

COMPARATIVE ANATOMY OF HEART IN VERTEBRATES

Introduction: The heart is a hollow muscular organ that rhythmically contracts and relaxes. During each contraction-relaxation cycle, blood is drawn from the veins into a thin walled collecting chamber, the atrium, and is then passed to a second thick walled chamber, the ventricle, which forcefully contracts to distribute the blood to the arteries. Backflow is prevented by one-way valves.

Basic Plan: Phylogenetically, the heart probably began as a contractile vessel, much like those found within the circulatory system of amphioxus.

Pericardium

The heart is covered by **pericardium** - also called **pericardial sac**, which is a double-walled sac containing the heart and the roots of the great vessels. The pericardial sac has two layers, a serous (visceral) layer and a fibrous (parietal) layer. It encloses the pericardial cavity, which contains pericardial fluid.

Function

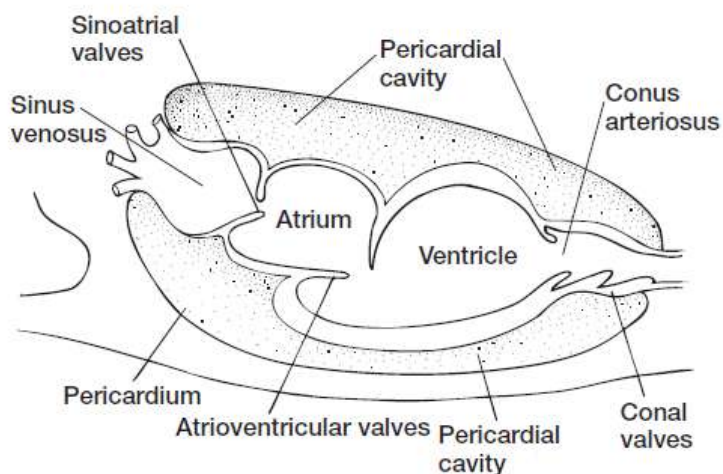
- Sets heart in mediastinum and limits its motion
- Protects it from infections coming from other organs
- Prevents excessive dilation of the heart in cases of acute volume overload
- Lubricates the heart

Cardiac Chambers:

In most fishes, the heart is part of a single circulation. Vessels serving gas exchange in the gills and systemic capillary beds are in series with each other. The basic plan of vertebrate heart is based on a primitive fish heart consisting four chambers, through which blood flows in the following sequence:-

- Sinus venosus**
- Atrium**
- Ventricle** and
- Finally the fourth and most anterior heart chamber, the **bulbus cordis**, before entering the ventral aorta.

Differences in structure,



ventricles.

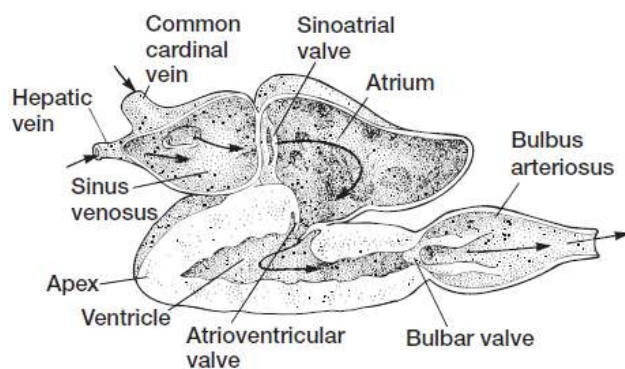
1. **Sinus venosus:** a large quadrangular cavity which precedes the atrium on the venous side of the chordate heart. In mammals, it exists distinctly only in the embryonic heart (where it is found between the two venae cavae).

2. **Atrium or Auricle:** the upper chamber through which blood enters the ventricles of the heart. The atria receive blood while relaxed (diastole), then contract (systole) to move blood to the

3. **Ventricle:** A ventricle is a large chamber with muscular walls toward the bottom of the heart that collect and expel blood received from atrium towards the peripheral beds within the body and lungs.
4. **Bulbus Cordis:**
 - a) Doubts about homology, and loose use of terms have led to confusion about nomenclature for this fourth chamber. According to K.V. Kardong (Vertebrates, 6th Ed, 2012) the term bulbus cordis is used form embryos.
 - b) In adults, this chamber is referred as **conus arteriosus** if its contractile walls possess cardiac muscle and as **bulbus arteriosus** if its elastic walls lack cardiac muscle. Internally, each may contain various numbers of conal valves.
 - c) A **conus arteriosus** is generally present in chondrichthyans, holosteans, and dipnoans.
 - d) Although absent as a distinct chamber in adult tetrapods, during development its embryonic forerunner, the bulbus cordis, divides into the bases of the major arteries leaving the heart.
 - e) In some fishes, most notably in teleosts, the bulbus arteriosus is thin walled with smooth muscle and elastic fibers, but it lacks both cardiac muscle and conal valves.
 - f) The adult bulbus arteriosus, like the conus arteriosus, arises generally from the embryonic bulbus cordis, but in some fishes the adult bulbus arteriosus may incorporate part of the adjoining ventral aorta as well.

Comparative account of Heart in different Vertebrate groups

A. Teleosts



1. Location: Heart is situated ventral to the oesophagus in the pericardial section of the coelom.

2. Covering: The heart is covered by a transparent protective covering, called pericardium. It is a single layer in fish. Within pericardium there is a pericardial fluid, protects the heart from the external injury.

3. Organs: Heart of fishes consists of 3-chambers — a sinus venosus, a single auricle and a single ventricle. No conus arteriosus. The embryonic heart of fish-es

consists of 4 chambers which include sinus venosus, auricle, ventricle and bulbus cordis but in adult the term conus arteriosus may be used instead of bulbus cordis if it possesses cardiac muscles (fig).

But according to Hildebrand (1982), the bulbus arteriosus is found in the portion of conus (Conus arteriosus) in teleosts which does not possess cardiac muscle but is highly elastic and passively evens the flow of blood into the afferent branchial arteries.

4. Sinus Venosus: Sinus venosus is a thin-walled sac. It receives deoxygenated blood by two precaval veins or ductus Cuvieri. It opens to the auricle by sinuauricular aperture, guarded by valves.

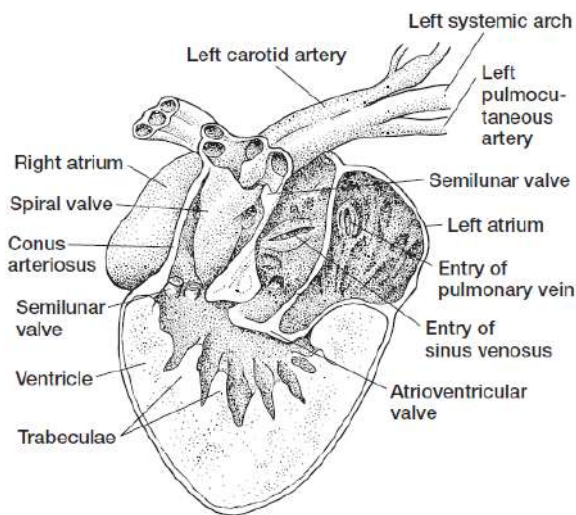
5. Auricle: Auricle is a thin-walled single chamber of the heart. It opens into the ventricle by auriculoventricular aperture. This aperture is guarded by valves. Sinus venosus and auricle both constitute the receiving chambers of the heart.

6. Ventricle: Single, conical, thick-walled, forwarding chamber of the heart.

7. Conus Arteriosus: There is no conus arteriosus. The bulbus aorta is a dilated part at the base of the ventral aorta, and not regarded as the part of the heart. It is the part of the arterial system.

8. Mechanism of Circulation: It is a kind of venous heart because only deoxygenated blood flows through sinus venosus and from auricle to ventricle. The flow of blood maintains uni-directional flow. Hence it is called single circuit heart and is called primitive type heart among vertebrates.

B. Amphibia



1. Location: Heart is located mid-ventrally in the anterior part of the body cavity.

2. Covering: The heart is covered by a transparent protective covering, called pericardium. It is a single layer in fish. Within pericardium there is a pericardial fluid, protects the heart from the external injury.

3. Organs: 5 chambers. Sinus venosus, two auricles, single ventricle and conus arteriosus (Fig. 10.144C). Out of 5 chambers, the two auricles and single ventricle are regarded as permanent chambers, and sinus venosus and conus arteriosus are considered as accessory chambers.

4. Sinus Venosus: It is a dorsally placed, thin-walled triangular sac, formed by the union of two precavals and a post caval. It receives deoxygenated blood by three vena cavae. It opens into right auricle through sinuauricular aperture which is guarded by sinuauricular valve. It is well-developed.

5. Auricle: There are two unequal sized auricles. The left auricle is smaller than the right. Two auricles and a sinus venosus are the receiving parts of the heart. The two auricles are placed anterior to the ventricle. These auricles are separated internally by inter-auricular septum. Both the auricles are sharply marked off from the ventricle externally by a narrow constriction, called coronary sulcus.

The left auricle receives oxygenated blood from the lungs, through two pulmonary veins. The right auricle receives deoxygenated blood from the sinus venosus through sinuauricular aperture. Two auricles open into the ventricle by a common auriculoventricular aperture.

This aperture is guarded by membranous valves, called auriculoventricular valves. The valves remain attached with the wall of the ventricle by fine thread-like Chordae tendineae.

6. Ventricle: Single, thick-walled highly muscular forwarding chamber, with the apex pointed towards the caudal end. The inner wall of the ventricle is thrown into muscular ridges, known as columnae carnae.

7. Conus Arteriosus: From the base of the ventricle arises a stout tube-like structure called conus arteriosus (Pylangium) which proceeds forward as truncus arteriosus (Synangium). The lumen of the conus arteriosus is divided into two Channels by a spiral valve.

The left channel of the spiral valve is known as cavum pulmocutanum and the right one is called cavum aorticum. Each branch of truncus arteriosus gives three arches, known as carotid, systemic and pulmonary.

The deoxygenated blood passes through the cavum pulmocutaneum to the lungs through the pulmonary arch and less oxygenated blood travels through the cavum aorticum to the different parts of the body and cephalic region.

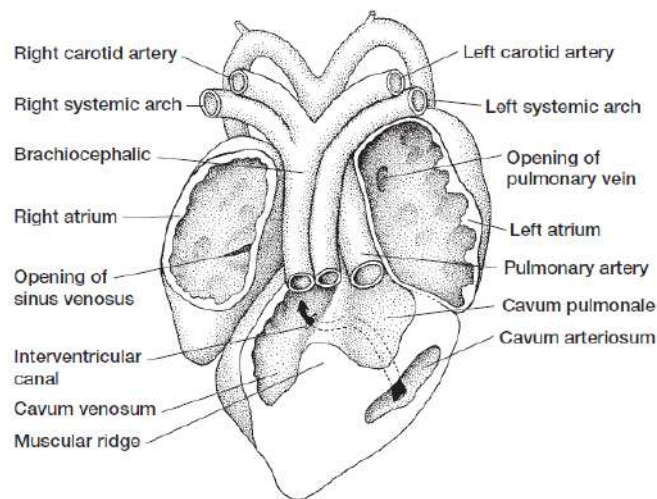
Remark: The truncus arteriosus is not to be considered as the part of the heart. It is the basal stem of the three main arteries.

8. Mechanism of Circulation: The right auricle receives deoxygenated blood and left auricle receives oxy-genated blood. The two auricles contract and the blood is driven to the ven-tricle. The blood mixes into the lumen of the ventricle and by contraction, reaches into the conus arteriosus.

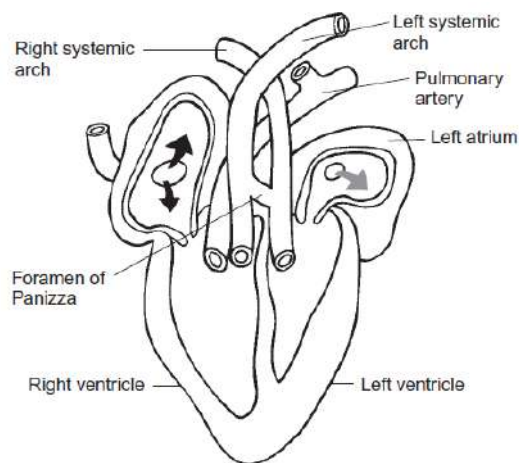
As the conus arises from right side, a large quantity of deoxygenated blood goes to the cavum pulmocutaneoum, then goes to the pulmocutaneous arteries. The mixed blood from the middle region of the ventri-cle goes to the systemic arches though the cavum aorticum and lastly the oxy-genated blood goes to the carotid arteries.

Ultimately the spiral valve helps in the entry of blood into different arches. Therefore, it pre-sents a transitional stage due to separation of auricle.

C. Reptilia



Lizard Heart



Crocodile Heart

- 1. Location:** Heart is located in the anterior part of the thoracic cavity.
- 2. Covering:** The heart is covered by a transparent protective covering, called pericar-dium. It is a single layer in fish. Within pericardi-um there is a pericardial fluid, protects the heart from the external injury.
- 3. Organs:** In Calotes, there are 3 perma-nent chambers — two auri-cles and an incompletely divided ventricle, but there is no conus arteriosus (Fig.). In crocodiles, the heart is completely 4-chambered — the two auricles, and two completely divided ventricles. In crocodiles, no sinus venosus and conus arteriosus (Fig.).

4. Sinus Venosus: The sinus venosus of reptiles represents from larger size (turtles) to small or vestigial in other groups. It is a thin-walled triangular receiving chamber placed dorsal to the auricles. It receives deoxygenated blood by three venae cavae, two anterior and one posterior.

It opens into right auricle through sinuauricular aperture, guarded by sinuauricular aperture. In crocodile the sinus venosus is absent. In lizards the sinus venosus is the first chamber and contains the pace-maker.

5. Auricle: There are two auricles, known as right and left auricles. These are thin-walled receiving chambers and placed anterior to the ventricle. The auricular region is wider than the ventricular portion and right auricle is larger than the left.

The inner lining of the right auricle is provided with a number of muscular ridges, known as muscoli pectinati. It receives the deoxygenated blood. The left auricle receives oxygenated blood through a common pulmonary vein.

The pulmonary aperture is circular in outline and not provided with valves. Internally the two auricles are separated by an inter-auricular septum which extends posteriorly within ventricle and possesses its tip auriculoventricular valves.

The two auricles open into the ventricle by a common auriculoventricular aperture. In the crocodiles all the structures of the auricles are same except two separate auriculoventricular apertures.

6. Ventricle: Incompletely divided, thick-walled, highly muscular chamber. The lumen of the ventricle is provided with an incompletely divided inter-ventricular septum in most groups except crocodiles. In crocodiles this septum is complete. The two sides of the crocodilian heart are connected by an aperture, which connects between the bases of the left and right aortic trunks.

The inner cavity of the ventricle in lizards has been arbitrarily divided into three regions, namely cavum pulmonale in the right side, cavum arteriosum in the left side and cavum venosum in the middle. The right part of the inter-ventricular septum is called Cavum ventrale and the left part of the inter-ventricular septum is called cavum dorsale.

In crocodiles 4-chambered heart with only two aortic arches are seen. In crocodiles the pulmonary trunk and left aortic arch develop from the right ventricle and only right aortic arch develops from the left ventricle.

7. Conus Arterius: Absent.

8. Mechanism of Circulation: The heart of lizard represents a transitional stage which approaches a double circuit stage but has not reached it completely due to lacking of complete separation of the ventricle.

In crocodiles the heart is completely 4-chambered. The right part always gets deoxygenated blood and the left part gets oxygenated part. All the apertures are guarded by muscular valves that prevent the back flow of blood. The deoxygenated blood goes to the lungs through the pulmonary aorta from the right ventricle.

The oxygenated blood of the left ventricle constitutes the major circuit over the body. The blood circulation represents a double circuit stage, which attains maximum completely among reptiles.

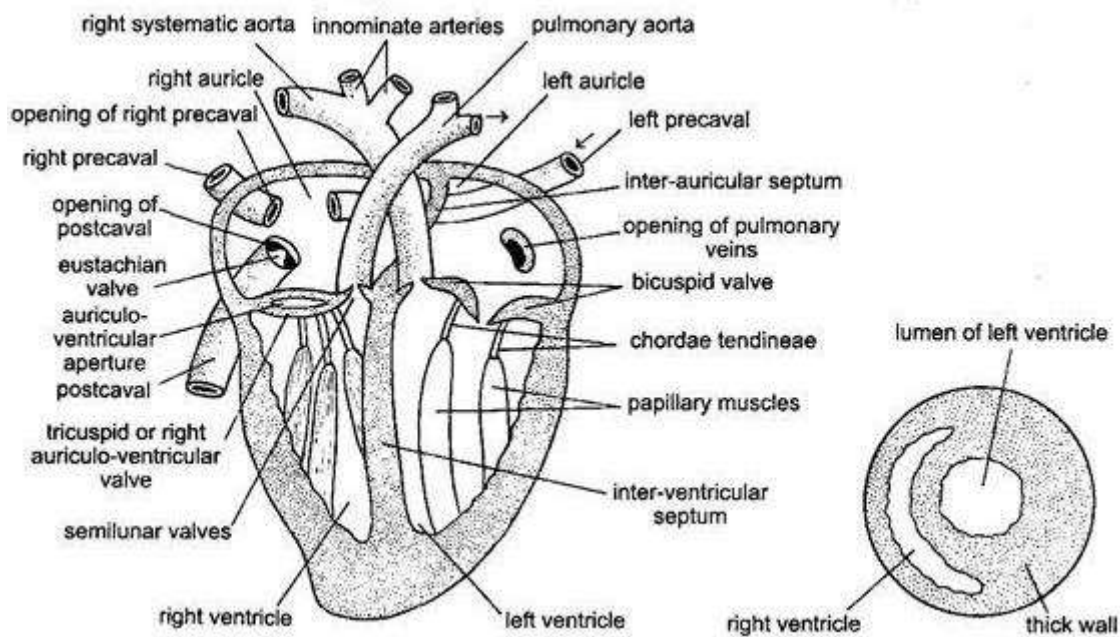
D. Aves:

1. Location: Heart is situated in the thoracic cavity between the two lungs and is slightly towards the left side.

2. Covering: The heart is covered by a transparent protective covering, called pericardium. It is a single layer in fish. Within pericardium there is a pericardial fluid, protects the heart from the external injury.

3. Organs: 4 chambered heart. No conus arteriosus and vestigial sinus venosus. Right ventricle partly covers the left (Fig.).

4. Sinus Venosus: Vestigial.



5. Auricle: Auricles are comparatively thick-walled receiving chamber and placed anterior to ventricle. The two auricles are separated internally by inter-auricular septum. The wall of the right auricle bears sinoauricular node or pace-maker and the atrial septum bears auriculoventricular node (A-V node).

The right auricle receives deoxygenated blood from three caval veins and the left auricle receives oxygenated blood through four pulmonary veins. The right auricle opens into the right ventricle by a right auriculoventricular aperture which is guarded by a single muscular flap-like valve. The left auriculoventricular aperture is provided with 3 valves which are composed of two cusps.

6. Ventricle: Ventricle is a thick-walled, highly muscular forwarding chamber of the heart. It is divided into two by a complete muscular septum. The lumen of the ventricle is thrown into muscular ridges, called columnae carnae. Only two aortic arches originate from the ventricle. The right ventricle gives rise to pulmonary arch and the left ventricle gives rise to single right aortic arch.

The opening of the arches are guarded by three cup-like semilunar valves. The right auriculoventricular aperture is guarded by a single valve but the left auriculoventricular aperture is guarded by a membranous valve and provided with two cusps (bicuspid).

7. Conus Arterius: Absent.

8. Mechanism of Circulation: The heart of pigeon is a double circuit heart and there is no chance of mixing up of deoxygenated and oxygenated blood. The circulation represents an evolutionary advancement in birds over reptiles and its working efficiency has reached maximum.

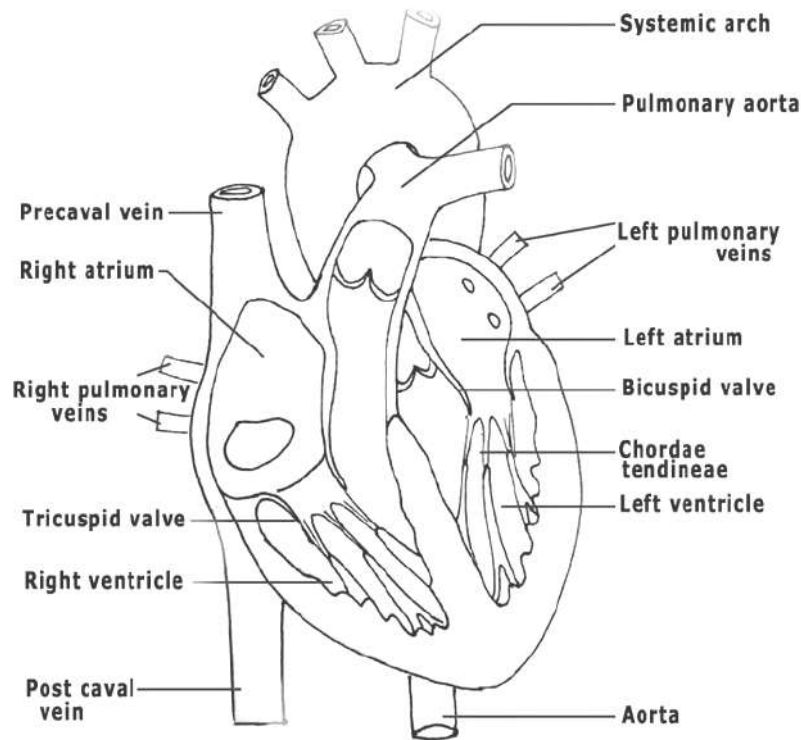
E. Mammalia

1. Location: Heart is situated in the thoracic cavity between the two lungs and is slightly towards the left side.

2. Covering: It is a double layered. The inner layer is called visceral layer which is highly vascularized and outer connective tissue layer, called peritoneal layer.

3. Organs: 4 chambered heart. No conus arteriosus and vestigial sinus venosus. Right ventricle partly covers the left (Fig.). The sinus venosus is absent in adult mammals.

4. Sinus Venosus: Absent. The embryonic sinus venosus is merged with the right atrium in the adult stage.



5. Auricle: Comparatively thick walled receiving chamber. The right auricle receives deoxy-genated blood from the body through the anterior and posterior vena cavae. The three venae cavae open separately into the right auricle. In between the apertures of the two anteri-or venae cavae and to some extent guarding the posteri-or vena cava is the Eustachian valve.

The blood of the walls of the heart is brought to the auricle by means of an aper-ture, coronary sinus in the right auricle. The opening of coronary sinus is guarded by a coronary valve or valve of Thebesius.

The left auricle receives oxygenated blood from the lungs through four pulmonary veins. The inter-auricular septum bears an oval- shaped depression, called fossa ovalis. This depres-sion indicates the position of foramen ovale which was the aperture during the embryonic stage.

This aperture becomes closed before the birth of the animal. The fossa ovalis is surrounded by an annular-shaped prominent ridge, called annulus ovalis.

The two auricles open into the ventricles by separate apertures. The left auriculo-ventricular aperture is provided with bicuspid or mitral valve. The lumen of the left ventricle is provided with a number of muscular ridges, called trabeculae carnae. The right auriculo-ventricular aperture or ostrium is provided with a tricuspid valve which is composed of three cusps.

6. Ventricle: Ventricle is a thick-walled, highly muscular forwarding chamber of the heart. It is divided into two by a com-plete muscular septum. The lumen of the ventricle is thrown into muscular ridges, called columnae carnae. Only two aortic arches originate from the ventricle. The right ventricle gives rise to pulmonary arch and the left ventricle gives rise to single right aortic arch.

The openings of the arches are guarded by three cup-like semilunar valves. The right auriculo- ventricular aperture is guar-ded by a single valve but the left auriculo ventricular aperture is guarded by a membranous valve and provided

with two cusps (bicuspids). Except the pulmonary trunk arises from the right ventricle and the left aortic arch arises from the left ventricle.

7. Conus Arteriosus: Absent.

8. Mechanism of Circulation: The heart of pigeon is a double circuit heart and there is no chance of mixing up of deoxygenated and oxygenated blood. The circulation represents an evolutionary advancement in birds over reptiles and its working efficiency has reached maximum.

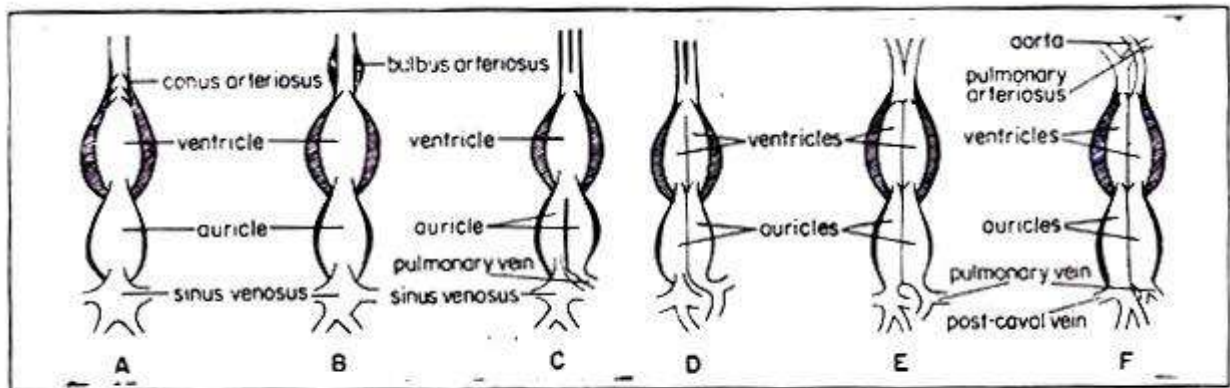


Fig. 10.144 : Showing the basic similarities in the structural plan of vertebrate hearts. A = Elasmobranchs, B = Teleost, C = Amphibia, D = Reptilia (typical), E = Crocodile and F = Birds and Mammals. Note the gradual elimination of sinus venosus and conus arteriosus in course of evolution and acquisition of two auricles and two ventricles.

Structural Plan of Vertebrate Hearts