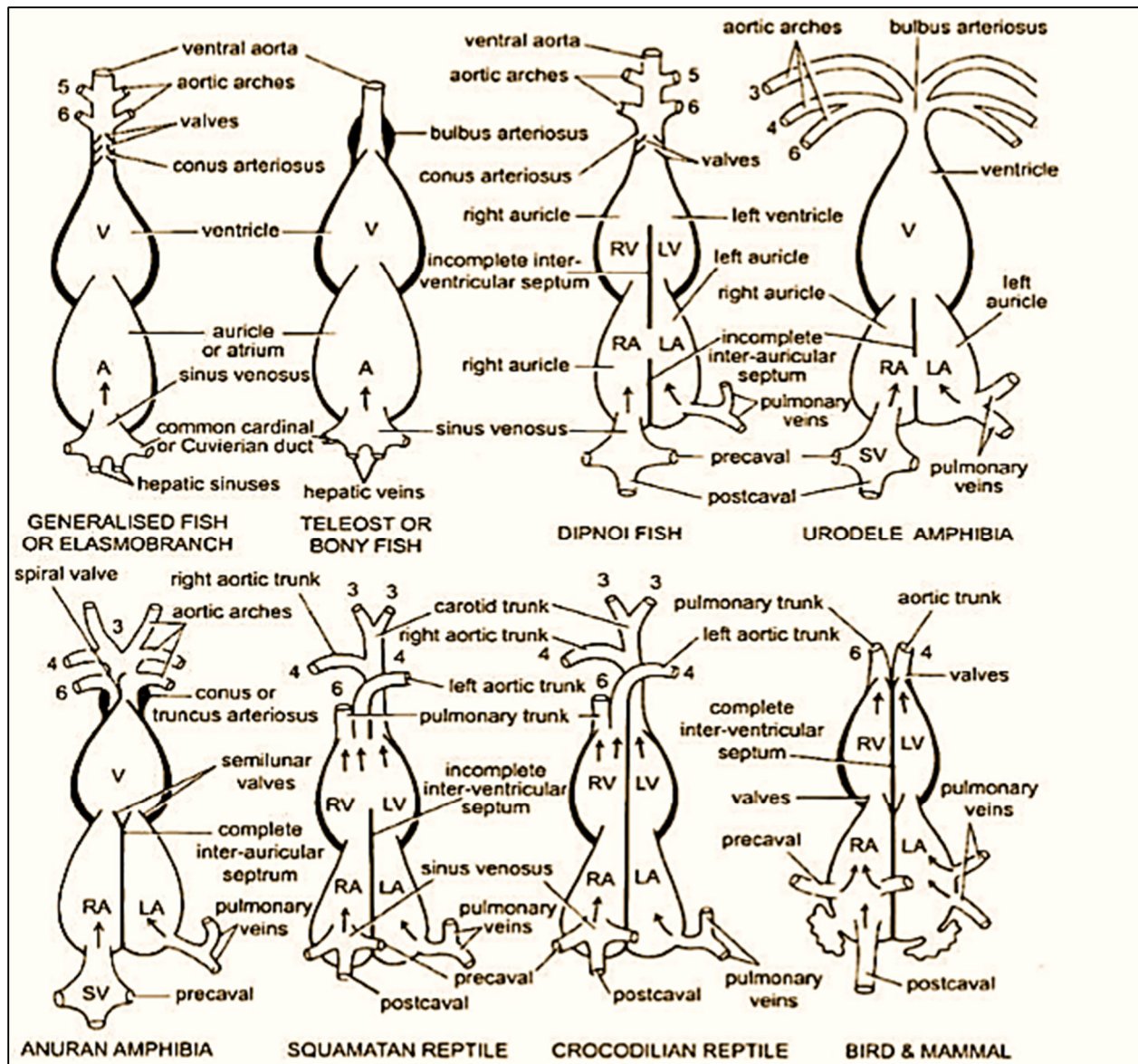


Evolution of Heart

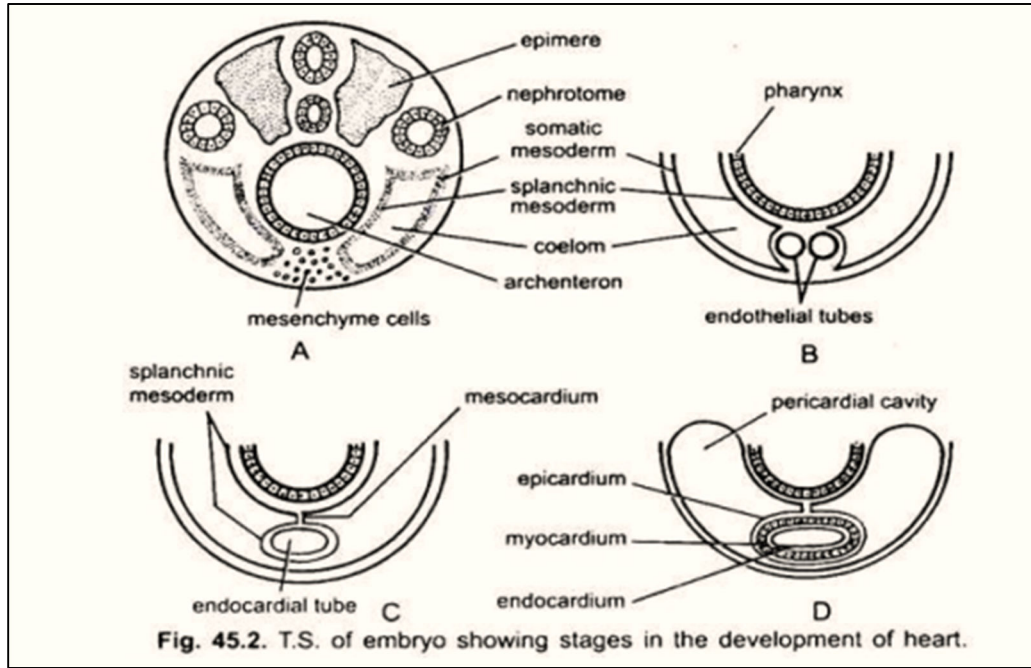
The heart probably began as a **contractile vessel**, much like those found within the circulatory system of amphioxus. In most **fishes**, the heart is part of a **single circulation**. The **embryonic fish heart consists of four chambers**, which are also in series, so that blood flows in sequence from the **sinus venosus, to the atrium, to the ventricle**, and finally to the fourth and most anterior heart chamber, the **bulbus cordis (conus arteriosus in adult chondrichthyans, holosteans and dipnoans, its contractile walls possess cardiac muscle or bulbus arteriosus in adult teleost, elastic wall lacks cardiac muscle)**. In **tetrapods**, the ventral aorta often becomes reduced, sometimes persisting only as a small section of vessel at the base of major departing aortic arches. In these cases, the term **truncus arteriosus** is most apt. The **inner wall of the myocardium, especially of the ventricle**, often forms projecting cones of muscle termed **trabeculae** that are set off by deep recesses. **Coronary vessels** are especially **well developed in elasmobranchs, crocodiles, birds, and mammals**, in which they supply most of the myocardium. In addition to the **conal valves**, the endocardium develops sets of valves between its chambers: **The sinoatrial (SA) valves form between the sinus venosus and the atrium, and the atrioventricular (AV) valves form between the atrium and ventricle**. Contraction of the entire heart usually begins within a restricted region in the **sinus venosus called the pacemaker, or sinoatrial (SA) node**, and then spreads through a conducting system of fibers into the ventricle and other contracting regions of the heart. In mammals, the conducting system includes, **in addition to the SA node, a second node, the atrioventricular (AV) node in the wall of the heart**. The AV node **consists of Purkinje fibers**, neuronlike fibers that are modified cardiac muscle cells. **Birds and mammals have four-chambered hearts**, but of the original four fish chambers, only **two persist as major receiving compartments, the atrium and the ventricle**, both of which are **divided into left and right compartments** to produce four anatomically separate chambers.



Origin of Heart

In an embryo the mesenchyme forms a group of endocardial cells below the pharynx. These cells become arranged to form a pair of thin endothelial tubes. The two endothelial tubes soon fuse to form a single endocardial tube lying longitudinally below the pharynx. The splanchnic mesoderm lying below the endoderm gets folded longitudinally around the endocardial tube. This two-layered tube will form the heart in which the splanchnic mesoderm thickens to form a myocardium or muscular wall of the heart and an outer thin epicardium or visceral pericardium. The endocardial tube becomes the lining of the heart known as endocardium. Folds of splanchnic

mesoderm meet above to form a dorsal mesocardium which suspends the heart in the coelom. Soon a transverse septum is formed behind the heart which divides the coelom into two chambers, an anterior pericardial cavity enclosing the heart and a posterior abdominal cavity.



Single-Chambered Heart

- **Amphioxus**

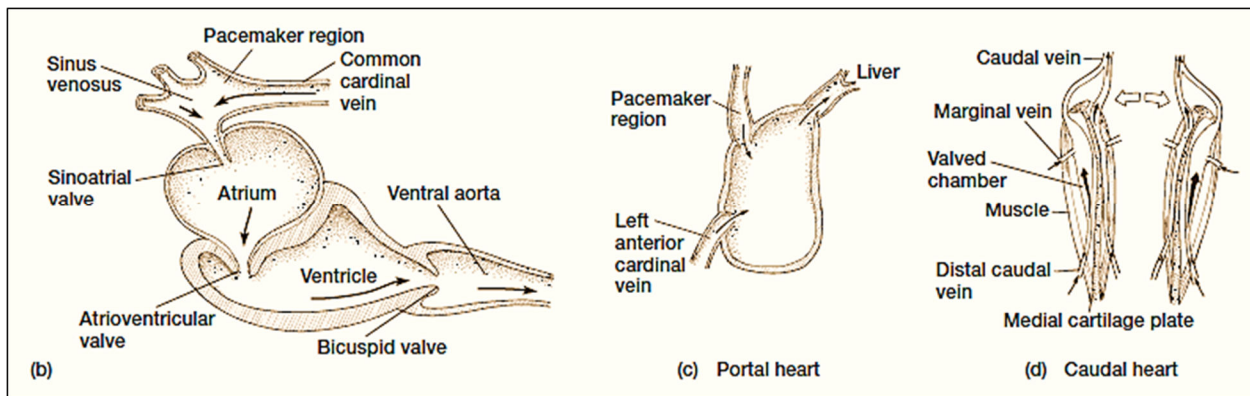
In Amphioxus (primitive chordate), a true heart is not found. A part of ventral aorta beneath the pharynx is muscular and contractile and acts as heart.

Two-Chambered Heart

Except Dipnoi, the circulatory system in fishes from cyclostomes to teleosts, only unoxygenated blood goes to the heart, from there it is pumped to the gills, aerated and then distributed to the body. The heart of cartilaginous dogfish is muscular and dorsoventrally bent S-shaped tube with four compartments in a linear series.

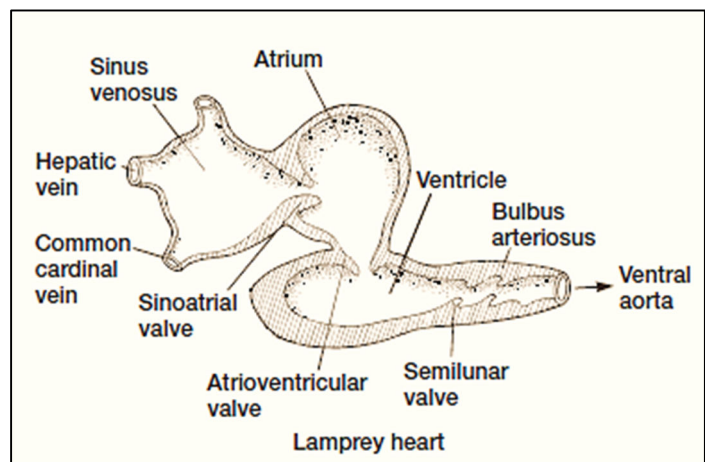
- **Hagfish**

The hagfish heart is called a branchial heart to distinguish it from unique accessory blood pumps elsewhere in its circulation. These supplementary circulatory pumps are sometimes called accessory “hearts,” in quotation marks because they contract but usually lack the cardiac muscle of true branchial hearts. The cardinal hearts lying within the anterior cardinal veins are like sacs whose pumping action is initiated by skeletal muscles around their outer walls. The paired caudal hearts, which are located in the tail, represent a unique blood pumping mechanism among vertebrates. The portal heart is a single, expanded vascular sac that receives venous blood from one anterior and one posterior cardinal vein, and then it contracts to drive the blood through the liver.



- **Lamprey (Branchial Heart)**

It includes three compartments through which blood flows sequentially— sinus venosus, atrium, and ventricle but in contrast to the hagfish heart, it is innervated and, further, the ventricle empties into the bulbus arteriosus, whose walls lack cardiac muscle but contain smooth muscle cells arranged longitudinally and circumferentially. One-way valves separate compartments. The sinoatrial and atrioventricular valves prevent retrograde blood flow. The luminal walls of the bulbus arteriosus

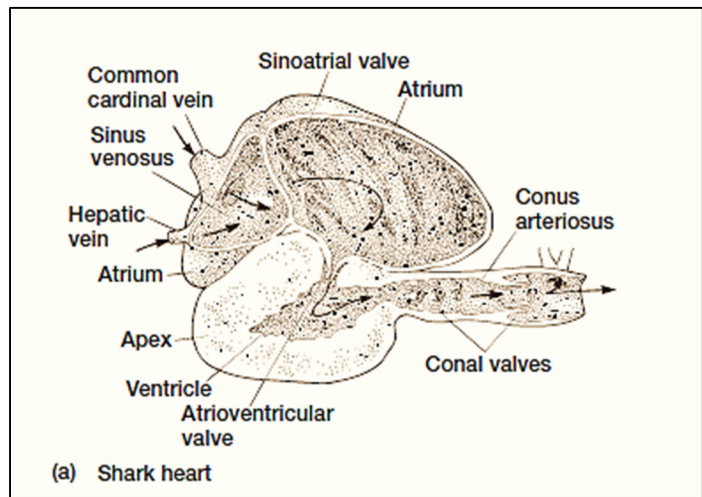


longitudinally and circumferentially. One-way valves separate compartments. The sinoatrial and atrioventricular valves prevent retrograde blood flow. The luminal walls of the bulbus arteriosus

are thrown into leaflets, collectively forming the semilunar valves, which prevent reverse blood flow and possibly aid in distributing blood to the aortic arches. From the arches, blood flows to the delicate gill capillaries next in line in the circulation.

- **Elasmobranch**

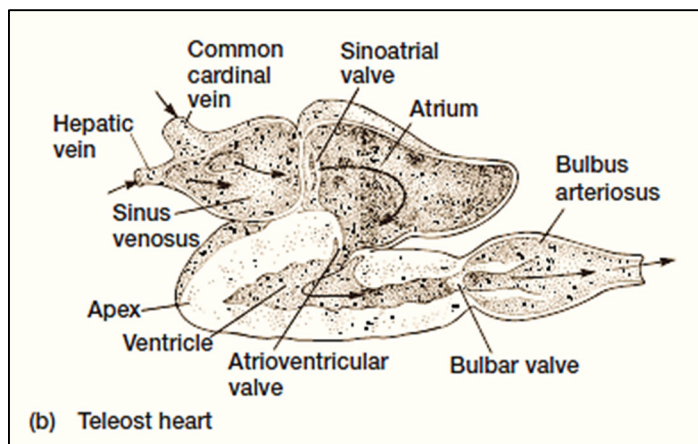
The hearts of chondrichthyans and bony fishes consist of four basic chambers—sinus venosus, atrium, ventricle, and conus arteriosus (or bulbus arteriosus)—with one-way valves stationed between compartments. Like the other chambers, the muscular conus arteriosus contracts, acting as an auxiliary pump to help maintain blood flow into the ventral



aorta after the onset of ventricular relaxation. Its contraction also brings together the conal valves located on its opposing walls. When these valves meet, they prevent the backflow of departing blood.

- **Teleost**

In teleosts, the conus arteriosus may regress, leaving only remnants of a myocardial conus, or be replaced entirely by an elastic, noncontractile bulbus arteriosus, lacking cardiac muscle but invested with smooth muscle, collagen, and elastic fibers. A single pair of bulbar valves at the



juncture of the bulbus arteriosus and the ventricle prevents retrograde flow. The S-shaped arrangement of chambers in the fish heart places the thin-walled sinus venosus and atrium dorsal

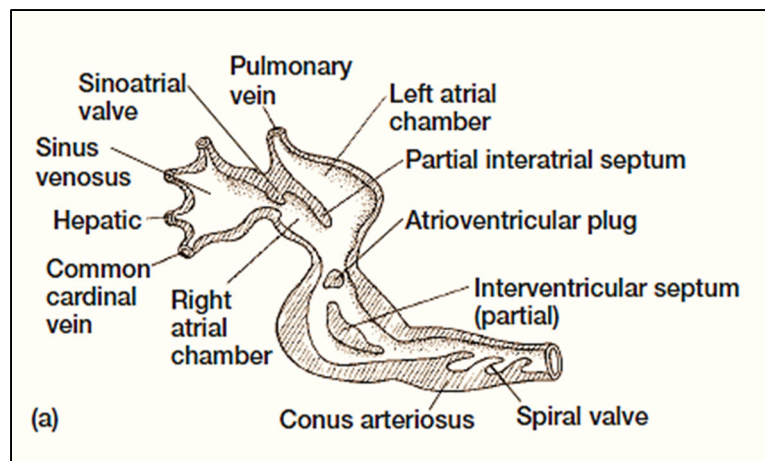
to the ventricle, so that atrial contraction assists ventricular filling. Blood flows from posterior chambers to anterior chambers in the following sequence.

Three-Chambered Heart

In dipnoans a partial septum divides the atrium into a right and left chamber. This is correlated with the use of the swim-bladder as an organ of respiration and represents the first step toward the development of the double-type circulatory system whereby both oxygenated and unoxygenated blood enter the heart and are kept separate. Blood from right auricle of the lungfish passes into the right ventricle and is then pumped into the primitive lung-like gas bladder by pulmonary arteries which branch off from the sixth pair of aortic arches. The oxygenated blood returns to the left atrium by way of pulmonary veins like amphibians.

- **Lungfish**

The first chamber to receive returning blood is still the sinus venosus. In all three lungfish genera, the single atrium is partially divided internally by an interatrial septum (pulmonalis fold) that defines a larger right and smaller left atrial chamber. Pulmonary

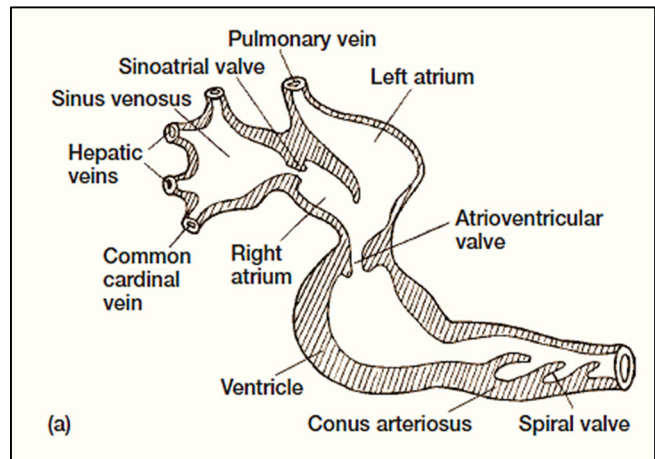


veins conveying blood from the lungs empty into the sinus venosus (Australian lungfish, *Neoceratodus*) or directly into the left atrial chamber (South American lungfish, *Lepidosiren*, and African lungfish, *Protopterus*). The sinus venosus conveying systemic venous blood opens into the right atrial chamber. In place of the atrioventricular valves is the atrioventricular plug, a raised cushion in the wall of the ventricle. It moves into and out of the opening from the atrium, like the AV valves, to prevent retrograde flow of blood into the atrium. The ventricle is also divided internally, but only partially, by an interventricular septum. The spiral valve within the conus arteriosus aids in separating oxygenated and deoxygenated blood. Apparently derived from conal

valves, the spiral valve consists of two endocardial folds whose opposing free edges touch but do not fuse.

- **Amphibia**

The heart includes a sinus venosus, right and left atria divided by an anatomically complete interatrial septum, a ventricle lacking any internal subdivision, and a conus arteriosus with a spiral valve (except for salamanders of the genus *Siren*, which have a partial interventricular septum). The conus arteriosus of the frog heart arises

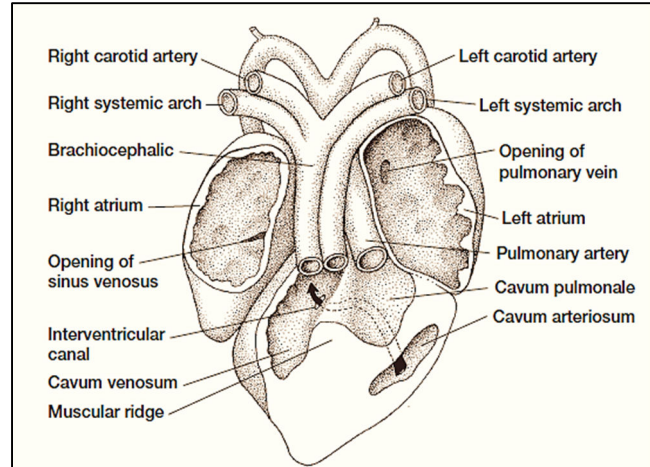


from a single trabeculate ventricle. Semilunar valves lie at the base of the conus and prevent retrograde flow of blood back into the ventricle. Internally, a spiral valve twisting through nearly a complete rotation establishes two channels within the conus, each of which guides blood to specific sets of systemic and pulmocutaneous arches. The systemic and pulmocutaneous arches both arise from the truncus arteriosus, a remnant of the ventral aorta, but the two sets of arches receive blood from different sides of the spiral valve. Unlike frogs, in which the pulmocutaneous artery branches give rise to the cutaneous artery, salamanders lack a cutaneous artery. Instead, branches from vessels supplying the systemic circulation carry blood to the salamander skin. The pulmonary artery and the systemic arches in salamanders arise from the truncus arteriosus.

- **Reptiles**

The sinus venosus is reduced in comparison to amphibians but it retains the same functions. It is still the first chamber to receive venous blood and contains the pacemaker. The atrium is completely divided into right and left atria. Prominent atrioventricular valves guard the entrance to the ventricles. The conus arteriosus (or bulbus cordis) appears during early embryonic development but becomes divided in the adult to form the bases (trunks) of three large arteries leaving the ventricle: the pulmonary trunk and the right and left systemic trunks. In snakes, a valved interaortic foramen connects the bases of adjacent aortae. But the shunting of blood

made possible by this foramen has not been explored. Usually, the brachiocephalic artery, delivering blood to the subclavians and carotids, emanates directly from the right aortic arch, but in some turtles, it arises directly from the ventricle, crowded in with the trunks of the three aortic arches. The ventricle is a single chamber functioning as a single fluid pump to drive blood into the

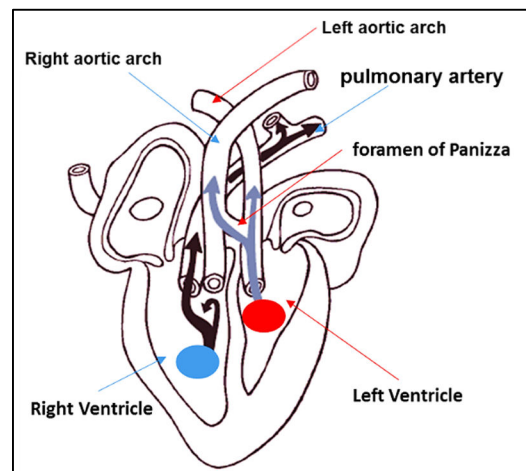


major arteries leaving the heart. Internally, however, it has three interconnected compartments: the cavum venosum and the cavum pulmonale separated from each other by a muscular ridge, and the cavum arteriosum connected to the cavum venosum via an interventricular canal.

Note:

Crocodilian Hearts

The conus arteriosus (bulbus cordis) produces the bases of the trunks of the three departing arteries—pulmonary and left and right aortic trunks. One-way lunar valves at the bases of each trunk permit blood to enter the conus but halt reverse backflow into the ventricle. The sinus venosus is reduced but still functions as the receiving chamber for returning systemic blood. The atrium is completely subdivided



into two distinct left and right chambers, and the sinus venosus empties into the right atrium. The pulmonary vein enters the left atrium in adults, but it does not open into the left atrium during embryonic development. The ventricle is divided by an anatomically complete interventricular septum into distinct left and right chambers. The pulmonary trunk and left aortic arch open off the thick-walled right ventricle. The right aortic arch opens off the left ventricle. A

narrow channel called the **foramen of Panizza** connects the left and right aortic arches shortly after they depart from the ventricle.

The embryonic conus arteriosus splits into three instead of two vessels:

- (i) Pulmonary arch carrying blood to the lungs from right side of the ventricle.
- (ii) Right systemic aorta carrying blood from left side of the ventricle to the body by way of right fourth aortic arch.
- (iii) Left systemic comes from the right ventricle to the left fourth aortic arch.

Four-Chambered Heart

The hearts of birds and mammals have four chambers. In birds, the sinus venosus is reduced to a small but still anatomically discrete area. The conus arteriosus (bulbus cordis) is only a transient embryonic chamber that gives rise to the pulmonary trunk and a single aortic trunk in the adult. In mammals, the sinus venosus is reduced to a patch of Purkinje fibers, or sinoatrial node, in the wall of the right atrium. The sinoatrial node functions as a pacemaker, initiating the wave of contraction that spreads across the heart as in all other vertebrates. Birds and mammals, both consist of parallel pumps with double circulation circuits. The right side of the heart gathers deoxygenated blood from systemic tissues and pumps it into the pulmonary circuit. The left side of the heart pumps oxygenated blood from the lungs through the systemic circuit. The hearts of birds and mammals are anatomically divided into left and right compartments; thus, there is no cardiac shunting with changing ventilation rates.

