The Circulatory System

In the simplest multicellular animals such as the cnidarians, almost all cells are in contact with the external environment, so there is little need to transport materials internally. Any cell can get its nutrients from the surrounding water and can expel its waste directly back from where it came. As animal body plans evolved to further complexity, however, a need developed for a circulatory system that could transport materials such as nutrients, oxygen, and waste products throughout the body. Annelids have a simple closed circuit of blood vessels with five small hearts, which are really just pulsating vessels themselves. Insects and other arthropods have an open circulatory system that bathes their internal organs. The open circulatory system consists of one dorsal vessel that pulsates, keeping the blood moving throughout the body of the insect.

**Vertebrate Circulatory Systems**

Vertebrates have evolved an intricate closed circulatory system that consist of a heart and three principal types of blood vessels: **arteries**, **capillaries**, and **veins**.

Arteries carry blood away from the heart and have thick, elastic, muscular walls that can dilate or contract to control blood pressure within the vessels. Because blood in the arteries has been relatively recently pumped out of the heart, arterial blood pressure tends to be high. The blood in arteries is usually rich in oxygen, since it is being pumped out to the body to provide oxygen and other nutrients to the cells. The only exceptions are the pulmonary arteries, which carry blood to the lungs to pick up its supply of oxygen. Since blood in the pulmonary arteries hasn’t yet reached the lungs, it is oxygen poor.

Arteries are too large to service every little cell in the body. As arteries get farther from the heart, they begin to branch into smaller and smaller vessels, which eventually branch into thousands of capillaries. The walls of the smallest capillaries are only one cell thick, allowing nutrients, waste products, oxygen, and carbon dioxide to diffuse between the blood and the surrounding tissues. After providing nutrients and oxygen and picking up waste, capillaries begin to merge into larger and larger vessels, eventually converging into veins.

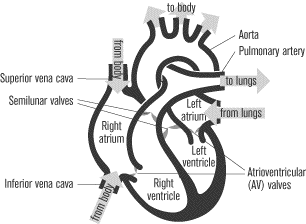
Veins carry blood toward the heart. The blood in veins is not pushed by pumping of the heart, so the blood pressure and forward momentum of the blood in veins is lower than in arteries. Blood in veins is largely pushed along by the contractions of the skeletal muscles as the organism moves around. To ensure that the blood in veins flows toward the heart, veins contain unidirectional valves. Venous blood has already provided nutrients to cells, so it is usually deoxygenated, giving it a characteristic blue color. The lone exception, once again, is the pulmonary veins. Since this blood is flowing back to the heart from the lungs, it is fully oxygenated and bright red.

**Patterns of Circulation in Vertebrates**

As vertebrates have evolved, they have developed increasingly efficient circulatory systems. The circulatory system in fish is one closed loop: blood is pumped from the heart to the gill capillaries, where oxygen is picked up from the surrounding water. The blood then continues on to the body tissues, and the vessels eventually become capillaries again to allow for nutrient and gas exchange in the tissues. Then the deoxygenated blood is returned to the heart and pumped to the gills once more. This system is inefficient because the blood loses a lot of momentum in the gill capillaries. After leaving the gill capillaries, it travels slowly and with a lower pressure, affecting the delivery of oxygen to the body tissues.

Amphibians, reptiles, birds, and mammals have overcome this problem by evolving two circuits within the circulatory system: the **pulmonary circuit** and the **systemic circuit**. After the blood is pumped from the heart to the lungs to be oxygenated, it is returned to the heart before it is pumped out to the rest of the body.

**The Heart**

Amphibian and reptile hearts are inefficient because they make no distinction between oxygenated and deoxygenated blood. Their hearts have only two chambers: one chamber for receiving blood from the lungs and the body, and another for pumping that blood back out. These two-chambered hearts allow oxygen-rich blood returning from the lungs to mix with oxygen-poor blood returning from the systemic circuit. The blood pumped to the body never contains as much oxygen as it could.

The avian (bird) and mammalian heart is *four*-chambered. It consists of two halves, one for oxygenated blood and the other for deoxygenated blood. Each half has one **atrium** and one **ventricle**, separated by one-way atrioventricular valves. The atrium is the chamber where blood returns to the heart, while the ventricle is the chamber where blood is pumped out of the heart. Oxygen-poor blood returning from the body enters the right atrium and then moves into the right ventricle, which pumps the blood through the pulmonary artery to the lungs, where it picks up oxygen and releases carbon dioxide. This newly oxygenated blood returns to the left atrium of the heart through the pulmonary veins. Blood in the left atrium moves into the left ventricle, from where it is pumped out through the **aorta**, the largest artery, into other arteries, arterioles, and capillaries. The blood provides oxygen to the cells, picks up carbon dioxide, and gathers back into veins. Eventually the deoxygenated blood flows through the superior vena cava and inferior vena cava back into the right atrium, starting the process over again.

The vertebrate heart is composed of special muscle tissue called cardiac muscle. These muscles are stimulated to contract in a regular and controlled rhythm by an electric pulse generated in a region of the heart called the sinoatrial node, or pacemaker. The pacemaker cells fire impulses spontaneously, without any stimulation from the nervous system. This impulse spreads among the heart cells, stimulating the atria to contract, forcing blood into the ventricles. At the junction of the atria and the ventricles, the impulse reaches another node, called the atrioventricular node. The atrioventricular node sends an impulse that causes the ventricular walls to contract, forcing blood out of the heart and into the aorta and pulmonary arteries. Although the heartbeat can be maintained without external stimulation by the nervous system, the autonomic nervous system can regulate the heart rate by speeding it up or slowing it down.

**The Blood**

The entire purpose of the circulatory system is to move oxygen and nutrient-rich blood to where it needs to go. Blood is a liquid tissue that is composed of a fluid called **plasma** and three types of specialized cells: **red blood cells**, **white blood cells**, and **platelets**.

The plasma of the blood is composed mainly of water, allowing it to contain many dissolved substances, such as the glucose that provides cells with energy; carbon dioxide in the form of carbonic acid; hormones that carry important chemical signals to their target organs; salts such as calcium, potassium, and sodium; lipids; and nitrogenous waste. The plasma also contains proteins that assist in blood clotting, in the immune response, and in preventing the loss of too much blood fluid from the capillaries.

Red blood cells are biconcave disks with no nucleus and no major organelles (if you took a ball of putty and squashed it between two fingers, it would look like a red blood cell). Red blood cells are the most abundant cell type in the blood. Their primary function is to transport oxygen through the blood. Red blood cells are filled with **hemoglobin**, an iron-containing protein that can bind to oxygen molecules. When the concentration of oxygen is high, as it is in the lungs, one molecule of hemoglobin can bind up to four molecules of oxygen. When the concentration of oxygen is very low, as it is in the capillaries of oxygen-poor tissue, the hemoglobin gives up its oxygen, releasing it into the tissues where it is needed.

White blood cells are important in fighting off infectious disease. There are two general classes of white blood cells: phagocytes and lymphocytes. These cells will be explained more fully during the discussion of the immune system later in this chapter.

The third type of blood cell is the platelet. Platelets are not really cells at all; they are packets of cytoplasm that release the enzyme thromboplastin when they come into contact with a foreign substance within the blood or the rough edges of an open wound. Thromboplastin sets off a chain reaction that converts fibrinogen, a soluble protein found in the blood plasma, into fibrin, a tough, insoluble fibrous protein that traps red blood cells and thereby forms blood clots that stop blood loss from an open wound.

**Blood Types**

Red blood cells manufacture proteins called **antigens** that coat the cell surface. These proteins help the immune system to determine if a cell is a foreign invader or part of the body’s normal tissues. In the case of human red blood cells, there are two major types of antigens that can be formed: antigen A and antigen B. According to genotype, an individual might have one or both of these antigens expressed, or she may have neither. If a person’s red blood cells contain only antigen A, she is said to have type A blood. If only antigen B is present, the blood is type B. Type AB blood contains both antigens, and type O blood contains neither antigen A nor B.

In order to combat foreign cells, the blood plasma contains antibodies for all antigens that are *not* expressed on its own red blood cells. These antibodies would cause any foreign blood cells to clump together, forming a dangerous clot. A person with type A blood has anti-B antibodies in the plasma, a person with type B blood has anti-A antibodies in the plasma, a person with type AB blood has no antibodies in the plasma, and a person with type O blood has both anti-A and anti-B antibodies. A person with type AB blood can therefore receive a blood transfusion of any type because his or her blood contains no antibodies that would clump up the foreign cells. For this reason, AB blood is often called the universal recipient. In contrast, a person with type O blood can receive *only* type O blood in a transfusion because she has both anti-A and anti-B antibodies in the plasma, which would immediately clump any blood that contained antigens A or B. But since type O blood has no antigens, it could be given to a person of any type blood in a transfusion without clumping. Type O blood is called the universal donor.

Blood type is a codominant trait; we explained the inheritance patterns of blood type in the codominance section of the chapter on genetics.