40.1C: Types of Circulatory Systems in Animals

The circulatory systems of animals differ in the number of heart chambers and the number of circuits through which the blood flows.

Learning Objectives

- Describe how circulation differs between fish, amphibians, reptiles, birds, and mammals

Key Points

- Fish have a single systemic circuit for blood, where the heart pumps the blood to the gills to be re-oxygenated (gill circulation), after which the blood flows to the rest of the body and back to the heart.
- Other animals, such as amphibians, reptiles, birds, and mammals, have a pulmonary circuit, where blood is pumped from the heart to the lungs and back, and a second, systemic circuit where blood is pumped to the body and back.
- Amphibians are unique in that they have a third circuit that brings deoxygenated blood to the skin in order for gas exchange to occur; this is called pulmocutaneous circulation.
- The number of heart chambers, atria and ventricles, mitigates the amount of mixing of oxygenated and deoxygenated blood in the heart as more chambers usually mean more separation between the systemic and pulmonary circuits.
- Warm-blooded animals require the more-efficient system of four chambers that has the oxygenated blood completely separated from the deoxygenated blood.
Key Terms

- **atrium**: an upper chamber of the heart that receives blood from the veins and forces it into a ventricle
- **ventricle**: a lower chamber of the heart

Simple Circulatory Systems

The circulatory system varies from simple systems in invertebrates to more complex systems in vertebrates. The simplest animals, such as the sponges (Porifera) and rotifers (Rotifera), do not need a circulatory system because diffusion allows adequate exchange of water, nutrients, and waste, as well as dissolved gases (figure a). Organisms that are more complex, but still have only two layers of cells in their body plan, such as jellies (Cnidaria) and comb jellies (Ctenophora), also use diffusion through their epidermis and internally through the gastrovascular compartment. Both their internal and external tissues are bathed in an aqueous environment and exchange fluids by diffusion on both sides (figure b). Exchange of fluids is assisted by the pulsing of the jellyfish body.

Figure 1: Animals without circulatory systems: Simple animals consisting of a single cell layer, such as the (a) sponge, or only a few cell layers, such as the (b) jellyfish, do not have a circulatory system. Instead, gases, nutrients, and wastes are exchanged by diffusion.

For more complex organisms, diffusion is not efficient for cycling gases, nutrients, and waste effectively through the body; therefore, more complex circulatory systems evolved. Closed circulatory systems are a characteristic of vertebrates; however, there are significant differences in the structure of the heart and the circulation of blood between the different vertebrate groups due to adaptation during evolution and associated differences in anatomy.

Fish Circulatory Systems

Fish have a single circuit for blood flow and a two-chambered heart that has only a single atrium and a single ventricle (figure a). The atrium collects blood that has returned from the body, while the ventricle pumps the blood to the gills where gas exchange occurs and the blood is re-oxygenated; this is called gill circulation. The blood then continues through the rest of the body before arriving back at the atrium; this is called systemic circulation. This unidirectional flow of blood produces a gradient of oxygenated to deoxygenated blood around the fish’s systemic circuit. The result is a limit in the amount of oxygen that can reach some of the organs and tissues of the body, reducing the overall metabolic capacity of fish.
Figure \(\PageIndex{1}\): **Examples of animal circulatory systems**: (a) Fish have the simplest circulatory systems of the vertebrates: blood flows unidirectionally from the two-chambered heart through the gills and then to the rest of the body. (b) Amphibians have two circulatory routes: one for oxygenation of the blood through the lungs and skin, and the other to take oxygen to the rest of the body. The blood is pumped from a three-chambered heart with two atria and a single ventricle. (c) Reptiles also have two circulatory routes; however, blood is only oxygenated through the lungs. The heart is three chambered, but the ventricles are partially separated so some mixing of oxygenated and deoxygenated blood occurs, except in crocodilians and birds. (d) Mammals and birds have the most efficient heart with four chambers that completely separate the oxygenated and deoxygenated blood; it pumps only oxygenated blood through the body and deoxygenated blood to the lungs.

**Amphibian Circulatory Systems**

In amphibians, reptiles, birds, and mammals, blood flow is directed in two circuits: one through the lungs and back to the heart (pulmonary circulation) and the other throughout the rest of the body and its organs, including the brain (systemic circulation).

Amphibians have a three-chambered heart that has two atria and one ventricle rather than the two-chambered heart of fish (figure b). The two atria receive blood from the two different circuits (the lungs and the systems). There is some mixing of the blood in the heart’s ventricle, which reduces the efficiency of oxygenation. The advantage to this arrangement is that high pressure in the vessels pushes blood to the lungs and body. The mixing is mitigated by a ridge within the ventricle that diverts oxygen-rich blood through the systemic circulatory system and deoxygenated blood to the pulmocutaneous circuit where gas exchange occurs in the lungs and through the skin. For this reason, amphibians are often described as having double circulation.
Reptile Circulatory Systems

Most reptiles also have a three-chambered heart similar to the amphibian heart that directs blood to the pulmonary and systemic circuits (figure c). The ventricle is divided more effectively by a partial septum, which results in less mixing of oxygenated and deoxygenated blood. Some reptiles (alligators and crocodiles) are the most primitive animals to exhibit a four-chambered heart. Crocodilians have a unique circulatory mechanism where the heart shunts blood from the lungs toward the stomach and other organs during long periods of submergence; for instance, while the animal waits for prey or stays underwater waiting for prey to rot. One adaptation includes two main arteries that leave the same part of the heart: one takes blood to the lungs and the other provides an alternate route to the stomach and other parts of the body. Two other adaptations include a hole in the heart between the two ventricles, called the foramen of Panizza, which allows blood to move from one side of the heart to the other, and specialized connective tissue that slows the blood flow to the lungs. Together, these adaptations have made crocodiles and alligators one of the most successfully-evolved animal groups on earth.

Mammal and Bird Circulatory Systems

In mammals and birds, the heart is also divided into four chambers: two atria and two ventricles (figure d). The oxygenated blood is separated from the deoxygenated blood, which improves the efficiency of double circulation and is probably required for the warm-blooded lifestyle of mammals and birds. The four-chambered heart of birds and mammals evolved independently from a three-chambered heart.

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