Comparative Anatomy of Vertebrate Hearts

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Introduction

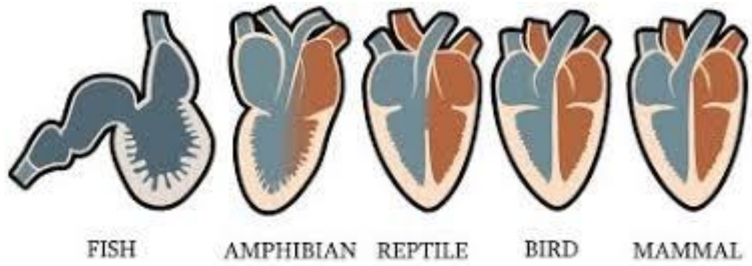
The heart is the centre of the circulatory system whose primary role is to pump blood through the pulmonary and systemic systems of the body network. The circulatory system is a body-wide network of vessels that transports nutrients, respiratory gases, metabolic waste and hormones, distributes and dissipates heat and assists in defending the body against disease. The first heart-like organ appeared in our biological history over 500 million years ago (Mya) and has undergone many changes and adaptations during its evolution from a singlelayered tube with own contractility supporting an open circulatory system, to a powerful four-chambered muscular pump devoted to loading and unloading a large amount of blood around a closed, valved circuit circulatory system. The vertebrate heart is biologically specific to a species and is the product of millions of years of fine tuning.

Vertebrate heart

All chordates possess a dorsal nerve cord and a notochord which is supported by surrounding muscle. The three major subphyla of the Phylum Chordata are the urchordates (Subphylum Urchordata), cephalochordates (Subphylum Cephalochordata) and vertebrates (Subphylum Vertebrata). Vertebrates are distinguished by a multi-chambered heart and a closed vascular system with capillaries lined with endothelial cells. Whereas the tunicates and amphioxi species possess tubular hearts that contract peristaltically , evolutionary gene mutations ensured that the anatomy and physiology of the vertebral heart became more compleX. The vertebrate heart is formed via the folding of the lateral cardiogenic mesodermal layer of the embryonic disk to create the tubular heart. The heart section of the tube then loops around and produces a protruding ventricle and atrium, leaving the remaining inner tubular system with its original tubular appearance.

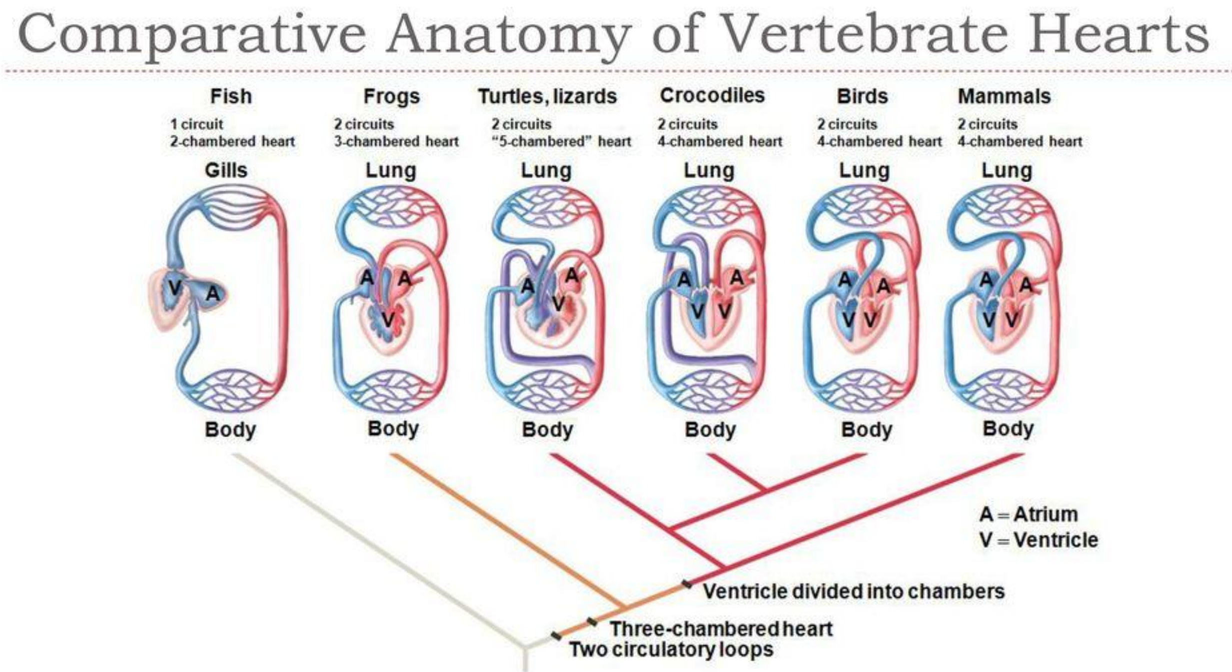
Function

The heart is a hollow muscular organ that rythmically 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 forceably contracts to distribute the blood to the arteries. Backflow is prevented by one-way valves.



Note that the partial septum in the reptile ventricle becomes a complete divider in birds and mammals.

In the image above, you can see the progressive changes in the heart between ancestral vertebrates, the fishes, and the most derived forms, the birds and mammals. Fish have a simple two chambered heart which is, in essense, just a thickening of a section of the circulatory system, and the blood flows in a single circuit from heart to gills to body and back to the heart. Starting with the amphibians, the first of the vertebrates with lungs, the circulatory system adds a second loop or circuit. This design has the blood flow through the heart twice on each trip around the system, once on the way to the lungs and once on the way back from the lungs, giving it an extra boost. This is called ***double circulation***. In amphibians, with two atria but only a single ventricle, this results in the mixing of deoxygenated and oxygenated blood, but amphibians also gather oxygen through their moist skin, so this inefficiency is not critical. Beginning with the reptiles, a septum or wall develops that partly divides the deoxygenated from the oxygenated blood in the ventricle, and this is important because reptiles, with a watertight skin, rely entirely on their lungs for oxygen. Reptiles also have the unique ability to redirect or shunt blood leaving the heart back through the heart without passing through the body circuit, and to shunt deoxygenated body blood back through the body without going to the lungs. The purpose of this shunt (see the purple vessels in the figure below) is not entirely understood. The former is thought to be a way to prioritize oxygenation of the heart during periods of high exertion, while the latter is believed to be a way to enhance digestion, because of increased acidity of deoxygenated blood due to carbon dioxide buildup. Among the extant reptiles, only the crocodilians have fully extended the septum and have a four-chambered heart, but there is speculation that dinosaurs may have had this innovation as well. Birds and mammals have the same four-chambered design, which has increased efficiency because deoxygenated and oxygenated blood cannot mix.



Red blood vessels carry oxygen-rich blood. Purple vessels carry mixed blood. Blue vessels carry deoxygenated blood.

Conclusion

Convergence is the tendency of independent species to evolve similarly when subjected to the same environmental conditions. The primitive blueprint for the heart and circulatory system emerged with the arrival of the third mesodermal germ layer in bilaterians. Since then, they have evolved from a single layered tube to a multiple chambered heart some 500 My later. Although the heart is physiologically specific to the anatomy of each individual species, it has evolved along the same directional path. Of note, recent contributions are making a robust case that the hearts of the amniotic vertebrates, and mammals in particular, birds and reptiles share a common building plan during their development, when evolutionarily maintained transcription factors master the growth of heart chambers and related structures. Very recent and careful segmental study of the crocodilian heart highlighted common features between crocodilian and human heart as well as substantial differences, underscoring at the same time a common aspect likely derived from evolutionarily maintained morphology programmes. The physiological adaptations of the avian heart include the larger sized heart in comparison with the rest of its body, an increased heart rate, and six times the cardiac output volume when compared with other vertebrates. Ultimately, the peculiar shape of the myocardial muscle in mammals is important to understand human heart function in various pathophysiological setting