, herbivores
6. Fermentation - extra chambers for bacterial action to break down plant cellulose - foregut fermenters -intestinal fermenters.

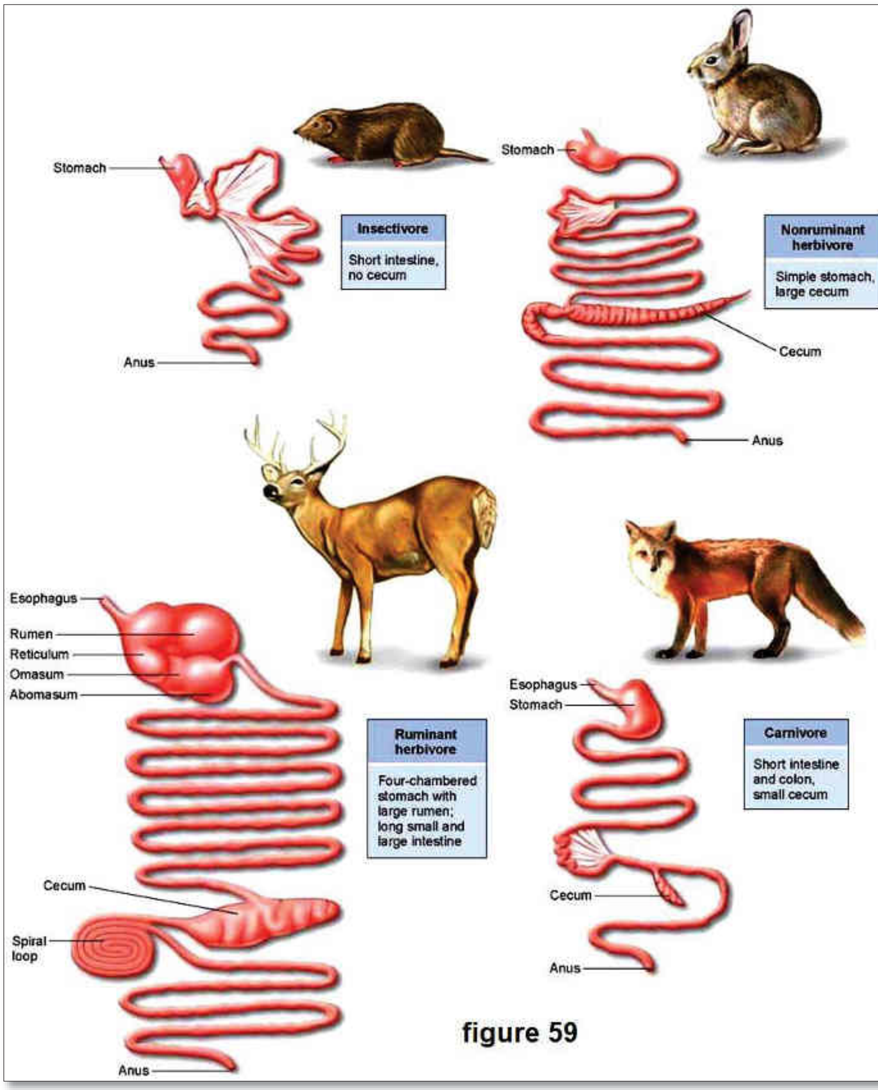


figure 59

Comparative Anatomy Circulatory System

Vertebrates have the most highly evolved circulatory system in the animal kingdom that performs a variety of functions including:

- Transport of respiratory gases, nutrients, metabolic wastes, hormones and antibodies
- Maintain internal environment (homeostasis) in conjunction with the kidneys
- Responds quickly to the changes in the body depending on the needs of the moment

Blood and blood vessels

I. Blood: is a fluid connective tissue containing cellular elements that are derived from mesoderm. There are two primary components to blood:

1. Plasma: constitutes approximately 2/3 of the blood and is composed of about 90% water.
   - ✓ The non-water component contains fibrinogen, which contributes to blood clotting, and globulins, which respond to the entry of foreign materials into the body.
2. Cellular: consists of two types of cells
   - ✓ Erythrocytes: the red blood cells which carry hemoglobin that binds oxygen for transport to the tissues.
   - ✓ Leukocytes: the white blood cells that destroy foreign bodies through phagocytosis and are also involved in the immunity.

Hemopoiesis

Blood cells are produced by hemopoietic tissues

1. In embryos, hemopoietic tissue is found distributed throughout the body.

2. In adults, hemopoiesis occurs primarily in the red bone marrow (which contains stem cells, the primordia of blood cells) and the spleen.

Blood vessels are the first indicator of the formation of the circulatory system. Blood islands first form in the yolk and then become contiguous to form a network of vessels.

II. Blood vessels and heart

The circulatory system is made up of two primary components:

1. Blood vascular system: a closed system composed of:
   - Arteries
   - Veins
   - Capillaries
   - Heart
2. Lymphatic system: drains fluids that accumulate in the tissues (tissue fluids), which are first collected by lymphatic capillaries, which pass into lymphatic vessels and then empty into the venous system.

1. Blood vessels

A. Arteries (Fig.60)

- Carry blood away from the heart.
- Have muscular, elastic walls.
- Terminate in capillary beds (Fig60).

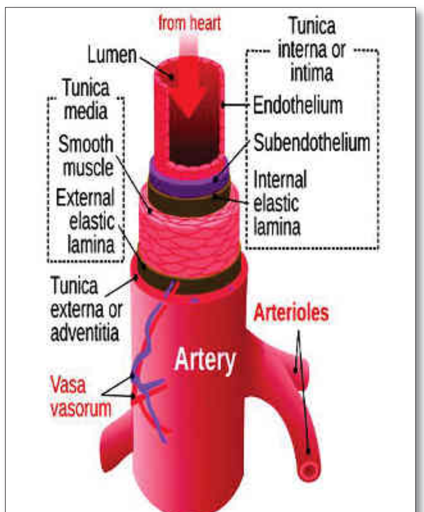


figure 60

B. Veins (Fig.61)

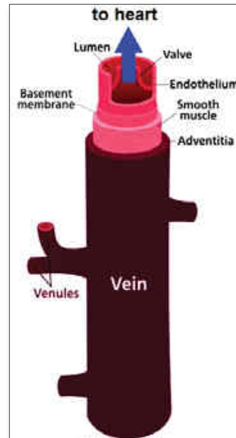


Figure 61

- Carry blood back to the heart.
- Have less muscle in their walls than arteries but the walls are very elastic.
- Begin at the end of capillary beds.

C. Capillaries (Fig62)

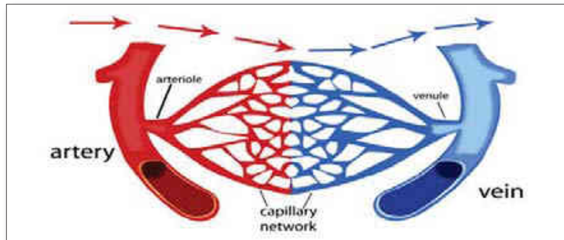


figure 62

- Have very thin walls (endothelium only).
- Site of exchange between the blood and body cells

D. The Heart

- The embryonic heart is formed from the splanchnic layer of the mesoderm. When first developed, the heart is composed of two layers:
  1. The endothelium forms the lining of the heart
  2. The myocardium forms the muscular part of the heart, containing cardiac muscle fibers.
- A muscular pump (cardiac muscle).
- Contains a pacemaker to regulate rate but rate can also be influenced by the autonomic nervous system.

Arterial channels

- They supply most tissues with oxygenated blood (but carry deoxygenated blood to respiratory organs). In the basic pattern:

1. The ventral aorta emerges from heart & passes forward beneath the pharynx.

2. The dorsal aorta (paired above the pharynx) passes caudally above the digestive tract.

3. Six pairs of aortic arches connect the ventral aorta with the dorsal aortas.

Comparative Anatomy of Heart and Aortic arches

Hagfish (Fig.63)

- The heart has two chambers separated by a cartilaginous rod. When muscles contract to bend this rod, the volume of each chamber changes; one side expanding to draw in blood and the other contracting to expel blood.
- Valves prevent backflow of blood.
- open blood vessels

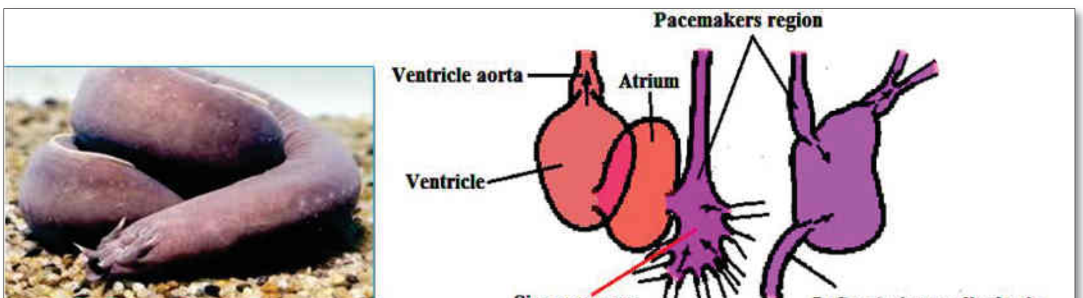


figure63

Cartilaginous fishes (Ex. Shark Fig.64A)

- The heart is composed of four chambers aligned in series (linear configuration): **sinus venosus, atrium, ventricle, and conus arteriosus.**
- Veins collecting blood from the body drain into the sinus venosus.
- The contraction of the atrium (thin-walled muscular sac) and ventricle (thick, muscular walls) forces the blood into the ventral aorta via the conus arteriosus that leads into the gills.

Aortic arches of fishes (Fig.64B)

General pattern of development of arches in cartilaginous fishes:

- Ventral aorta extends forward below pharynx & connects developing aortic arches. The first pair of arches develop first.
- Segments of first pair are lost & remaining sections become efferent pseudobranchial arteries.
- Arches 2 - 6 become occluded
    1. dorsal segments=efferent branchial arteries
    2. ventral segments = afferent branchial arteries
- As a result, blood entering an aortic arch from ventral aorta must pass through gill capillaries before proceeding to dorsal aorta.

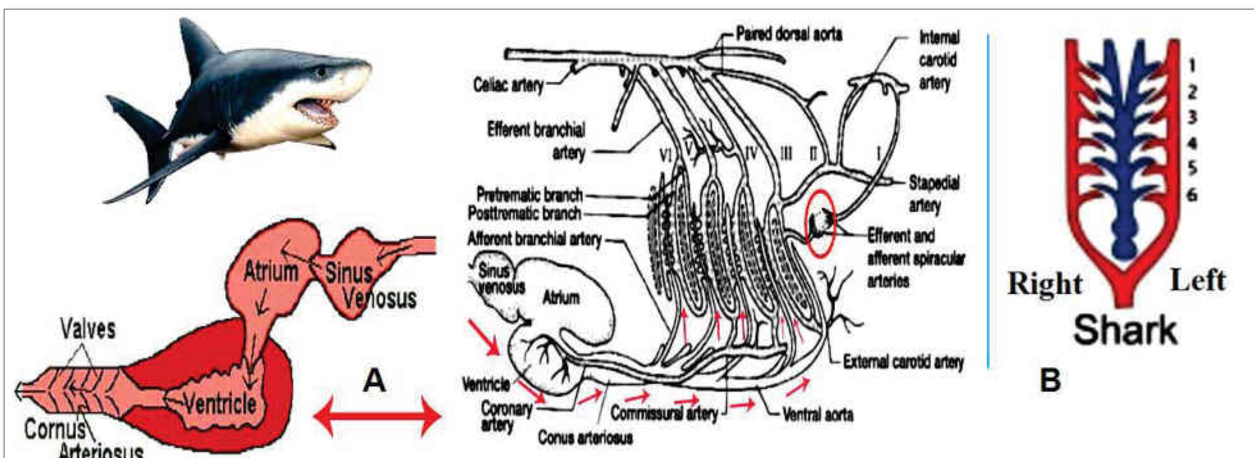


figure 64

Teleosts (Bony fish)

- Heart is similar to that of cartilaginous fishes, except a bulbus arteriosus (a muscular extension of the ventral aorta) is present rather than a conus arteriosus (a muscular extension of the ventricle) **(Fig.65A)**.

- **Aortic arches of fishes General pattern of development of arches in Teleosts**

1. The same changes convert 6 pairs of embryonic aortic arches into afferent & efferent branchial arteries.
2. Arches 1 & 2 are usually lost **(Fig.65B)**.

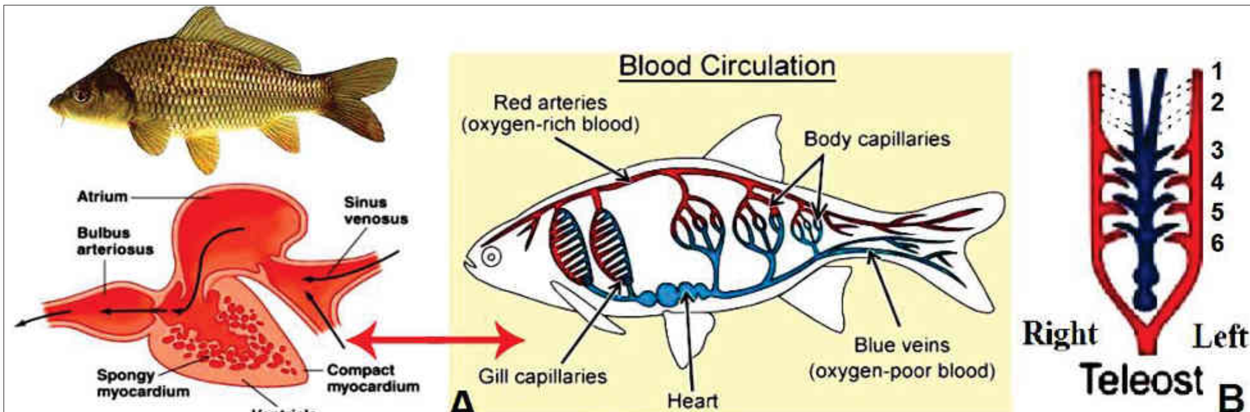


figure 65

Lungfish & Amphibians (Fig.66).

- Partial or complete partition within atrium (complete in anurans and some urodeles)
- Partial interventricular septum (lungfish) or ventricular trabeculae (amphibians) to maintain separation of oxygenated & unoxygenated blood
- Formation of a spiral valve in the conus arteriosus of many dipnoans and amphibians. The spiral valve alternately blocks & unblocks the entrances to the left and right pulmonary arches (sending unoxygenated blood to the skin & lungs).

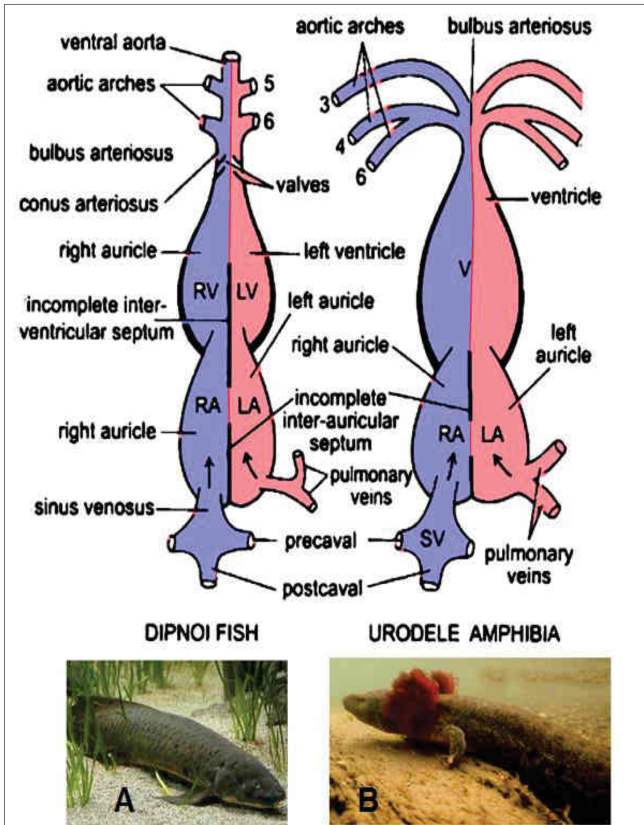


figure 66

- Shortening of ventral aorta, which helps ensure that the oxygenated & unoxygenated block kept separate in the heart moves directly into the appropriate vessels
- Modifications are correlated with the presence of lungs & enable oxygenated blood returning from the lungs to be separated from deoxygenated blood returning from elsewhere.

Aortic arches (Fig.67).

- **Lungfish:** The pulmonary artery branches off the 6th aortic arch and supplies the swim bladder (& this is the same way that tetrapod lungs are supplied).
- **Urodeles:** most terrestrial urodeles have 4 pairs of arches; aquatic urodeles typically have 3 pairs (3, 4, & 6).

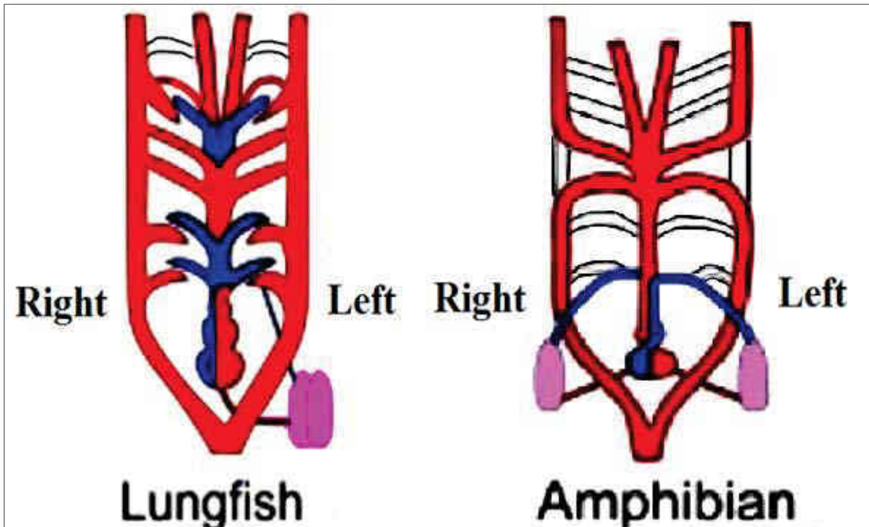


figure 67

The Frog Heart (Fig.68A).

- The frog heart has 3 chambers: two atria and a single ventricle.
- The atrium receives deoxygenated blood from the blood vessels (veins) that drain the various organs of the body.
- The left atrium receives oxygenated blood from the lungs and skin (which also serves as a gas exchange organ in most amphibians).
- Both atria empty into the single ventricle.
  - While this might appear to waste the opportunity to keep oxygenated and deoxygenated bloods separate, the ventricle is divided into narrow chambers that reduce the mixing of the two blood. So when the ventricle contracts, oxygenated blood from the left atrium is sent, relatively pure, into the carotid arteries taking blood to the head and brain
- Deoxygenated blood from the right atrium is sent, relatively pure, to the pulmocutaneous arteries taking blood to the skin and lungs where fresh oxygen can be picked up. Only the blood passing into the aortic arches has been thoroughly mixed, but even so it contains enough oxygen to supply the needs of the rest of the body.

Aortic arches of Amphibians (Fig.68B):

Anurans: have 4 arches early in development (larval stage); arch 6 develops a pulmonary artery (to lungs) while arches 3, 4, & 5 supply larval gills. At metamorphosis:

- Aortic arch 5 is lost.
- The dorsal aorta between arches 3 & 4 is lost, so blood entering arch 3 (carotid arch) goes to the head.
- A segment (ductus arteriosus) of arch 6 is lost so blood entering this arch goes to the skin & lungs.
- Aortic arch 4 (systemic arch) on each side continue to the dorsal aorta & distributes blood to the rest of the body.

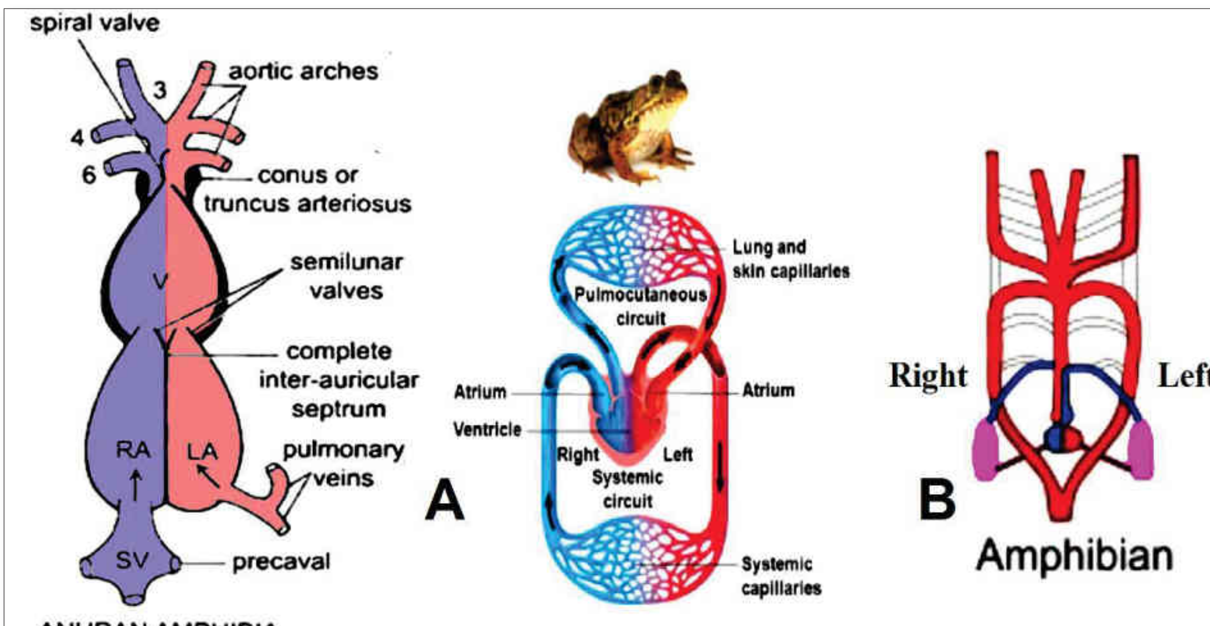


figure68

Heart of Amniotes

- Heart consists of two atria & two ventricles &, except in adult birds & mammals, a sinus venosus.
- Complete interatrial septum.
- Complete interventricular septum only in crocodilians, birds, & mammals; partial septum in other amniotes.
- It is enclosed by double walled pericardium.

The Lizard Heart(Fig.69A):

- Most reptiles have a partial partition in the ventricle so that the mixing effect of oxygenated and deoxygenated blood can be minimized.
- The left half of the ventricle pumps oxygenated blood (received from the left atrium) to the body. The right half pumps deoxygenated blood (received from the right atrium) to the lungs.
- Crocodiles have a complete interventricular partition. . In all reptiles, the sinus venosus is less prominent than in the amphibians.

Aortic arches of Reptiles(Fig.69C):

- Three aortic arches in adults (3,4,6).
- Ventral aorta no spiral valve but truncus arteriosus is split into 3 separate passages: 2 aortic trunks & a pulmonary trunk. As a result:

✓ Pulmonary trunk emerges from the right ventricle & connects with the 6th aortic arches (deoxygenated blood from right atrium goes to lungs).

✓ One aortic trunk comes out of left ventricle & carries oxygenated blood to the right 4'h aortic arch & to the carotid arches.

- ✓ The other aortic trunk appears to come out of right ventricle & leads to left 4th aortic arch.

Crocodilians ventricular septum is complete but a narrow channel called the Foramen of Panizza connects the base of the right & left systemic trunks (Fig.69D).

Role the foramen of Panizza in crocodiles

Deoxygenated blood from the right ventricle, sitting in the left aorta, can flow into the right aorta through the foramen of Panizza. When the heart is relaxed, some oxygenated blood from the left ventricle, sitting in the right aorta, can flow into the left aorta across this foramen. This allows blood to bypass the lungs while crocodile submerged. When crocodile is under water, blood pressure in the lungs increases, causing the blood to flow through the Foremen of Panizza and to the systemic circulation without going to the lungs. This bypass saves energy and reduces the work load of the heart.

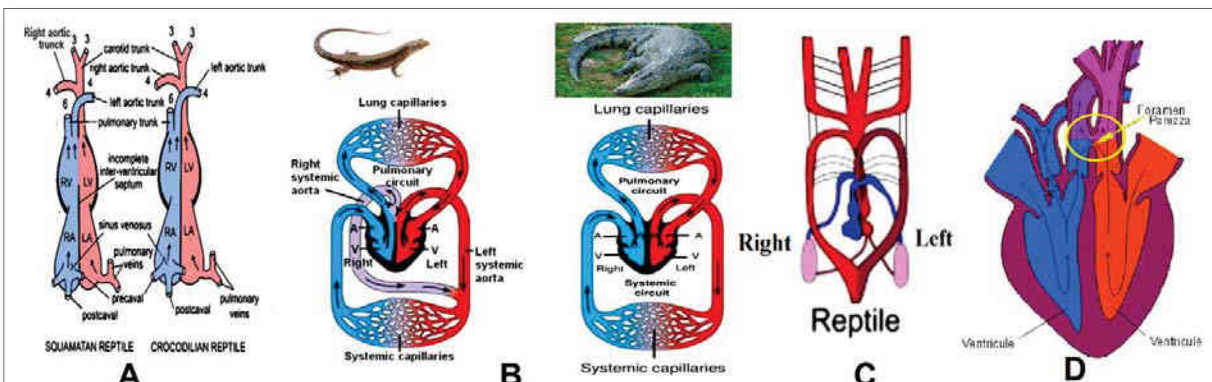


figure69

Heart of Birds & Mammals (Fig.70A)

- ➢ Birds and mammals have the most specialized hearts with two atria and two ventricles.
- ➢ Each chamber is completely separated from the others by thick muscular walls.
- ➢ In contrast with the reptiles, the conus and sinus venosus are absent.

- The right auriculo-ventricular aperture is guarded by tricuspid valve and the left by bicuspid valve (mytral valve).
- Oxygenated and deoxygenated blood never mix.
- Deoxygenated blood enters the right atrium and passes to the right ventricle. It then goes to the lungs, is oxygenated, and returns to the left atrium. The blood then passes to the left ventricle and enters the systemic circulation via the aorta.

Aortic arches of Birds & mammals (Fig.70B)

- Arches 1 and 2 degenerate completely, the dorsal aorta that runs between arches 3 and 4 degenerates on both the left and right sides.
- The third arches form the internal carotid arteries.
- The left fourth aortic arch contributes to the arch of the aorta. The right fourth aortic arch forms the proximal segment of the right subclavian artery.
- The fifth aortic arches are never present in the mammal.
- The proximal segment of the left sixth arch forms part of the pulmonary artery while the distal segment forms the ductus arteriosus.

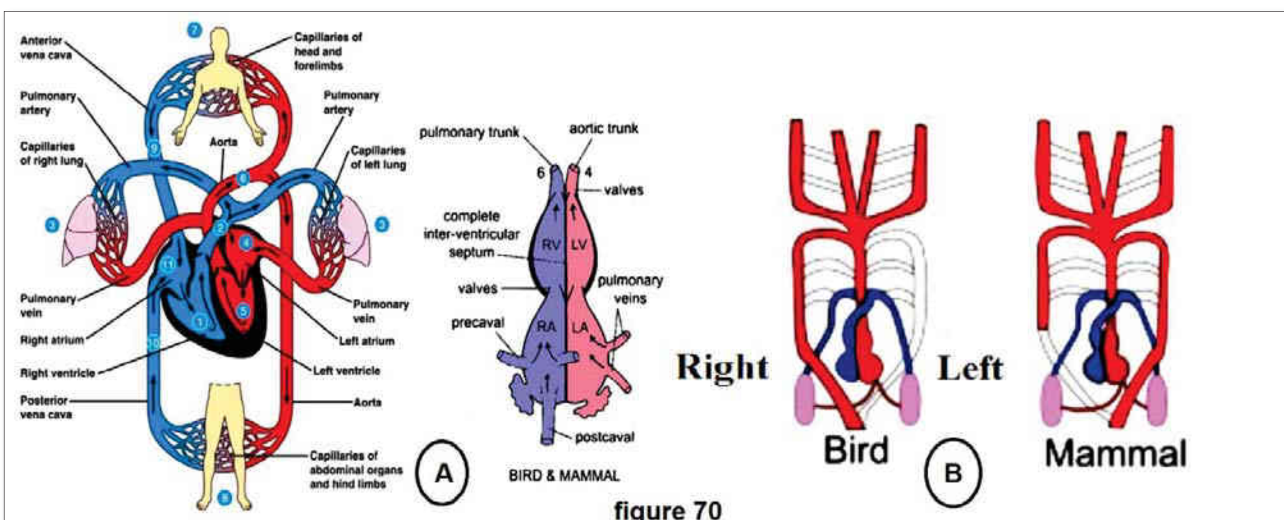


figure 70

Dorsal aorta

A. In fish, the dorsal aorta branches into the internal carotid arteries that supply oxygenated blood the head. Caudally, the dorsal aorta continues into the caudal artery, from which the following arteries:

- Coeliac and mesenteric (supply the abdominal viscera).
- Gonadal (supply the gonads).
- Renal (supply the kidneys). Intersegmental (associated with the myomeres).
- Subclavian (leads to the branchial arteries).
- Iliac (leads to the femoral arteries).

B. In tetrapods, the carotid system carries blood to the head and is derived from the third aortic arches. It is composed of:

1. the common carotid arteries, which branch into:
    - External carotid arteries, which supply the throat and the ventral part of the head.
    - Internal carotid arteries, which supply the brain and the rest of the head.
2. Dorsal aorta is the large median longitudinal artery that extends posteriorly and eventually branches into the caudal artery.

Other branches of the dorsal aorta include:

- Ventral visceral branches: the celiac artery, which leads to the stomach, duodenum, liver and pancreas, and the mesenteric artery, which serves the remainder of the liver and the gut.
- Lateral visceral branches: these branches serve the urogenital organs (renal, ovarian, spermatic)
- Dorsal somatic branches: these branches serve the spinal cord, muscles and skin.

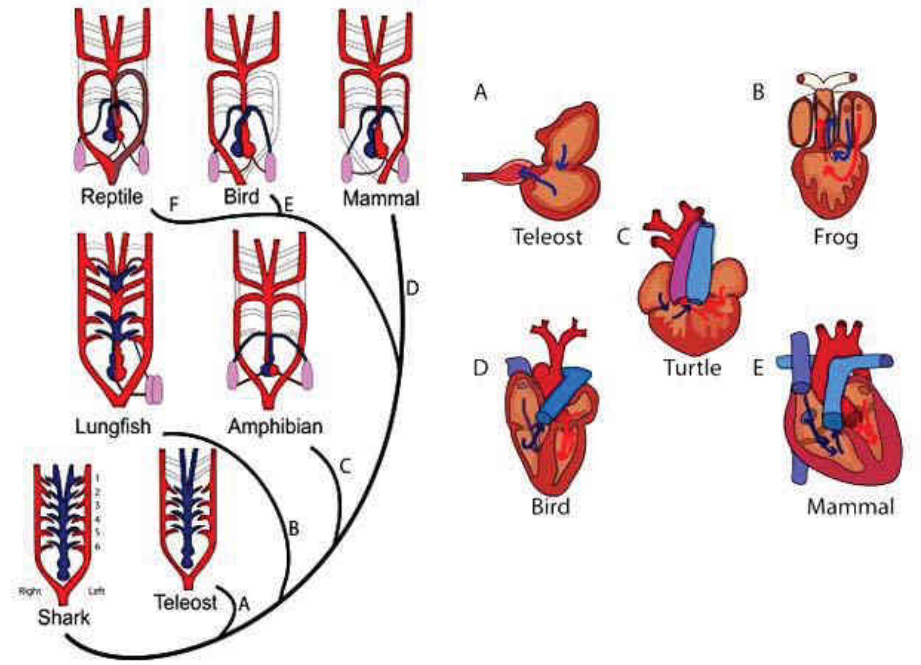
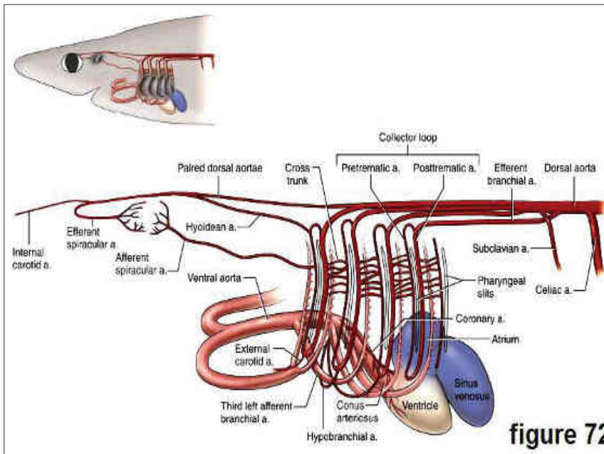


Figure 71: showed Aortic arches & Hearts of chordatae



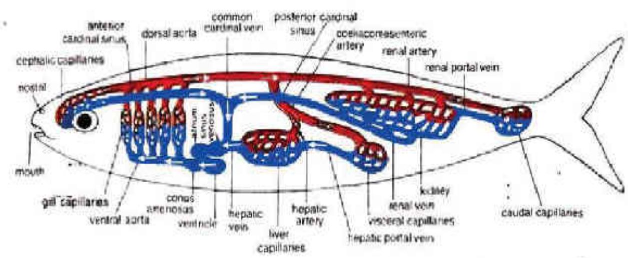


figure 72 Fish Circulatory system

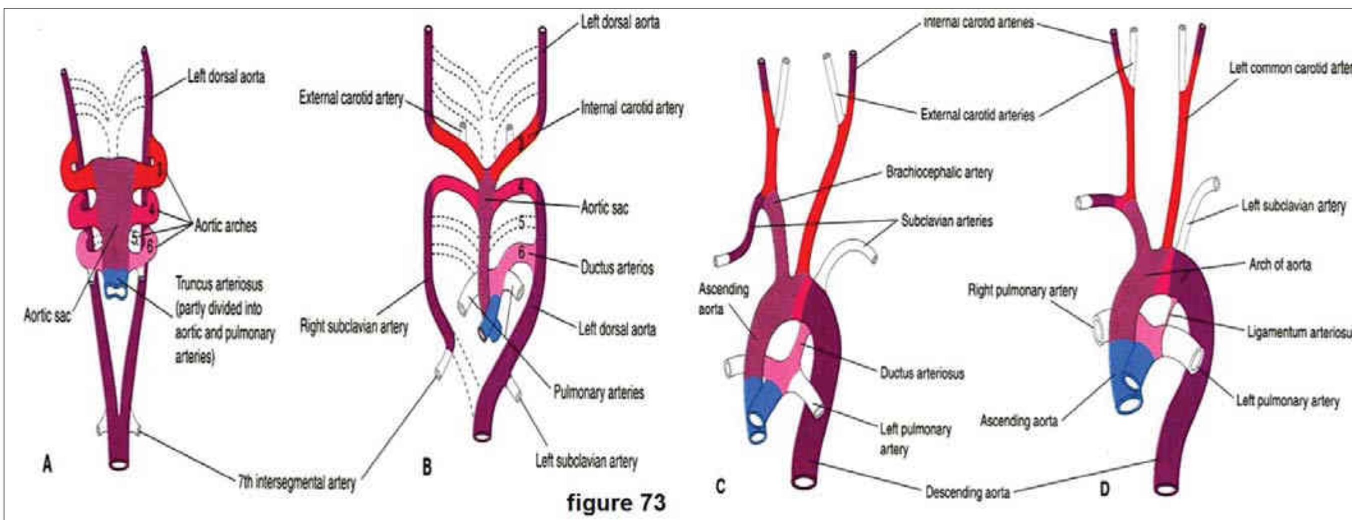


figure 73

The venous channels in sharks (Fig.74):

1. Cardinal streams: Sinus venosus receives all blood returning to heart. Most blood enters sinus venosus via common cardinals. Blood from head is collected by anterior cardinals. Post cardinals receive renal veins & empty into common cardinals.
2. Renal Portal stream: Early in development some blood from caudal vein continue fonvard as subintestina l (drains digestive system); this connection i s then lost. During development, afferent renal veins (from old postcardinals) invade kidneys, & old postcardinals near top of kidneys are lost; all blood from tail must now enter kidney capillaries.
3. Lateral Abdominal stream: Lateral Abdominal vein starts at pelvic fin (where it receives iliac vein) & passes along lateral body wall; receives brachial vein, then turns, becomes subclavian vein, & enters common cardinal vein.
4. Hepatic portal stream & Hepatic sinuses: Among 1st vessels to appear in vertebrate embryos are vitelline veins (from yolk sac to heart). One vitelline vein joins with embryonic subintestinal vein (that drains digestive system) & becomes the hepatic portal system. Between liver & sinus venosus, two vitelline veins are known as hepatic sinuses

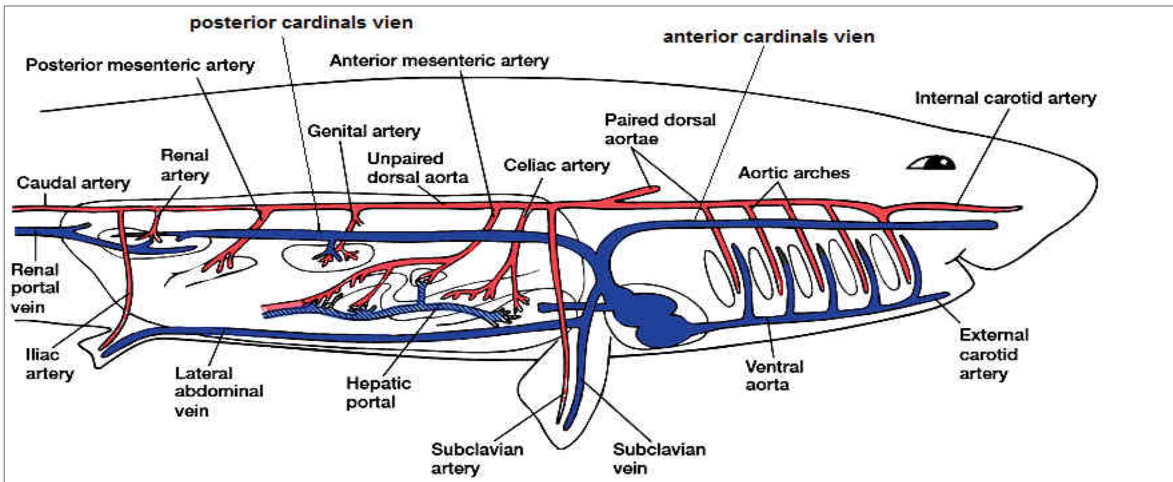


Figure74: Basic vertebrate circulatory pattern illustrated in a shark. The heart pumps blood to the ventral aorta, from which it is distributed to the paired aortic arches and then to the single dorsal aorta. From the dorsal aorta, blood flows forward to the head and posteriorly to the body, where major branches carry it to visceral and somatic tissues.

Venous channels in other fishes are much like those of sharks except:

- Cyclostomes have no renal portals.
- In most bony fishes, the lateral abdominals are absent & the pelvic fins are drained by postcardinal.

Venous channels of tetra pods

Early embryonic venous channels are very similar to those of embryonic sharks. Changes during development include:

Cardinal veins & precavae embryonic tetrapods have posterior cardinals, anterior cardinals, & common cardinals.

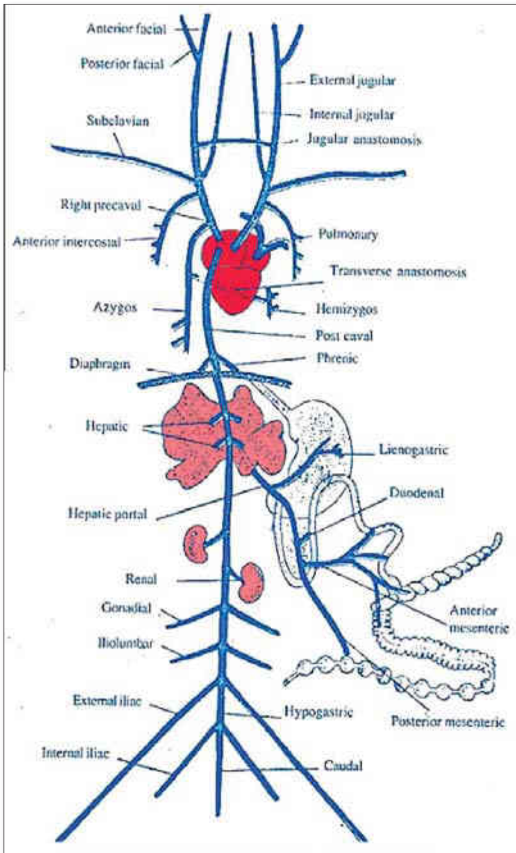
- Urodeles: posterior cardinals persist between caudal vein & Common cardinals in adults.
- Anurans, most reptiles, & birds: posterior cardinals are lost anterior to kidneys.
- Mammals: right posterior cardinal persists; part of left posterior cardinal persists.

Note: Common cardinals in tetrapods are called precavae; anterior cardinals are called internal jugular veins. Some mammals (e.g., cats & humans) lose the left precava; the left brachiocephalic carries blood from left side to right precava (sometimes called superior vena cava).

1. Postcava: Both posterior cardinals begin to develop in embryos, but only one persists & becomes the postcava. The postcava passes directly through the liver (sort of an 'expressway ' for blood from kidneys & the posterior part of the body to the heart). The postcava is sometimes called the inferior vena cava. In crocodilians, birds, & mammals, veins from hind limbs connect directly to postcava.
2. Abdominal stream: Early tetrapod embryos - paired lateral veins (like lateral

abdominals of sharks) begin in caudal body wall near hind limbs, continue cranially, receive veins from forelimbs, & empty into cardinal veins or sinus venosus. As development continues:

- Amphibians: Two abdominal veins fuse at midventral line & form ventral abdominal vein. Blood in this vessel goes into liver capillaries & abdominals anterior to liver are lost (so abdominal stream no longer drains anterior limbs).
- Reptiles: Two lateral abdominals do not fuse but still terminate in liver capillaries (so do not drain anterior limbs).
- Birds: retain none of their embryonic abdominal stream as adults.
- Mammals: no abdominal stream in adults (Fig.75).



VENOUS-SYSTEM-RABBIT
figure75

A.Renal Portal System (Fig.76A)

1. The renal portal system is derived from the posterior cardinal veins.
2. Blood from the posterior part of the body flows into the renal portal veins, which passes into the caudal vena cava.
   - Amphibians & some reptiles: acquires a tributary external iliac vein which carries some blood from the hind limbs to the renal portal vein. This channel provides an alternate route from the hind limbs to the heart.
   - Crocodilians & birds: some blood passing from hind limbs to the renal portal by-

passes kidney capillaries, going straight through the kidneys to the postcava.

- Mammals - renal portal system not present in adults.

B.Hepatic Portal System (Fig.76B)

- It is similar in all vertebrates; drains stomach, pancreas, intestine, & spleen & terminates in capillaries of liver.
- The hepatic portal system is derived from the subintestinal system. The hepatic portal vein receives blood from the gut region.
- Posterior to the liver the blood is collected into the hepatic vein, which joins with the caudal vena cava.

C.Coronary and pulmonary veins (Fig.76C):

- Pulmonary veins carry oxygenated blood from lungs to left atrium in lungfish & tetrapods. There are four pulmonary veins, two from each 1ung. The pulmonary veins are among the few veins that carry oxygenated blood.
- Coronary veins of the heart that drain blood from the capillary beds of the myocardium through the coronary sinus into the right atrium. A few small coronary veins that collect blood from a small area in the right ventricle drain directly into the right atrium.

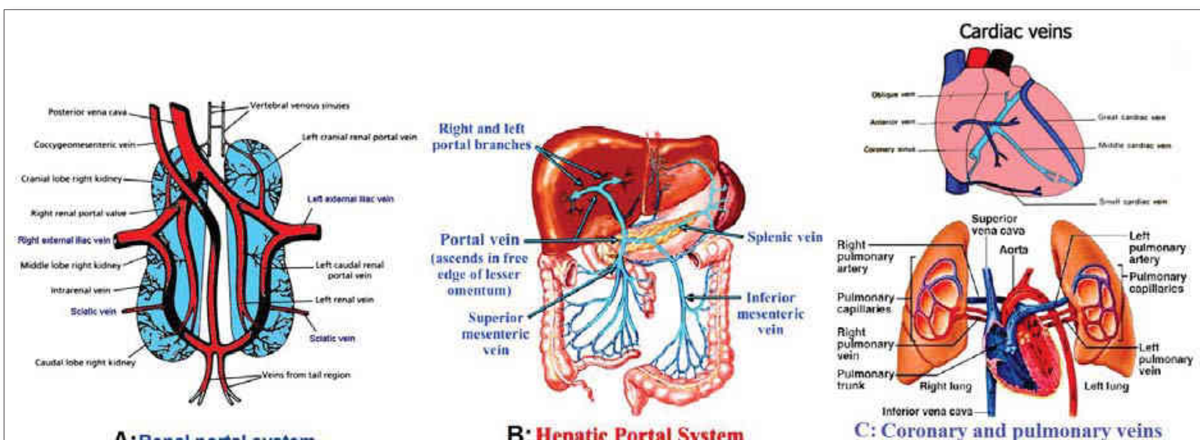


Figure76

Lymphatic system

Found in all vertebrates; consists of lymph vessels, lymph nodes, &, in some species, lymph hearts.

- Lymph vessels: found in most soft tissues of the body & begin as blind-end lymph capillaries that collect interstitial fluid valves present (in birds & mammals) that prevent backflow empty into 1 or more veins (e.g., caudal, iliac, subclavian, & posterior cardinal)
- Lymph node: located along lymph vessels; contain lots of lymphocytes & macrophages (phagocytic cells).
  - Lymph hearts: consist of pulsating smooth muscle that propels lymph fluid through lymph vessels; found in fish, amphibians, & reptiles.