Circulatory System in Vertebrates

- An adequate internal system for circulating nutrients and other materials throughout the body becomes necessary, called circulatory system.

x: In one celled body of Protozoans, distribution occurs through cytosis or streaming movements of cytoplasm.

- In simple and less active multicellular animals (Porifera, coelenterata, Helminthes etc.) exchanges occur by simple diffusion between various adjacent parts of their bodies.

- But most higher invertebrates and vertebrates are large and active, with most body organs and tissues well removed from exterior or gut. they possess a well-developed circulatory system for rapid internal transport of gases, nutrients, wastes etc.

Parts of circulatory system:

- chordates have a completely closed circulatory system
- Further distinguished into two systems → (I) blood vascular, (II) lymphatic

(I) Blood vascular system.

It consists of:
- (I) Heart
- (II) Arteries
- (III) Veins
- (IV) Capillaries
- (V) Blood

(I) Heart: – is modified blood vessels with muscular walls

(II) Arteries: – are blood vessels that carry blood away from the heart

(III) veins: – carry blood towards heart from capillary networks.

(IV) Capillaries: – minute tubes with thin walls in tissues, that connects the smallest arteries (arterioles) with the smallest veins (venules).

(V) Blood: – consists of fluid plasma and free cells or blood corpuscles.

- When blood flows through capillaries connected by arteries and veins, the blood vascular is said to be 'closed' as in annelids and vertebrates

x: on the other hand, molluscs and arthropods lacks capillaries and have an 'open' or 'lacunar' system.

① Lymphatic System:

- It occurs exclusively in chordates, except cyclostomes and cartilaginous fishes and consists of lymph and lymph channels.

(i) Lymph
(ii) Lymph Capillaries (iii) Lymph vessels (iv) Lymph nodes

(i) **Lymph**: is the tissue fluid lying between and bathing body cells.
- It is similar to blood plasma but lacks the R.BCs and some protein.

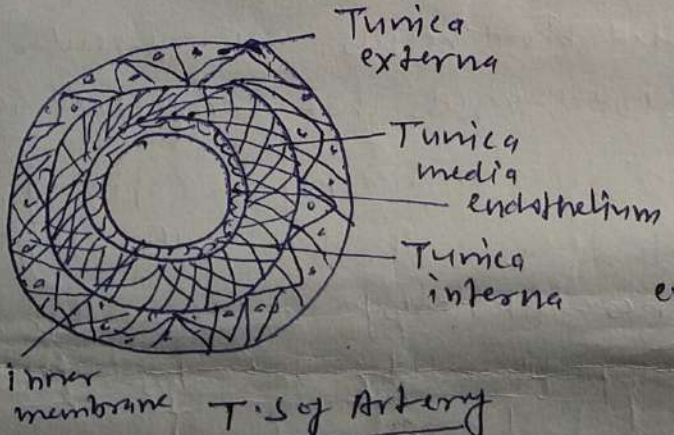
(ii) **Lymph Capillaries**: forming a network of minute blind ending channels, collect lymph.

(iii) **Lymph vessels**:- larger thin walled vessels formed by the union of lymph capillaries and finally emptying into veins.

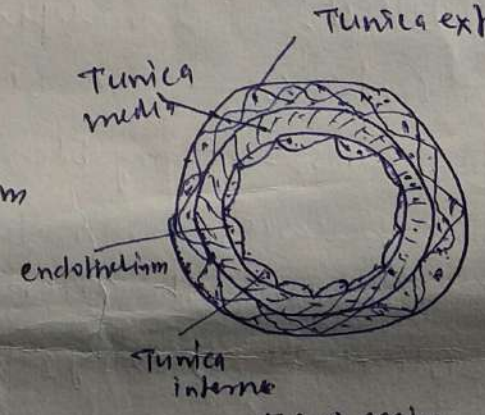
(iv) **Lymph nodes**: found only in mammals on lymph vessels, produce lymphocytes of blood and form an important link in body's defence mechanism.

Blood vascular System:

Blood always travels in tubes or blood-vessels of three kinds; arteries, capillaries and veins. Arteries generally carry the blood away from the heart, and veins towards the heart. Generally, arteries break up into arterioles of lesser diameter than the arteries of their origin, the arterioles subdivide into to arterial capillaries, similarly, venous capillaries join to form venules, which join to form veins of diameter larger than the venules. The capillaries are thus the thinnest vessels, roughly of 4/1,000 to 12/1,000 mm in diameter, where the arteries and veins seem to join.



T.S of Artery



T.S of vein

Arteries and veins have three coats. Beginning from the inside, these are: tunica interna or intima, the tunica media and the tunica externa or adventia. Intima is made up of flattened polygonal endothelial cells of mesodermal origin and is supported externally by a thin layer of elastic fibres forming internal elastic membrane. veins generally do not have the internal elastic membrane. The middle layer is composed of unstriped muscles and elastic fibrous tissues in a circular fashion. The outer coat is formed of strong collagen and elastic fibres that run longitudinally.

The three coats in the veins are less easily distinguished, tunica externa is the main layer and the tunica media is thin. It is because of the weak tunica media that the veins are thin walled and collapse when empty. All medium-sized veins in higher vertebrates have paired semilunar valves composed of a core of elastic tissues derived from the tunica media and covered with the endothelium (tunica interna). The valves prevent the back-flow of blood.

Blood capillaries are extremely thin blood vessels having only the endothelial layer supported on a basement membrane. Through the thin walls of capillaries not only materials can easily pass either side, but W.B.Cs also make their way through the inter-cellular pores.

The Heart.

All vertebrates have a pulsating heart that receives blood from the parts of the body at the posterior end by means of veins and pumps it into the arteries at the anterior end, which supply the blood to various organs including the breathing organs. Heart is always ventral to the gut, lying in a special coelomic compartment, the pericardium, separated from the rest of the body cavity by a transverse septum. In fishes, the septum is incomplete, and perforated by pericardio-peritoneal canals. The pericardium, like the peritoneal cavity, is lined with a parietal and a visceral layer of mesothelium. The outer mesothelium is the pericardial membrane, the inner is closely applied over the heart and is known as the epicardium. A serous (watery) pericardial fluid fills the space between the two mesothelial membranes.

1. Branchiostoma:

There is no heart as such, the moving force of the blood is provided by the muscular walls of the ventral aorta. In addition there are pulsatile bulbils at the origin of aortic arches, which provide additional force.

2. Cyclostomes:

The heart is two-chambered and the auricle lies on the left side of the ventricle, the sinus venosus is rather small and situated in the groove between auricle and ventricle. Conus arteriosus is rudimentary and 8 pairs of afferent branchial arteries arise from the ventral aorta. The base of ventral aorta is swollen to form the bulbous arteriosus. A single set of semilunar valves is present in the conus.

Blood from the gills is collected in a series of efferent branchial arteries that lead into the lateral aortae. At the anterior end the two aortae meet to form a cephalic circle from which arteries supply the head region. All other organs are supplied by arteries from the dorsal aorta.

3. Fishes:

They have two-chambered and purely venous heart, an undivided thin walled atrium or auricle receiving all the venous blood, and an undivided ventricle with thick muscular walls, pumping the blood into the conus arteriosus, which in turn, pushes the blood in to the ventral aorta and aortic arches for oxygenation. Thus only venous blood passes through the heart; this is known as 'single' type of circulatory system.

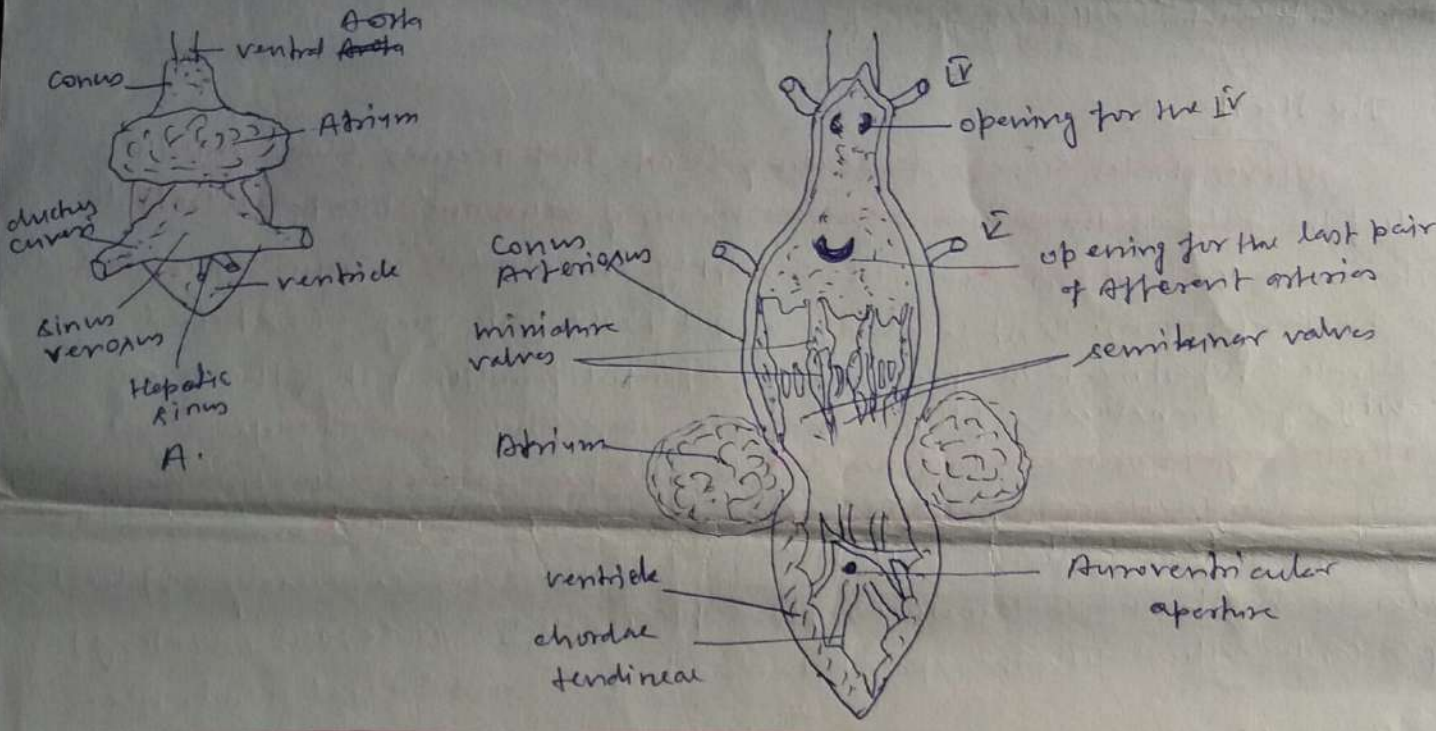


Fig: Scoliodon: The Heart: A- dorsal view B- dissection from ventral side (enlarged

The heart of Scoliodon is situated below the pharynx, and the pericardial cavity surrounding it communicates with the abdominal cavity by means of pericardio-peritoneal canals passing through the septum transversum. The atrium is a large triangular spongy and thin walled sac communicating dorsally with the sinus venosus by means of a sinu-auricular aperture guarded by a pair of valves and ventrally with the ventricle by a large atrio-ventricular aperture. The sinus venosus is a transversely elongated chamber with walls thinner than those of the atrium. It receives venous blood by a pair of large lateral veins, the ductii ~~cuvie~~ Cuvieri, and a pair of posterior hepatic sinuses.

Rhythmicity of Heart:

Rhythmic contraction of the heart is under the control of autonomic nervous system and special cardiac centres in the medulla oblangata regulate the heart-beats. Besides this 'central' control, there is a localized centre in the heart itself, which initiates and regulates the contraction. In fishes and all other vertebrates lower than birds and mammals, it is in the form of a patch of cardiac muscles-fibres of unusual type in the wall of ~~sinus~~ sinus venosus very close to the sinu-auricular opening and is known as sinuauricular node. The node is supplied by the vagus nerve having parasympathetic fibres. A wave of contraction arises from the node in the sinus venosus and passes on ~~the~~ to the auricle, ventricle and cones through the specialized cardiac muscles of the heart. Mixed with cardiac muscles are ganglia and nerve fibres but the actual wave spreads through the muscles. The fish's heart is myogenic in nature like those of molluscs and other vertebrates.

4. Amphibia: ~~The heart of the Indian frog Rana tigrina~~:

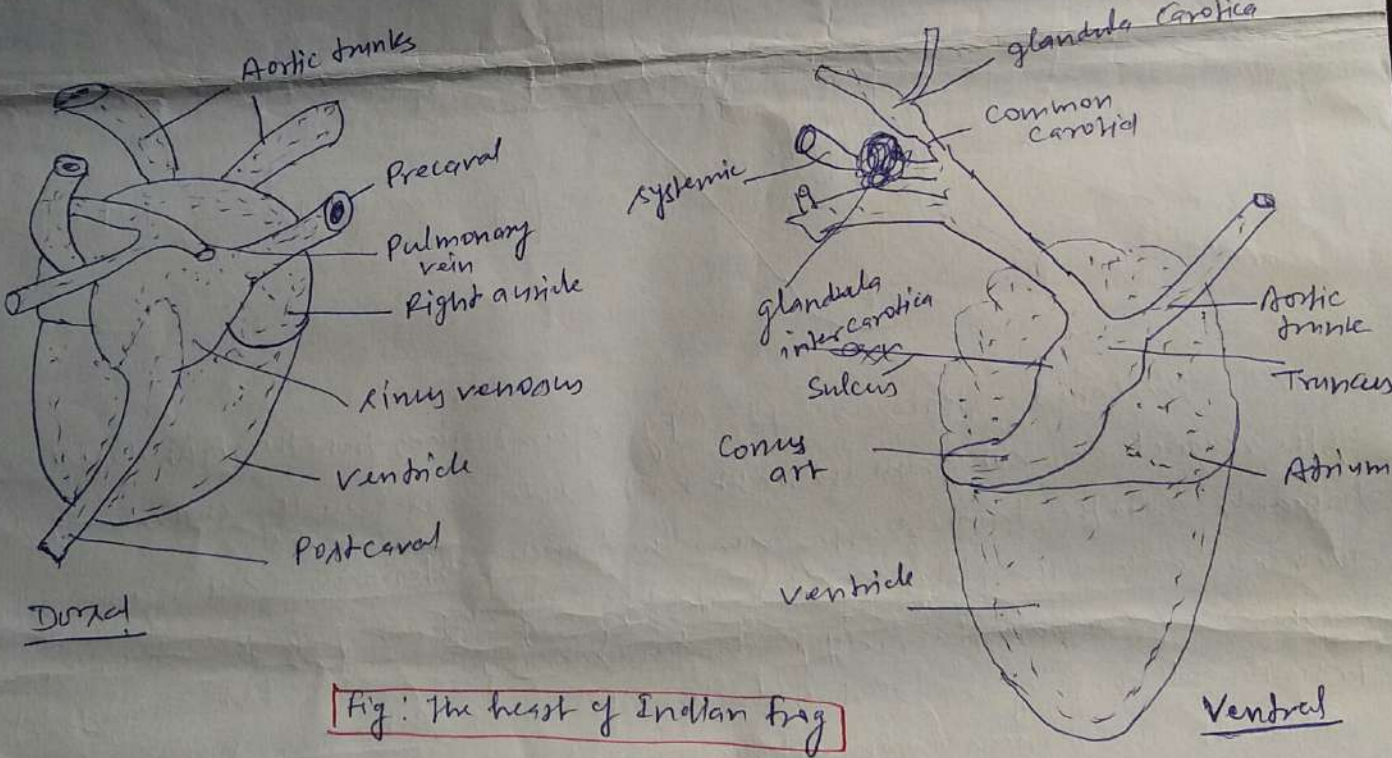


Fig: The heart of Indian frog

~~The heart of this frog was studied by several workers in India~~

The heart of Rana tigrina is basically 3-chambered; the right and left auricles (atria) and the ventricle. In addition, there is a sinus venosus and a conus or arteriosus. Since the interauricular septum is shifted more towards the left, the division of auricle is unequal, right auricle being larger and almost of double the size of the left auricle. The sinus venosus is a triangular chamber on the dorsal side and receives venous blood from three large veins,

two precaval and a post caval. well-oxygenated blood from the lungs is brought in the left auricle by means of two pulmonary veins, which join before opening into the left auricle. Sinus venosus shoots its blood into the right auricle. Ventricle is roughly as long and broad as the auricles put together, the apex is bluntly rounded and not conical as usually

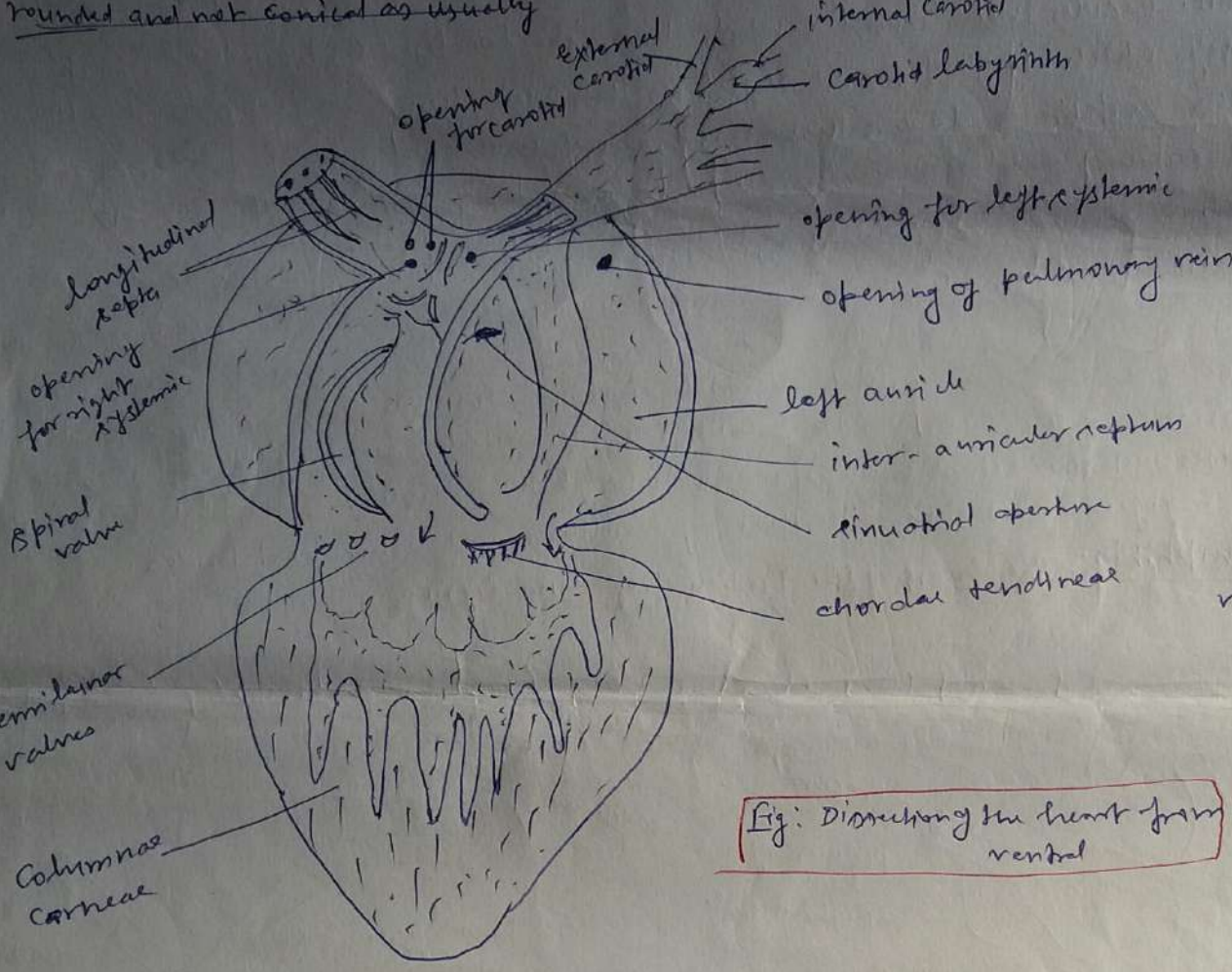
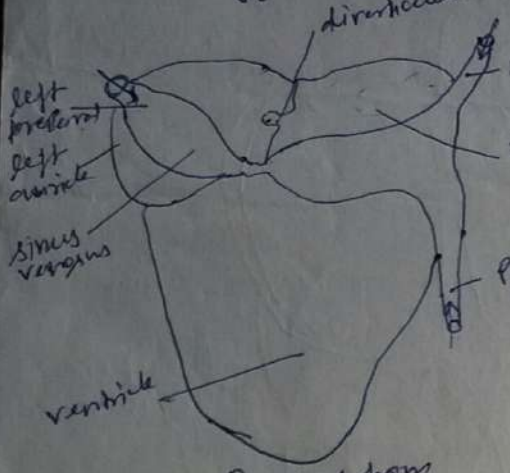


Fig: Dissecting the heart from ventral

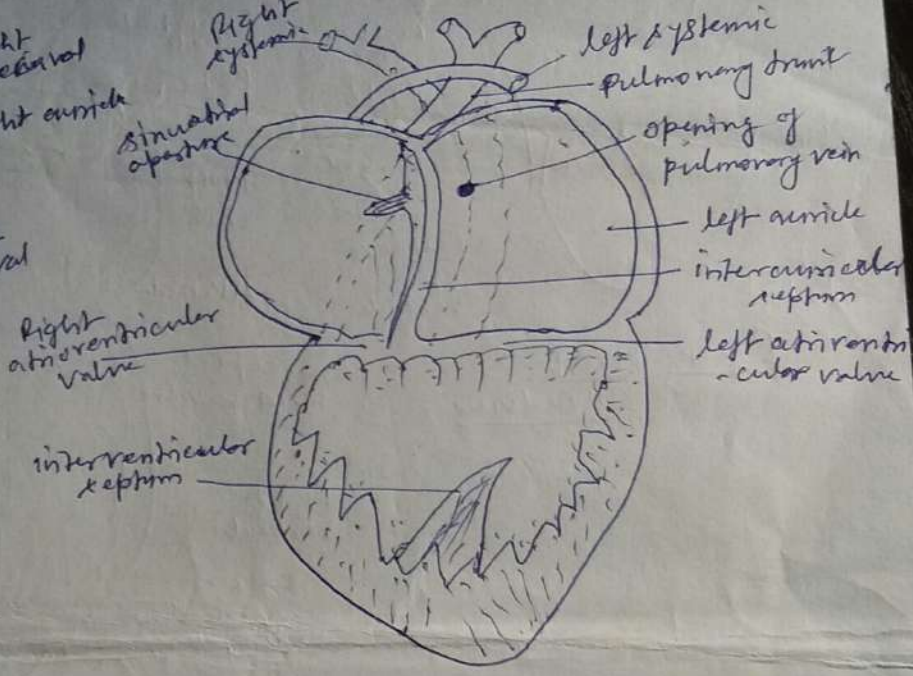
The conus arteriosus (~~cpo~~ (pylangium) arises from the right dorsal side of the ventricle and not from the right ventral side as is usually shown. It leads forwards into the truncus arteriosus. The truncus arteriosus (syrangium) represents the ventral aorta of the fishes and is morphologically different from the conus arteriosus as there is a complete absence of cardiac muscles in the truncus, but characteristically present in all parts of the heart including the conus. whereas conus is a part of the heart, the truncus is an artery. Truncus is demarcated from the conus by a transverse groove the sulcus. Conus is twisted spirally to the left before it joins the truncus.

5. Reptilia:

They are the first truly land vertebrates in which respiration takes place only by means of lungs. Hence there are two distinct streams of blood passing through the heart - an oxygenated stream through the left side and a less-oxygenated stream through the right side of the heart.



A. Heart from dorsal side



B - dissection of heart

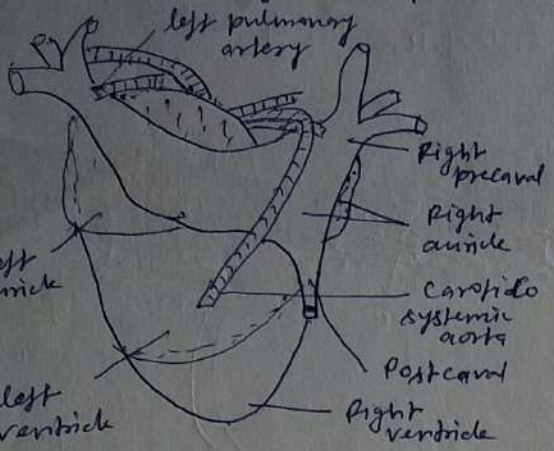
Fig: Uromastix

The heart of lizards Uromastix and Calotes are myogenic. Each has a thin-walled sinus venosus on the dorsal side closely attached to the auricles and formed by the meeting of the two precavals and one postcaval vein. There are no valves at the openings of caval veins into the sinus venosus. A constriction divides the sinus venosus into two parts.

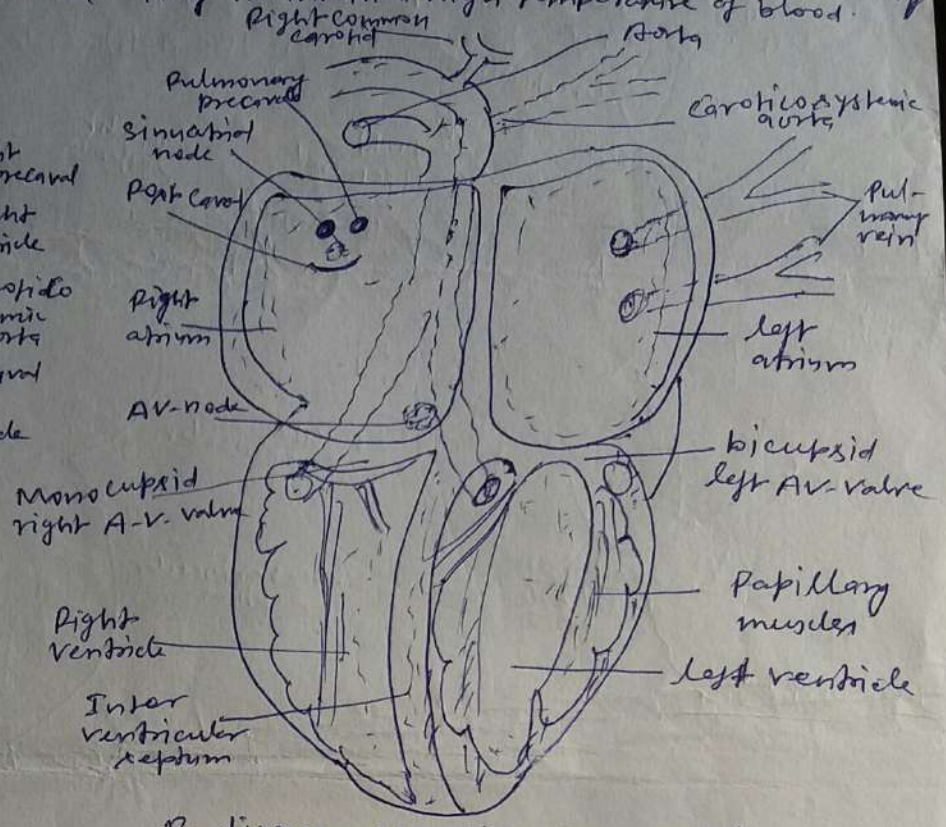
The sinuatrial aperture is a transverse slit in the right auricle guarded by folds of auricular wall. Right auricle is larger than the left and its antero-dorsal edges gives off a sac-like diverticulum of unknown significance. The inner surfaces of the auricles are raised into a network of muscular ridges, called musculi pectinati. The interauricular septum has a free posterior edges and divides the atrio-ventricular valve into right and a left half, thus the two auricles lead separately in to the ventricle. chordae tendinae are attached to the valves. Pulmonary veins opens into the left auricle by a common aperture unguarded by valve.

The left systemic also arises from the right side of the ventricle a bit ventrally, and crosses on to the left side. The right systemic arises from the left side of the ventricle and crosses over the right side. The two systemic connect with each other through the foramen of ~~Panizzi~~ Panizzae placed where the arches cross each other. Right auricle receives all the venous blood and left auricle all the oxygenated blood.

6. Birds. The first land vertebrates to have achieved Complete separation of pulmonary and systemic circulations are the crocodiles and birds. Pure oxygenated, and quick supply to the body including the head is one of the reasons contributing to the success of birds upon land. They maintain a high temperature of blood.



A. Pigeon: Heart Adorsal view



B. diagram of the dissection of the heart of a bird.

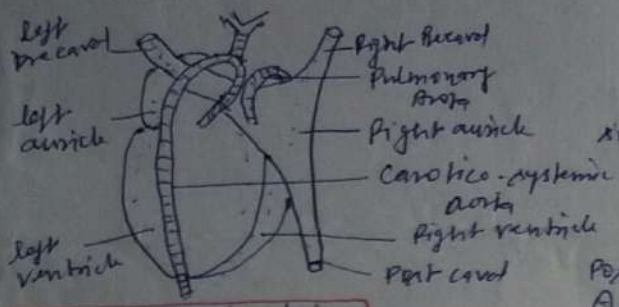
The heart of pigeon is of large size. It is four chambered; both auricle and ventricle are completely partitioned by septa and nowhere is there a chance of mixing up of the two kinds of blood. This is an important advancement made by birds over reptiles. The sinus venosus developed in the embryo is absorbed into the right auricle. The venous blood is thus returned directly into the right auricle by the three vena cavae. Four large pulmonary veins bring oxygenated blood from the lungs into the left auricle.

Larger birds have a relatively smaller heart and the heart-beat per minutes is also low; it comes to that the smaller birds have larger hearts and heart-beats are faster. Size of the R.B.C is also connected with the size of bird. RBC are smaller in actively flying birds than in the larger flightless birds.

The left atrio-ventricular aperture is guarded by a large valve with two flaps (the bicuspid valve) and separates the left auricle from the left ventricle.

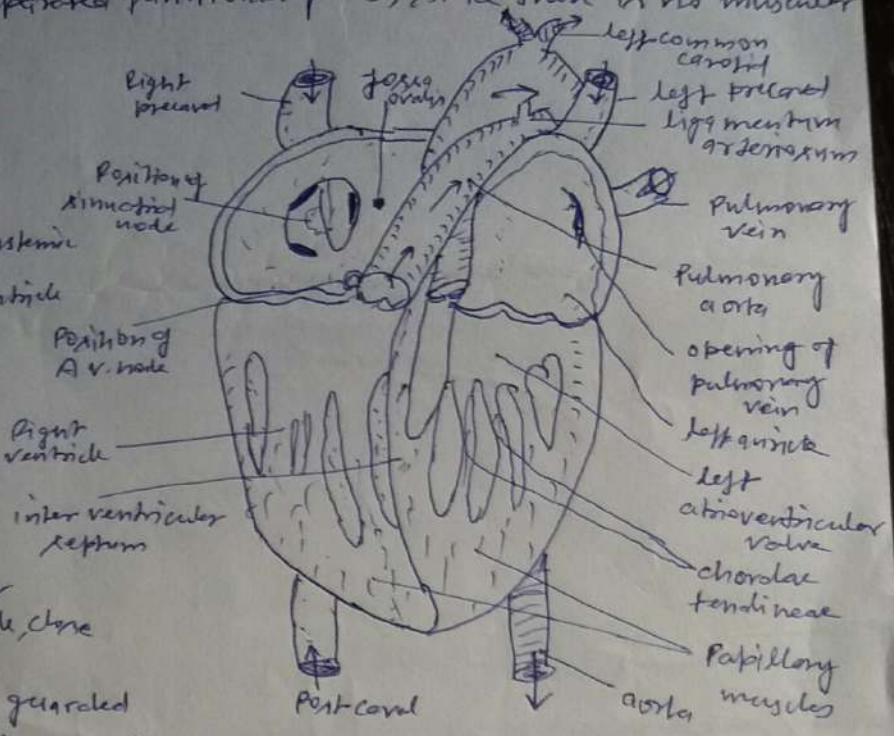
Right atrio-ventricular valve is in the form of a single large muscular fold only. chordae tendineae ~~of~~ attached to the left atrioventricular valve are inserted at the other ends to the strong muscular projections of the ventricular wall, called papillary muscles.

7. **Mammals**: the heart of mammals, such as that of rabbit, rat or of Squirrel is four-chambered, having completely divided auricle and ventricle. the auricles and ventricles are separated functionally also, since there is no muscular connection between them.



A- dorsal view

Fig: Mammalian heart



B. dissection from ventral

Sinus venosus is absorbed in to the right auricle early in the embryo and the sino-auricular node lies in the wall of right auricle, close to the point of entry of great veins.

Right atrioventricular opening is guarded by the atrioventricular valve composed of three somewhat irregular cones and corresponds to the tricuspid tricuspid valve of man's heart.

Strong chordae tendinea are stretched between the valves and the wall of the ventricle which is produced into thick muscular ridges called papillary muscles.

A single postcaval vein and two precaval veins enter the right auricle. Opening of postcaval in the atrium is guarded by the Eustachian valve.

Left atrioventricular opening is guarded by the atrioventricular valves composed of two membranous flaps and cusps and corresponds to the bicuspid valve of the heart. The valves of the heart operate passively opening and closing with the pressure of blood. Papillary muscles do not help to close the valves.

Typical Plan:

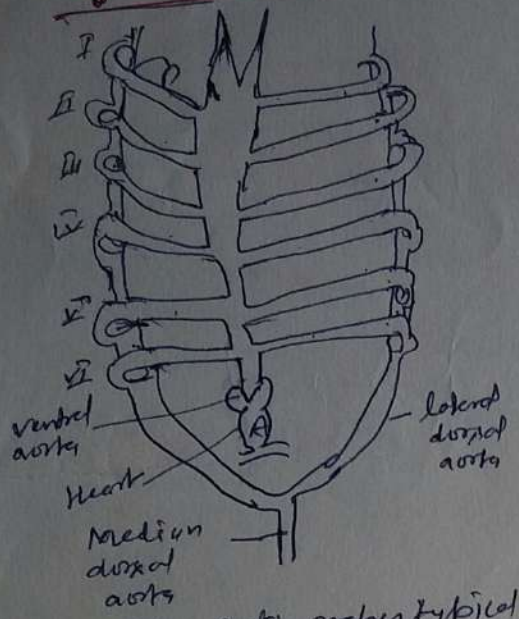


Fig: Aortic arches typical plan (ventral aorta)

The maximum number of aortic arches in a vertebrate is 6 pairs, however, there are exceptions, and since they develop in connection with the gill-clefts, they are named after the corresponding gill-arches of the visceral skeleton supporting the gill-clefts. According the first paired aortic arch is called the mandibular, the second is called the hyoid and the remaining arches are known as first, second, third and fourth branchial arches, or serially, they are the 3rd, 4th, 5th and 6th aortic arches, each lying in front of the corresponding gill-cleft. Aortic arches connect with the aortae directly before gills develop and an efferent system of arches is formed. Anterior continuations of the lateral and ventral aortae called radices (singular - radix) supply oxygenated blood to the head region.

① In Cyclostomes: The number of aortic arches is roughly the same as there are functional gill-clefts, e.g in Petromyzon there are 8 pairs, the first four pairs arise from the divided part of the ventral aorta, while the remaining four pairs arise from the unpaired part of the ventral aorta.

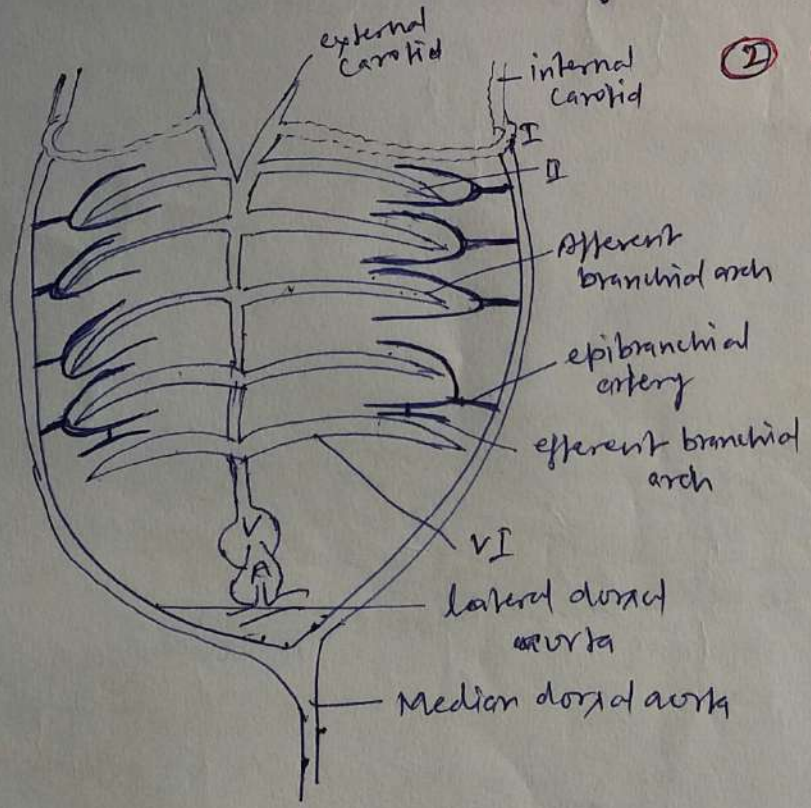


Fig: Aortic arches in elasmobranch fishes

heart 2-chambered

② In fishes: In the Elasmobranchs e.g Scoliodon, the ventral aorta divides at its anterior end and six pairs of arches appear in the embryo but then the mandibular pair disappears. The radices of ventral aorta become the external carotid arteries and those of the paired lateral aortae become the internal Carotid arteries. The adult aortic arches have corresponding efferent arches.

Further reduction takes place in the bony fishes, the Teleosts, where the mandibular and hyoid pairs disappear or remain as small branches of the 3rd arch, thus leaving only 4 pairs of aortic arches in the adult. Efferent arches connect with the lateral aortae.

3. Amphibia.

In the tailed Amphibia: In the tailed amphibia which have gills, at least in the larval condition, ventral aorta divides as usual into two radices or branches. Ist and 2nd pairs of aortic arches degenerate early, the 3rd arch together with the radix of the lateral aorta on each side becomes the internal carotid artery, the radix of ventral aorta becomes the external carotid artery, and the part of ventral aorta, from where the external and internal carotids seem to arise, becomes the common carotid. Thus the 3rd arch remains as the carotid arch, the 4th arch becomes the systemic arch, the 5th arch is usually reduced and 6th arch gives off a pulmonary branch to the developing lungs and a branch to the skin to become the pulmonary-cutaneous arch of the adult.

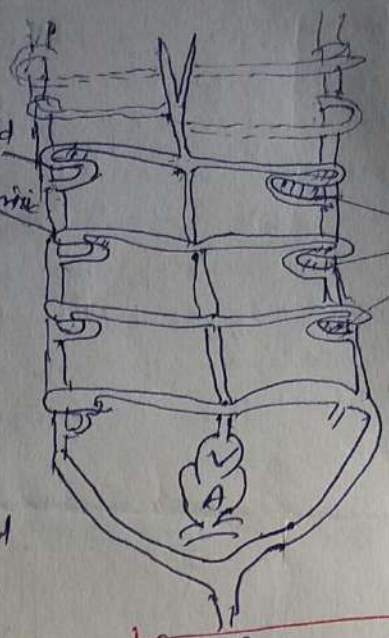


Fig: Aortic arches - frog's tadpole external gill stage.

In the tailless amphibia — In the tailless amphibia, such as the frogs, which pass through a tailed stage (tadpole), the aortic arches show change parallel to the changes in the respiratory organs. In the external gill-stage, arches from 3rd to 6th remain but only the 3rd, 4th and 5th arches break into the 3 pairs of external gills the 6th arch directly connects with the lateral aorta and gives off a branch to the developing lungs. The heart remains two-chambered i.e at the 'fish-stage'. In the internal gill-stage arches from 3rd to 6th connects with the internal gills, the 6th arch gives off a pulmonary branch to the lung and a cutaneous branch to the skin.

During metamorphosis, the 3rd aortic arch with the corresponding part of lateral aorta becomes the carotid arch, the 4th together with a part of lateral aorta becomes the systemic arch, the two systemic loop over and joins to form the common dorsal aorta, 5th arch disappears and the 6th, after losing its connection with the lateral aorta, becomes the pulmo-cutaneous arch.

④ Reptiles: only 3 pairs of aortic arches remain in the adult and ~~are no~~ at no stage in the life the gills develop. The 3rd arch becomes the carotid, 4th the systemic and 6th, the pulmonary. The radices of ventral and lateral aortae form the external carotid and internal carotid arteries respectively. Portions of lateral aortae between 3rd and 4th arches remain in some lizards and snake as ductii caroticus; ductii Botalli are also present in some.

Remarkable changes take place in the heart and aortic arches because of the tendency of separating the oxygenated blood from the deoxygenated. The auricle becomes divided into a right and a left chamber by the interauricular septum, the right receiving the deoxygenated blood from the sinus venosus and the left receiving oxygenated blood from the lungs.

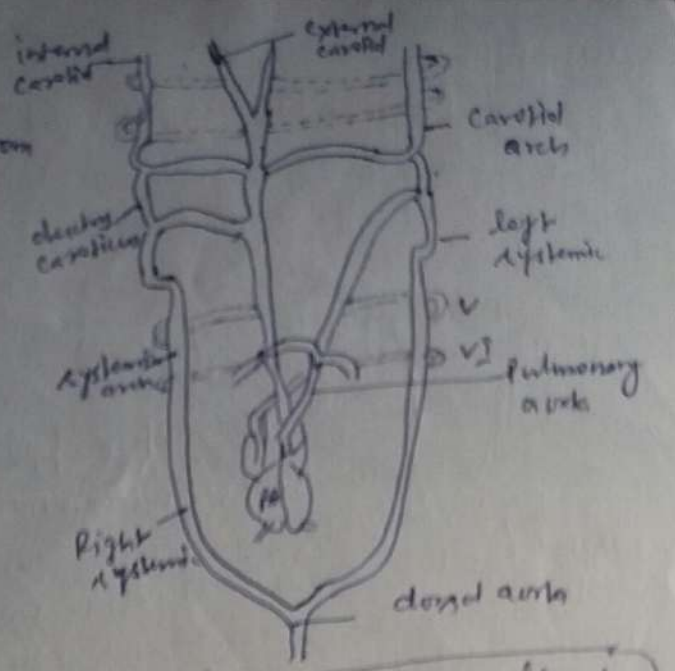


Fig: Aortic arches - A lizard heart 3-chambered ventricle only partially dividied

(c) Birds:

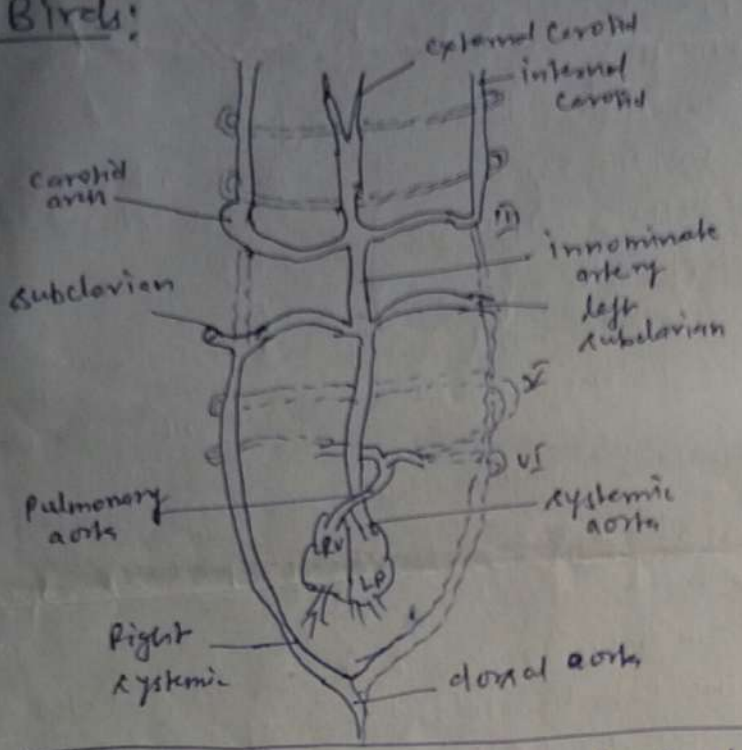


Fig: Aortic arches: Bird Heart 4-chambered

In Birds, aortic arches 1st, 2nd and 5th disappear soon after their appearance in the embryo, the other three remain in the adult as carotid, systemic and pulmonary. The heart shows further advancement by the complete division of the ventricle thus becoming 4-chambered. The right side of the heart receives the less oxygenated blood directly from the veins. The sinus venosus loses its separate identity by having merged with or absorbed in the right auricle, while the left side receives oxygenated blood. At no places in the heart or in the aortic arches mixing of blood occurs.

The conus and ventral aorta break up into two channels or aortae a right pulmonary aorta and a left systemic aorta opening in the ventricle of the corresponding side. The 4th aortic arch of the right side arises from the systemic aorta and together with the radix of lateral aorta becomes the systemic arch of the right side.

⑥ Mammals: In mammals, the heart is 4-chambered and the number and arrangement of aortic arches are the same as in the birds, except that in mammals, the 4th aortic arch of the right side loses its connection with the lateral aorta which degenerates, so that the median dorsal aorta is formed of the left systemic arch alone, arising from the left ventricle and carrying the oxygenated blood to the body. The 4th arch of the right side remains as the right subclavian artery. The left subclavian artery develops as an enlargement of one of the intersegmental arteries coming off the aorta in this region. Ductus arteriosus of the left side remains in the embryo till birth, later on it is reduced to ligamentum arteriosum.

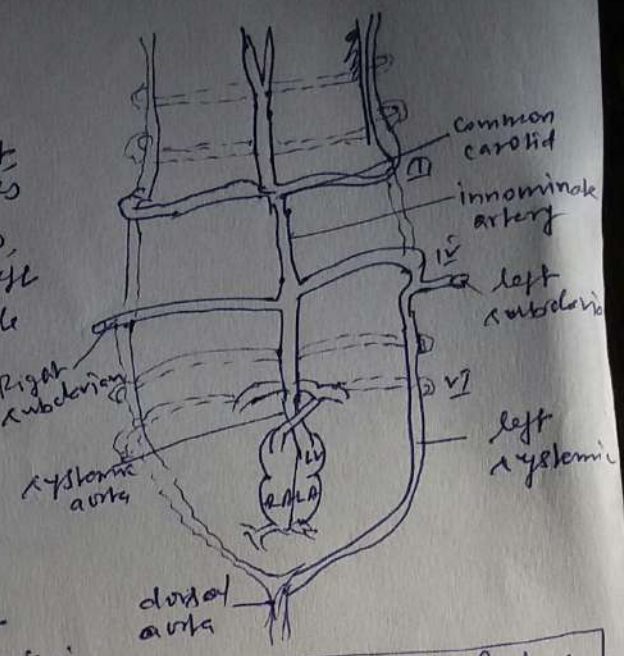


Fig: Aortic Arches: Mammal Heart 4-chambered

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