

# Anatomy and Physiology in Health and Disease

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## Cardiovascular System: Blood Vessels

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### *Introduction*

Blood vessels form a closed network of tubes that carry blood from one location in the body to another in a one way manner. There are several types of circulation in the human body. Systemic circulation is the circulation that transports blood from the heart to the cells of the body in order to deliver oxygen and nutrients to the cells (perfusion) and return the blood to the heart. The pulmonic circulation carries deoxygenated blood from the right side of the heart to the lungs where the blood is oxygenated and returns it to the left side of the heart. In addition to the systemic and pulmonic circulation, there are specialized circulatory networks in other regions of the body. An example is the cerebral circulation of the brain and the portal network of the small intestines and liver. The circulatory networks are composed of arteries, veins, and capillaries. Arteries carry blood away from the heart and veins return blood towards the heart. Capillaries are the smaller blood vessels that are involved in exchange of gases and nutrients.

### *Morphology of Blood Vessels*

Blood vessels are composed of three distinct layers of tissue. The internal layer of tissue, tunica intima is composed of a single layer of simple squamous epithelial cells with a small amount of supporting connective tissue. The middle layer of tissue, the tunica media is composed of smooth muscle arranged in a circular pattern with variable layers of elastic tissue. The outer region of the blood vessel is made of collagen and elastic fibers and is called the tunica adventitia.

Both arteries and veins have all three layers of tissue. However, the proportions of the three layers differ dramatically between arteries and veins. Arteries have a thicker tunica media than veins because they must be able to withstand the high pressures of the heart. Veins have a thicker layer of tunica adventitia because they are often located more superficially than arteries and more susceptible to trauma. The adventitia protects the vein from damage and makes it more difficult to lacerate the blood vessels. Arteries are often located deeper in the body and are protected by other tissue types. Pressure differences in the two blood vessels also dictate the need for another specialized structure in veins called valves. Veins are exposed to much less pressure than arteries and blood flow has a tendency to reverse directions in veins. Valves prevent the reverse in direction of blood flow and ensure that the blood continues to flow in a one way

direction towards the heart. Also because of the higher pressure in the arterial circulation, arteries have a clearly defined lumen, while veins have a larger, less defined lumen.

The smooth muscle of the tunica media is innervated by the sympathetic nervous system. Sympathetic nervous system stimulation will cause the blood vessel to constrict, a property known as vasoconstriction. The parasympathetic nervous system does not directly innervate the tunica media. The parasympathetic nervous system causes the blood vessels to dilate by blocking the sympathetic stimulation of the blood vessel. Arteries contain a thicker tunica media and a larger amount of smooth muscle than veins and thus are more susceptible to sympathetic stimulation than veins.

### *Arteries*

Arteries are blood vessels that carry blood away from the heart. While the majority of arteries carry oxygenated blood, the pulmonary arteries carry blood that is lower in oxygen saturation. The pulmonary arteries are the only arteries that carry deoxygenated blood. Deoxygenated blood is a misnomer because the blood is never completely deoxygenated. It is simply lower in oxygen saturation than arterial blood. There are two different types of arteries and they are classified according to the dominant tissue found in the tunica media.

Elastic arteries have a higher percentage of elastic tissue than smooth muscle tissue. These arteries are also known as conducting arteries. Elastic arteries always have a continuous amount of blood moving through them. No matter where the blood is going in the body, it has to pass through these elastic arteries. An example of an elastic artery is the aorta. Blood must traverse the aorta. Elastic arteries such as the aorta operate under very high pressures. The aorta is located at the exit of the left ventricle of the heart and it is exposed to the highest pressures exerted in the human body. After contraction of the heart, the aorta distends to accommodate the movement of blood from the left ventricle into the aorta. Once the heart begins to relax, pressure in the aorta drops precipitously and the distended aorta recoils due to recoil of the elastic fibers in the tunica media. This recoil helps to propel the blood through the aorta and generates a pressure. The pressure generated by contraction of the left ventricle is the systolic blood pressure; the pressure generated by recoil of the aorta that occurs when the left ventricle relaxes is the diastolic blood pressure.

Muscular arteries have a higher percentage of smooth muscle than elastic fibers. The majority of arteries in the human body are muscular arteries. They are also called distributing arteries because they distribute the blood throughout the body depending upon the metabolic needs of the moment. Tissue that is more metabolically active needs a greater amount of oxygen than less active tissue. Muscular arteries possess the ability to constrict and dilate in order to accommodate the metabolic needs of the moment.

Arterioles are smaller arteries that carry blood from larger arteries to the capillary bed where gas exchange will occur. Arterioles have between 1- 6 layers of smooth muscle, the closer

the arteriole is to the capillary bed, the less smooth muscle the arteriole will possess. Arterioles have a great degree of freedom to regulate the diameter of the lumen of the blood vessel. Particularly during times of hypoperfusion, arterioles will constrict and only transport blood to the organs that are particularly sensitive to oxygen. The brain, intestines, and kidneys are the last organs to lose perfusion during stressful situations.

### *Capillaries*

Capillaries are smaller blood vessels that can only accommodate a single erythrocyte at any moment. Capillaries do not contain the same three layers of tissue as arteries and veins. They are composed only of a simple squamous epithelium with some underlying connective tissue to support the capillary. In some circumstances, the entire capillary is made of a single epithelial cell that wraps around and adheres to itself. Capillaries are the location of gas and nutrient exchange in the human body.

In the systemic circulation, the arterial side of the capillaries is filled with oxygen rich blood that delivers oxygen to the cells. On the venous side of the capillary, oxygen deprived blood re-enters the capillary. Flow in and out of the capillaries is managed by hydrostatic pressures that are trying to physically push fluid out of the capillary and oncotic pressure that is trying to retain fluid in the capillary. We will examine this flow of fluid in and out of the capillary in the lymphatic and immunity chapter.

In the pulmonary circulation, the arterial side of the capillary is filled with deoxygenated or hypoxemic blood. The venous side of the capillary picks up the blood cells that are freshly oxygenated by passing through the respiratory membrane of the alveoli.

There is not a single type of capillary. Capillaries found in the brain, spinal cord and most connective tissues are composed of capillaries that are held together by tight junctions and prevent fluid from leaking out of the capillaries. These capillaries do not contain any fenestrations or sinusoids that readily allow large molecules and large amounts of water out the capillary. The blood brain barrier is made of continuous capillaries. Larger proteins and hydrophobic molecules must pass through the epithelial cell and their movement is regulated by transcytosis. Smaller hydrophilic molecules can diffuse across the cellular membrane.

Capillaries in the intestines and kidneys are fenestrated. In the intestines, nutrients are absorbed from the lumen of the small intestine into the capillaries of the portal circulation. In the kidneys, substances are re-absorbed from the filtrate that is produced in the glomerulus of the nephron into the efferent arteriole of the renal artery. The movement of these larger molecules necessitates the need for larger openings in the membrane of the capillary. These capillaries are not held together by tight junctions and contain numerous pores for the rapid water and small molecules.

In the bone marrow, blood cells are manufactured and secreted into the blood. Capillaries found in the bone marrow must contain large gaps that allow these cells to enter the blood system. These capillaries are known as sinusoidal capillaries. Some endocrine glands also contain sinusoidal capillaries. Sinusoidal capillaries contain large, irregular channels in the capillary.

Flow through capillaries is accomplished in capillary beds. Flow into the capillary bed is regulated by pre-capillary sphincters. The body is able to direct blood to tissues that are more metabolically active. Precapillary sphincters are regulated by local tissue mechanisms. The sphincters are sensitive to carbon dioxide production of metabolically active tissues. If the level of oxygen decreases the level of carbon dioxide will increase. This increase in the level of carbon dioxide will cause the precapillary sphincter to dilate and cause more blood to flow into the capillary bed. As the tissue demands of oxygen decrease, the precapillary sphincters will constrict and reduce the flow of blood into the capillary.

### *Veins*

Venules are attached to the capillary and merge together to form larger blood vessels known as veins. Veins operate under a much lower pressure than arteries. Flow in veins is more difficult than in arteries. Blood naturally moves from higher pressure to lower pressure. However, in the venous system often times gravity exerts a higher pressure than what is found in the vein. In this situation, blood flow will try to reverse its direction. Valves found in the veins attempt to prevent the flow from going the wrong direction. To augment the low pressure found in the venous system, skeletal muscle contraction helps to augment the flow of blood in the venous system. Contraction of skeletal muscles within tight compartments helps propel blood towards the heart.

The largest vein in the human body is the vena cava. There are two vena cava; the superior vena cava drains blood from the region of the body superior to the heart. While the inferior vena cava is responsible for transporting blood from the inferior portion of the body to the heart.

### Anastomoses

There are specialized connections of blood vessels in various regions of the body. In the palm of the hand, the palmar artery connects the radial and ulnar arteries together. This is referred to as an arterial anastomoses. In this situation, in the event of a thrombus formation in one of the arteries that supplies the hand with oxygen the other artery will supply the palmar artery which will effectively bypass the thrombus and perfuse the entire hand. The venous system which is subjected to much lower pressures, is at a greater risk of thrombus formation than the arterial circulation, and possess a larger number of venous anastomoses. Venous anastomoses connect various veins together and allow for alternative pathways of blood flow in the event of a thrombus. In the dermis of the integumentary system, you will find arterial/ venous

anastomoses. These anastomoses open up when the temperature outside of the body is much lower than the homeostatic set point. The anastomoses opens and prevents blood from traveling near the surface of the skin and prevents loss of heat in the body.

### **Systemic and Pulmonic Circulation**

The systemic circulation carries blood from the left ventricle of the heart to the capillaries of the systemic circulation. In the systemic circulation, the arteries carry oxygenated blood and veins carry deoxygenated blood. The main artery that carries blood from the heart to the systemic circulation is the aorta. The veins that return the blood to the heart, are the superior and inferior vena cava.

The pulmonary circulation transports blood from the right ventricle of the heart to the lungs for oxygenation. Blood travels from the right ventricle through the pulmonary trunk and pulmonary arteries. Blood returns to the heart through the pulmonary veins.

### **Pathologies of Blood Vessels**

Atherosclerosis is the abnormal deposition of fats and cholesterol in the lumen of the blood vessel. The buildup of plaque in the artery will eventually diminish the lumen of the vessel and decrease the amount of blood capable of flowing through the vessel. Atherosclerotic disease is a common cause of myocardial infarctions and cerebrovascular accidents.

Arteriosclerosis results from a physical change in the tissue makeup of the blood vessels. Elastic fibers are broken down and replaced with collagen fibers. This causes the artery to become harder and less responsive to pressure changes. Additionally, because of arteriosclerosis the blood vessel is unable to dilate when needed. This is commonly called hardening of the arteries. It is a common cause of hypertension (high blood pressure). Arteriosclerosis and atherosclerosis can affect any blood vessel. The coronary and cerebral arteries are particularly vulnerable.

Some blood vessels like the aorta are susceptible the formation of an outpouching or localized dialation known as an aneurysm. The aorta is particularly susceptible because of the high pressures that it is subjected to on a continual basis. An aneurysm occurs when blood begins to erode the tunica intima away from the tunica media. Aneurysms typically start off small and begin to grow and further dissect the blood vessel. The risk of an aneurysm is that the blood vessel will eventually rupture and the patient can die of hypovolemic blood loss. Symptoms of aneurysms vary and depend upon the size of the defect and the blood vessels that contains the defect.

### ***Conclusion***

Blood vessels are responsible for transporting blood to and from the cells of the body. Blood vessels are not static structures but are dynamically changing their lumen to accommodate

increased flow to deliver oxygen and nutrients to the most metabolically active cells. Blood vessels located at the exit of the heart are subjected to intensely high pressures and must be designed in such a way that they can withstand the forces of blood flow. Other blood vessels must be accustomed to very low pressures and designed in a manner that they can augment blood flow and prevent blood from reversing direction. The human blood vessel network is a brilliant network of vessels that accomplish all of the needs of the human body.