The Cardiovascular System: Blood Vessels

The blood vessels of the cardiovascular system form a closed circuit that carries blood from the heart to the lungs and body cells and back to the heart.

There are five major blood vessels: Arteries - they carry blood away from the heart and divide to form smaller branches of the arteries called arterioles. The arterioles divide to form the smallest blood vessels known as capillaries which are found in tissues and organs. The capillaries join to form larger venules, and the venules join to form larger veins which carry blood back to the heart.

Arteries

The walls of the arteries consist of three layers or tunics surrounding a hollow center, or lumen, through which blood flows.

1. tunica adventitia or externa - It is the thin outer layer which consists of collagen and elastic fibers. It functions in protecting the vessel and attaches it to surrounding tissues.

2. tunica media - It is the thick middle layer which consists of smooth muscle fibers and a thick layer of elastic tissue. The smooth muscle is regulated by vasomotor fibers from the sympathetic division of the autonomic nervous system. Impulses traveling on these fibers cause the muscles to contract and reduce the diameter of the vessels. The process is referred to as vasoconstriction. When the muscles relax, the diameter of the vessels increases and vasodilation occurs. The tunica media maintains blood flow and blood pressure through vasoconstriction and vasodilation.

3. tunica intima or interna - It is the thin inner layer which is composed of simple squamous epithelium specifically called endothelium.

Arteries are divided into three groups based on size and function:

1. elastic or conducting arteries - They are large, thick-walled arteries containing the protein elastin in all three tunics. The tunica media contains more elastic fibers and less smooth muscle than the arteries of the other two groups. The wall of the elastic artery stretches and recoils allowing for blood to flow continuously as the heart contracts and relaxes. Elastic arteries include the aorta, brachiocephalic artery, and common carotid arteries.
2. **muscular or distributing arteries** - They are medium-sized arteries that contain more smooth muscle than elastic fibers in the tunica media than that found in the other two groups. Muscular arteries distribute blood to various parts of the body and to organs. Muscular arteries include the renal artery, axillary artery, brachial artery, and femoral artery.

3. **arterioles** - They are the small arteries. Where the arterioles branch from the larger arteries, the walls contain all three tunics. As the arterioles reach the capillaries, the walls are composed only of endothelium surrounded by a few smooth muscle cells. Arterioles regulate blood flow from the arteries into the capillaries by vasoconstriction and vasodilation.

**Capillaries**

Capillaries are the smallest blood vessels and their walls are composed of a single layer of endothelium. There are two types of capillaries based on the structure of the endothelium.

1. **continuous capillaries** - They are the most common and are abundant in the skin and muscles. The endothelium forms a continuous lining.

2. **fenestrated capillaries** - The endothelium contains numerous open or membrane-covered pores or fenestrations. They function in the absorption of nutrients in the small intestine, movement of hormones in endocrine organs, and filtration of the blood plasma in the kidneys.

Capillaries may directly connect arterioles to venules or they may form highly branched networks, called capillary beds. Capillary beds are composed of two types of capillaries.

1. **vascular shunt** - A vascular shunt directly connects an arteriole to a venule. The arteriole at the beginning of a capillary bed connects to a thoroughfare channel. The thoroughfare channel connects to a venule on the opposite side of the capillary bed. Blood flowing through a vascular shunt bypasses tissue cells and is regulated by the smooth muscle in the arterioles.

2. **true capillaries** - They branch off of arterioles and form a network before connecting to a thoroughfare channel. At the beginning of each true capillary there is a precapillary sphincter that regulates the flow of blood into the capillary bed. Blood flowing through true capillaries exchanges gases and nutrients with the tissues.

The main mechanism of exchange of substances is by diffusion. Movement also occurs by osmosis and filtration. Nutrients, such as amino acids, glucose, and lipids, respiratory gases such as oxygen and carbon dioxide, and metabolic wastes diffuse through the capillary walls. Oxygen and nutrients diffuse out of the blood and
into body tissue cells. Carbon dioxide, which is a waste product of cells, diffuses from the tissues into the blood of the capillaries.

The movement of water and dissolved substances through the capillary walls is affected by hydrostatic pressure and osmotic pressure. Hydrostatic pressure is the force of blood against the wall of the vessel. It is also known as filtration pressure because it forces fluids through the wall. Osmotic pressure is due to the presence of large amounts of plasma proteins that tend to draw water into the capillaries by osmosis. At the arteriole end of the capillary the hydrostatic pressure is higher than the osmotic pressure. Fluids leave the capillary and enter the tissues. At the venule end of the capillary, the osmotic pressure is higher than the hydrostatic pressure and fluids move from the tissues into the capillary. More fluid leaves the capillary at the arteriole end than enters the capillary at the venule end. The excess fluid in the tissues is picked up by lymphatic vessels and returned to the blood of the veins.

**Venules**

Capillaries unite to form larger venules. At the capillary end of the venule, the wall consists of endothelium. As the venule approaches a vein, the wall consists of all three tunics.

**Veins**

The walls of veins consist of all three tunics, but the walls are thinner and contain less smooth muscle and elastic fibers than the arteries. The thickest layer is the tunica adventitia. By the time blood reaches the veins, the pressure is low and thick walls are not necessary.

Many veins, particularly those of the arms and legs, contain valves. Valves prevent the backflow of blood due to gravity. The combination of skeletal muscle contractions, valves, and pressure changes during breathing aid in returning blood back to the heart. When skeletal muscles surrounding the veins contract, they tighten around the veins forcing the valves to open. When the muscles relax, the valves close and prevent the backflow of blood. During breathing, inhalation decreases the pressure in the thoracic cavity and increases the pressure in the abdominal cavity as the diaphragm moves downward. The valves in the abdominal veins open and blood is forced toward the heart. During exhalation, the valves close in the abdominal veins and the backflow of blood is prevented.
Anastomoses

Most parts of the body receive branches from more than one artery or more than one vein. The branches form anastomoses. Anastomoses provide alternate routes called collateral channels by which blood can reach a tissue or organ. When a vessel is blocked, blood can still reach the tissue or organ through anastomoses.

Physiology of Circulation

Blood flow is the volume of blood moving through a blood vessel, organ, or the entire circulatory system. Blood flows due to differences in pressure and it moves from an area of higher pressure to an area of lower pressure.

Blood pressure is the force of blood per unit area on the wall of a blood vessel and it is usually measured in arteries.

Three factors affect or influence blood pressure:

1. cardiac output - Blood pressure varies directly with cardiac output. An increase in cardiac output increases blood pressure, and a decrease in cardiac output decreases blood pressure.

2. peripheral resistance - It is the opposition or impedance to blood flow due to friction between the blood and the walls of the vessel.

Resistance may be caused by three factors:

a. viscosity - It is the thickness or "stickiness" of the blood. The higher the viscosity, the greater the resistance and the higher the blood pressure.

b. vessel length - The longer the vessel, the greater the resistance, and the higher the blood pressure.

c. vessel diameter - The smaller the diameter, the greater the resistance, and the higher the blood pressure.

3. blood volume - It is the total amount of blood in the cardiovascular system. Blood pressure is directly proportional to blood volume. The greater the blood volume, the greater the blood pressure, and the lower the blood volume, the lower the blood pressure.
Regulation of Blood Pressure

Blood pressure is regulated by three mechanisms:

1. neural controls (nervous system)

There are five neural controls:

a. vasomotor center - It consists of a cluster of sympathetic neurons in the medulla which controls the diameter of blood vessels. The vasomotor center continually sends impulses to the smooth muscle of the walls of the vessels which results in a partial state of contraction known as vasomotor tone. When impulses from the sympathetic nervous system increase, vasoconstriction occurs and blood pressure increases. When impulses decrease, vasodilation occurs and blood pressure decreases.

b. vasomotor fibers - They are efferent fibers of the sympathetic nervous system and located in the smooth muscle of blood vessels. When the vasomotor fibers are stimulated by impulses from the vasomotor center, they release norepinephrine. Norepinephrine causes vasoconstriction and an increase in blood pressure.

c. baroreceptors - They are mechanoreceptors that detect changes in the pressure in the arteries. Baroreceptors are located in the aorta, carotid arteries, and the large arteries of the neck and thorax. When the blood pressure in the arteries increases, the baroreceptors are stimulated and impulses are sent to the vasomotor center. The vasomotor center is inhibited, vasodilation occurs, and blood pressure decreases. Impulses are also sent to the cardioinhibitory center in the medulla which reduces heart rate and the force of contraction of the heart.

d. chemoreceptors - Chemoreceptors are sensitive to the oxygen level, carbon dioxide level, and hydrogen ion concentration (pH) in the blood. They are located in the aorta, carotid arteries and the large arteries of the neck. A decrease in the level of oxygen, a decrease in hydrogen ion concentration, or an increase in the carbon dioxide level in the blood stimulates the chemoreceptors. Impulses are sent to the vasomotor center resulting in vasoconstriction and an increase in blood pressure.

e. higher brain centers - The cerebral cortex and the hypothalamus regulate blood pressure by sending impulses to the vasomotor center during times of stress, anger, or other strong emotions resulting in vasoconstriction and an increase in blood pressure.
2. chemicals - Chemicals in the blood may directly affect the smooth muscle in the walls of blood vessels or it may affect the vasomotor center. Epinephrine and norepinephrine produced by the adrenal glands increase the force and rate of contractions of the heart and they also cause vasoconstriction. Antidiuretic hormone (ADH), produced by the hypothalamus and released from the posterior pituitary, causes vasoconstriction during blood loss due to a hemorrhage.

3. renal regulation - The kidneys may directly or indirectly regulate blood pressure. Direct regulation occurs when blood pressure decreases and more water is returned to the blood. It increases blood volume and raises blood pressure. As blood pressure increases, water is removed from the blood and urine is formed. Indirect regulation occurs when the kidneys produce angiotensin II. Angiotensin II is a vasoconstrictor and it also raises blood pressure by stimulating the production of aldosterone from the adrenal glands. Aldosterone increases the movement of sodium ions into the blood which increases water retention resulting in an increase in blood volume and an increase in blood pressure.

Autoregulation

Autoregulation is local control of blood flow and it involves an automatic adjustment of the flow of blood to a tissue, organ, or region of the body. It occurs in response to the particular needs and requirements of the tissue, organ, or region. The principal stimulus for autoregulation is the level of oxygen. When the oxygen level decreases it stimulates the release of vasodilator substances such as potassium ions, hydrogen ions, carbon dioxide, and lactic acid. The vasodilator substances produce local dilation of blood vessels and relaxation of precapillary sphincters. The result is the increase in blood flow to the tissue, organ, or region which increases the oxygen level.