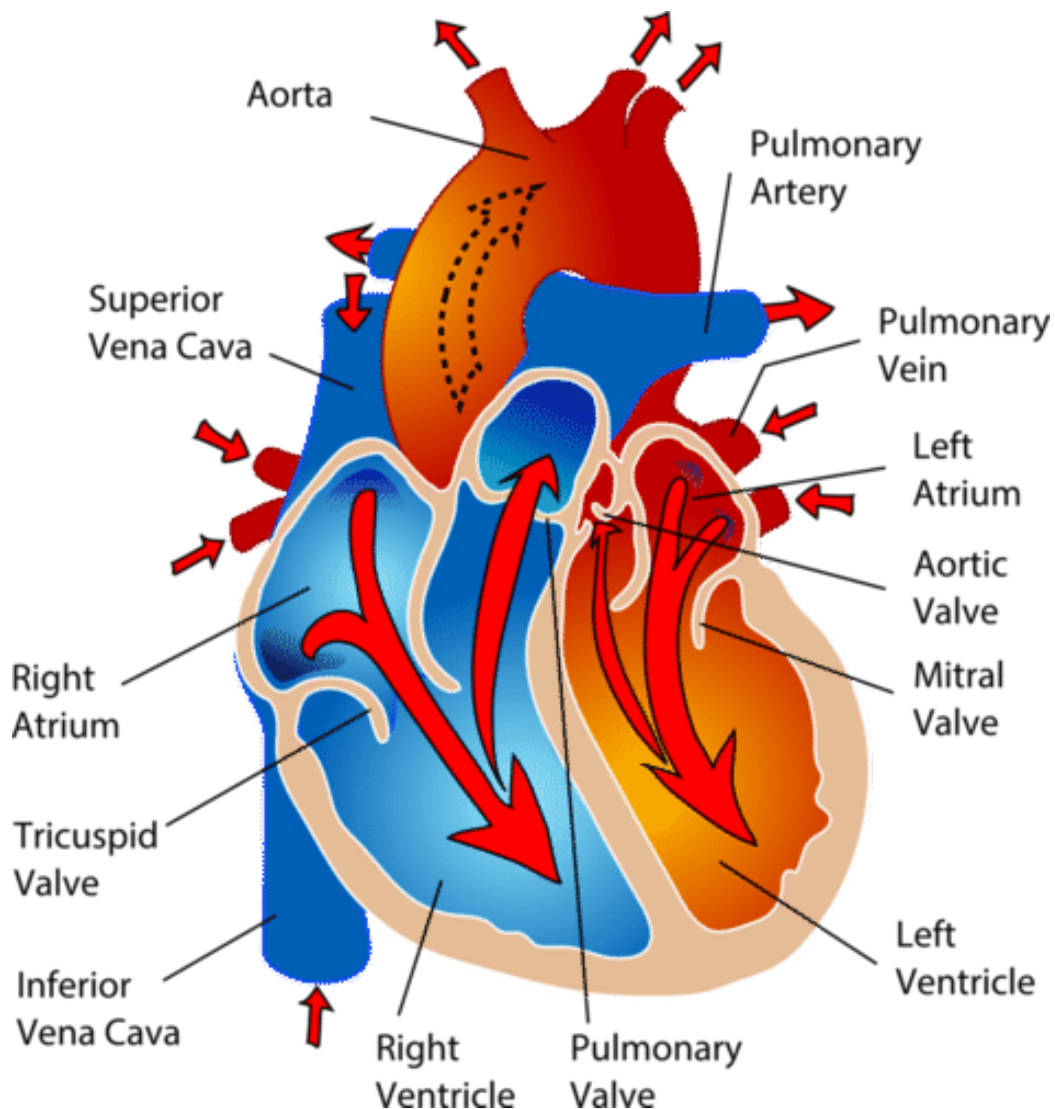


# Unit 8 Circulatory System

The circulatory system is responsible for transporting materials throughout the entire body. It transports nutrients, water, and oxygen to your billions of body cells and carries away wastes such as carbon dioxide that body cells produce. It is an amazing highway that travels through your entire body connecting all your body cells.

The main parts of the circulatory system are the heart, arteries, capillaries, and veins. Each of these parts is discussed in detail within this section. Additional topics include the lymphatic system and fetal circulation.

Did you know one drop of blood contains a half a drop of plasma, 5 MILLION red blood cells, 10 thousand white blood cells, and 250 thousand platelets?

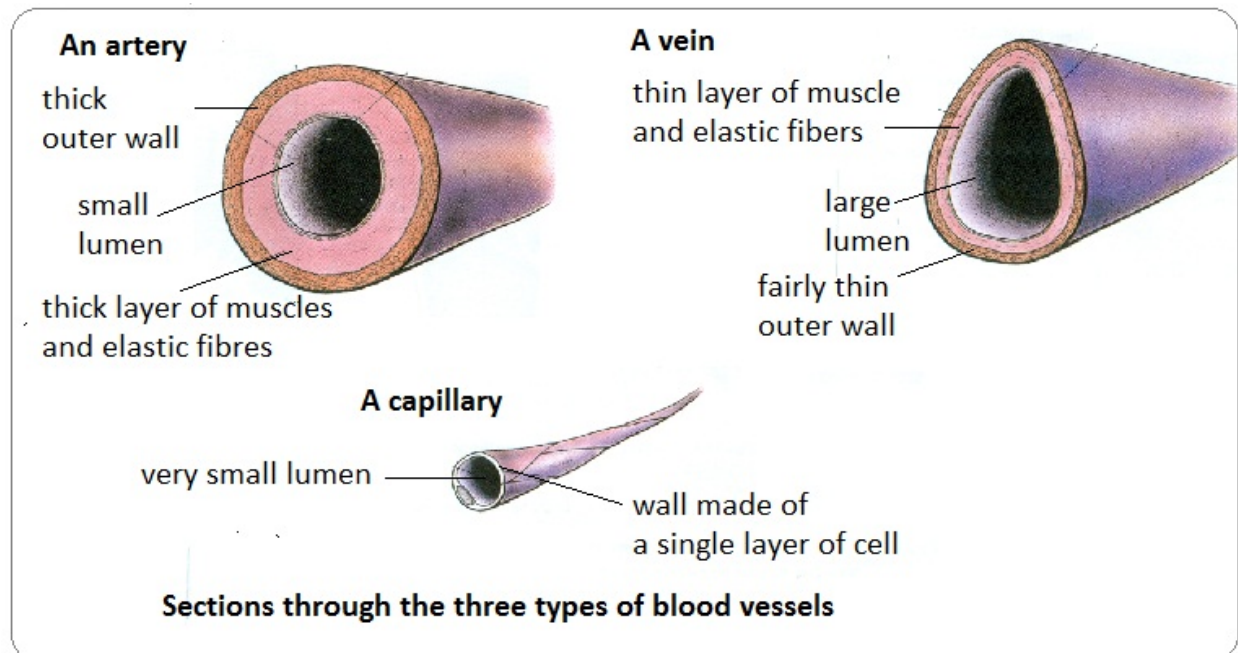


<https://www.ck12.org/biology/blood-vessels/lesson/Blood-Vessels-MS-LS/>

## Types of Blood Vessels

Humans have a closed circulatory system that carries blood inside blood vessels to and from the tissues. Blood is pumped by the heart into arteries that transport blood to the capillaries where nutrients and wastes are exchanged across the thin capillary walls. The blood is then returned to the heart by veins.

An average adult human has approximately 100 000 kilometers of blood vessels. Arranged end to end, they would circle the Earth two and a half times. These blood vessels transport blood on a non-stop journey from the heart into the arteries, which branch into arterioles, which lead to capillaries that merge into venules, which merge into veins that return to the heart.



<https://www.google.ca/url?sa=i&source=images&cd=&ved=2ahUKFwiVo9Dvs9TjAhVCxFOqKHVCQCFIQiRx6BAgBEAU&url=https%3A%2F%2Fsocratic.org%2Fquestions%2F5a7f616511ef6b3263b495cf&psig=AOvVaw2MQI2xkTByrz-uOico0SDa&ust=1564293046307856>

### Arteries and Arterioles

Arteries carry blood away from the heart toward a specific part of the body. The walls of arteries have three main layers. The inside layer that is in direct contact with blood is made up a simple squamous epithelium surrounded by connective tissue containing elastic fibres. Smooth muscle makes up the thick middle layer and outer layer is more connective tissue. These three layers make up a strong, elastic vessel that can contract or relax to regulate blood flow and moderate changes in blood pressure between heartbeats.

Arterioles are small arteries. One artery may branch into many arterioles that supply blood to the tissues. Smooth muscles in arterioles control blood pressure by constricting or dilating. Sphincters (rings of smooth muscle) at the entrance to capillary beds also control blood flow.

### Capillaries

Capillaries are very small vessels, approximately 10 micrometers wide. Capillary walls are one cell thick, which allows for easy exchange of gasses, nutrients, and wastes with the tissues. Oxygen and nutrients

are delivered to tissues by the blood, and carbon dioxide and wastes are carried away from the tissues by blood that exits the capillaries.

Capillary beds are found everywhere in the body, and this explains why bleeding takes place anywhere an injury occurs. In locations where blood enters a capillary bed, such as at the end of an arteriole, sphincters (rings of muscle) control the flow of blood into the capillary bed. These sphincters allow blood to be actively directed (shunted) toward areas that require increased blood flow. After a meal, the capillaries of the intestines require more blood flow. During exercise, muscles need the oxygen carried by red blood cells.

### ***Venules and Veins***

Venules are small veins. Venules collect the blood that drains from capillary beds. The blood from many capillaries converges into a single venule and move back towards the heart. Venules and veins have the same three layers as arteries but the smooth muscle and connective tissue layers are thinner.

Veins are larger blood vessels that collect blood and return it to the heart. They have thinner walls and larger lumen than arteries. Blood flow in the veins is promoted by movement of the body (muscle contraction) and the presence of one-way valves in veins that do not allow the backflow of blood. These valves allow for the return of blood to the heart from the lower body against the downward pull of gravity. About 70% of the blood in the body is held in veins.

VIDEO: Blood Vessels, Part 1 - Form and Function: Crash Course A&P #27

LINK: <https://youtu.be/v43ej5lCeBo>

### ***Blood Pressure***

Blood pressure is the pressure blood exerts on the walls of blood vessels. Blood pressure drops with increased distance from the heart due to the branching of the blood vessels and the resulting increases in cross-sectional area. The effect is much like a mighty river fanning out into a delta. Once the pressure has dropped in the capillary beds it cannot be increased until it returns to the heart. The lower pressure in veins explains the importance of one-way valves and muscular movement to return blood to the heart.

Blood pressure is greatest in the arteries and this is why arteries have thick, elastic, muscular walls. Blood pressure is lowest in the vena cava (0 to 20 mmHg), which is furthest from the heart. As blood moves away from the heart, the branching of arteries into arterioles into capillaries reduces blood pressure and blood velocity. This reduction is due to a huge increase in cross-sectional area in the capillaries. Blood leaving the capillaries converges into venules and then veins. The resulting decrease in cross-sectional area increases the velocity of blood flow but the pressure remains low.

VIDEO: The Heart, Part 1 - Under Pressure: Crash Course A&P #25

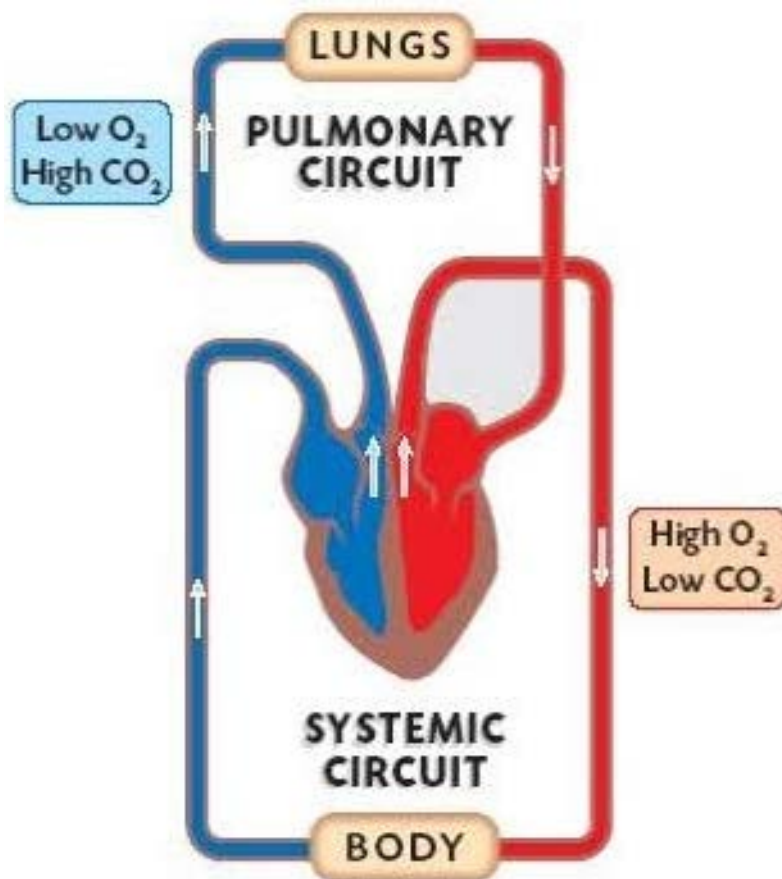
LINK: <https://youtu.be/X9ZZ6tcxArl>

## Circuits and Pathways

This section introduces the pulmonary and systemic circuits of the circulatory system and the main blood vessels of the body. These large blood vessels are the arteries and veins that transport blood between the heart and the major organs or areas of the body. In most cases, the artery and vein are named after their location in the body or the system or area to which they transport blood. For example, the renal artery carries blood to the renal system or kidneys and the renal vein carries blood away from the kidneys and back to the heart. The subclavian artery and vein are named for their location under the clavicle or collar bone. You will see many similar examples.

### *Pulmonary and Systemic Circuits*

The circulatory system is responsible for the transport of blood throughout the body. The heart acts as the pump for this system. The circulatory system takes oxygen to all of the tissues in the body and carries away wastes, such as carbon dioxide. The circulatory system has two circuits – the pulmonary circuit and systemic circuit.



<https://www.quora.com/What-is-double-circulation>

The pulmonary circuit involves the transport of blood to and from the lungs. Deoxygenated blood returns to the right side of the heart, where it is pumped by the right ventricle into the pulmonary artery and through the capillaries of the lungs. In the capillaries of the alveoli, oxygen enters the blood and

binds to hemoglobin in red blood cells as carbon dioxide diffuses out of the blood into the lungs for removal. The oxygenated blood then travels through the pulmonary vein to the left atrium of the heart and joins the systemic circuit.

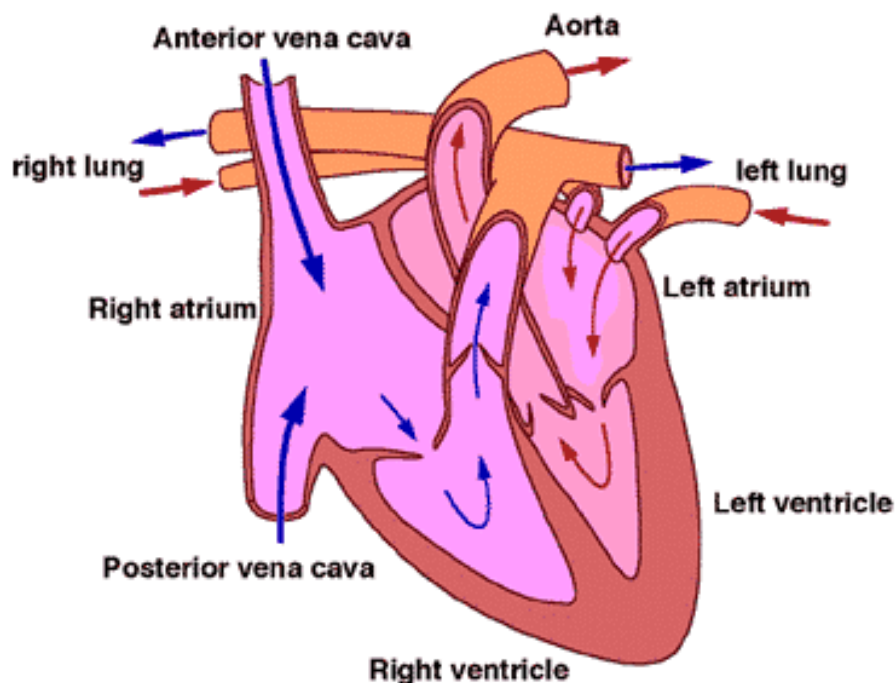
The pulmonary circuit involves the transport of blood to and from the lungs. Deoxygenated blood returns to the right side of the heart, where it is pumped by the right ventricle into the pulmonary artery and through the capillaries of the lungs. In the capillaries of the alveoli, oxygen enters the blood and binds to hemoglobin in red blood cells as carbon dioxide diffuses out of the blood into the lungs for removal. The oxygenated blood then travels through the pulmonary vein to the left atrium of the heart and joins the systemic circuit.

The systemic circuit involves the transport of blood to and from all the tissues of the body. This circuit is much larger than the pulmonary circuit, so the walls of the left ventricle of the heart are much larger than on the right side. This thicker muscle generates the force required to pump blood throughout the systemic circuit. Here's the path it takes:

- Oxygenated blood is pumped by the left ventricle into the aorta
- The aorta branches into many smaller arteries that carry blood to all areas of the body
- Via the capillaries, oxygen is delivered to cells and carbon dioxide is removed
- Deoxygenated blood returns from the upper body through the anterior vena cava and from the lower body through the posterior vena cava
- The anterior vena cava and posterior vena cava enter the right atrium of the heart
- From there, blood enters the pulmonary circuit to become re-oxygenated

VIDEO: Blood Flow Through the Heart | Heart Blood Flow Circulation Supply

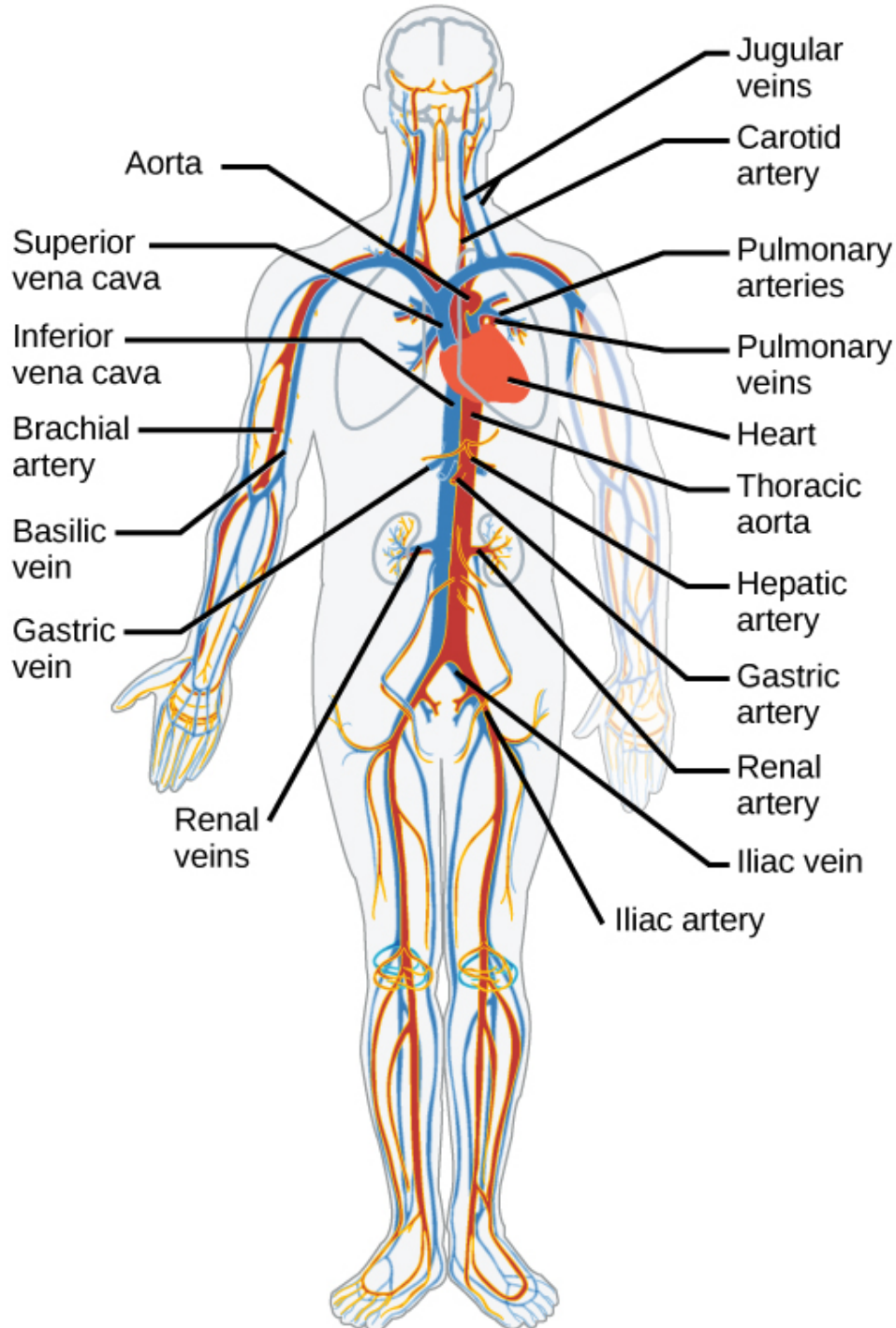
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[http://mandevillehigh.stpsb.org/teachersites/laura\\_decker/path\\_of\\_blood.bmp](http://mandevillehigh.stpsb.org/teachersites/laura_decker/path_of_blood.bmp)

### **Major Blood Vessels and Pathways of Blood**

Think of the major veins and arteries of the systemic circuit as a map of the pathway of blood from the heart to a specific organ system, then through the lungs, and finally back to the heart. A red blood cell delivers oxygen to only one destination on each trip through the body.



### **Main Blood Vessel Functions**

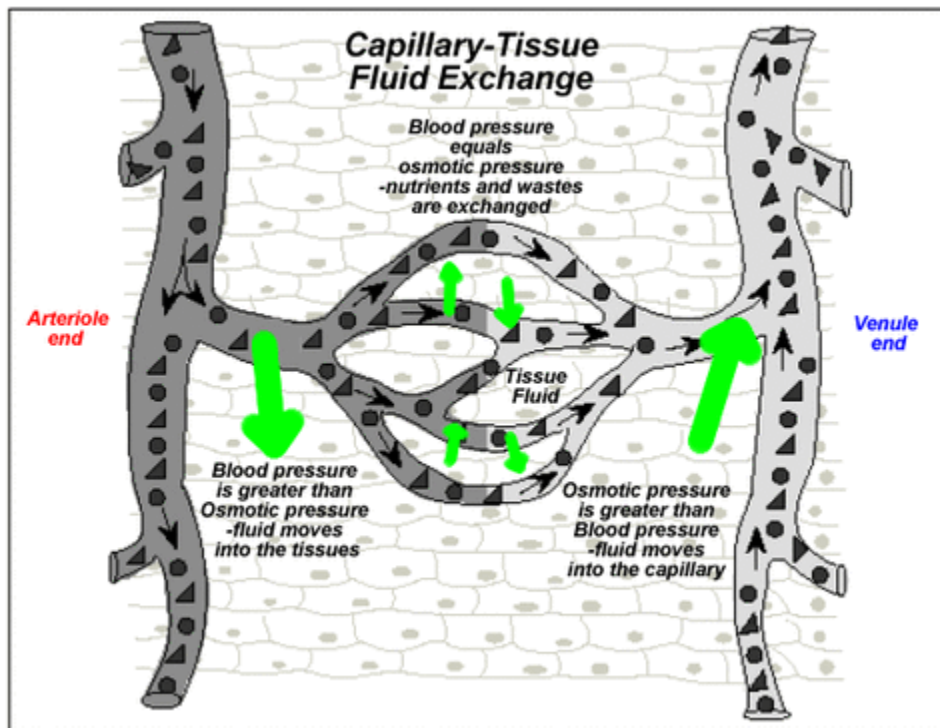
Aorta	Largest artery in the body; receives oxygenated blood, at pressure, directly from the left ventricle and transports it to the body
Anterior vena cava	Large vein that collects deoxygenated blood from head and arms and returns it to the right atrium of the heart
Posterior vena cava	Large vein that collects deoxygenated blood from the abdomen and lower body and returns it to the right atrium of the heart
Pulmonary artery	Receives deoxygenated blood, at pressure, from the right ventricle and takes it to the lungs
Pulmonary vein	Carries oxygenated blood from the lungs to the left atrium of the heart
Coronary arteries	Branch off the aorta and take oxygenated blood to the heart muscle
Coronary vein	Return deoxygenated blood from the heart muscle to the right atrium
Carotid arteries	Take oxygenated blood to head
Jugular veins	Take deoxygenated blood from the head back to the anterior vena cava
Subclavian arteries	Lie beneath the clavicles; take oxygenated blood to the arms
Subclavian veins	Lie beneath the clavicles; take deoxygenated blood from the arms back to the anterior vena cava
Mesenteric arteries	Take oxygenated blood to the intestines
Hepatic portal vein	Carries blood rich in nutrients from the intestines to the liver for processing before returning to the heart
Hepatic vein	Returns deoxygenated blood from the liver to the posterior vena cava
Renal arteries	Take oxygenated blood to the kidneys
Renal veins	Return deoxygenated blood from the kidneys to the posterior vena cava
Iliac arteries	Take oxygenated blood to the legs
Iliac veins	Return deoxygenated blood from the legs to the posterior vena cava

## Capillary Tissue Fluid Exchange

Capillary-tissue fluid exchange occurs in capillary beds where blood is in close proximity – within one endothelial cell layer – to tissue fluid that surrounds all the cells in the body. The process describes why oxygen and nutrients enter the tissue fluid from the blood and why carbon dioxide and metabolic wastes leave the tissue fluid and enter the blood. This lesson requires knowledge of membranes, diffusion, and osmotic pressure. A quick review of osmosis may be helpful in understanding this concept.

As blood moves away from the heart, the branching of arteries into arterioles and arterioles into capillaries reduces blood pressure and blood velocity. This reduction in pressure and velocity is due to a huge increase in cross-sectional area in the capillaries. The lower velocity in the capillaries allows the time necessary for effective capillary tissue-fluid exchange. Blood leaving the capillaries converges into venules and then veins. The resulting decrease in cross-sectional area increases the velocity of blood flow but the pressure remains low.

Recall that the walls of capillaries are one cell thick and allow for the rapid diffusion of molecules from the blood into the tissue fluid, and from the tissue fluid into the blood, depending on the concentration gradient that exists for each molecule. For example, oxygen moves from the blood into the tissues because it is in higher concentration in the blood than in the tissues where it is being used up in cellular respiration. Carbon dioxide produced by cellular respiration is more concentrated in the tissues, so it diffuses from the tissues into the blood where its concentration or partial pressure is lower.



<http://biology12plo.weebly.com/uploads/2/8/8/0/28804401/253098022.gif?475>

Capillary-tissue fluid exchange is controlled by the blood pressure in the capillaries and the osmotic pressure of blood. As blood enters the capillary bed at the arterial end, the blood pressure on the walls



of the capillary is about 40 mmHg. By the time blood travels to the venous end of a capillary bed, the blood pressure drops to about 15 mmHg. Blood pressure pushes plasma fluid from the blood into the tissues. The osmotic pressure exerted by blood due to high concentrations of dissolved salts and plasma proteins is fairly stable at about 25 mmHg. These dissolved salts and proteins make blood hypertonic to tissue fluid. The osmotic pressure of blood pulls water (tissue fluid) back into the blood.

At the arterial end of the capillary bed, the net pressure favours the movement of fluid into the tissues. The blood pressure (40 mmHg) is greater than the osmotic pressure of blood (21 mmHg), and the result is a net movement of fluid (blood plasma) from the capillary into the tissue fluid surrounding cells. This fluid delivers dissolved oxygen and nutrients, such as glucose and amino acids that are taken up by cells. Blood proteins and formed element (blood cells) are too big to leave the capillary.

In the middle of a capillary bed, blood pressure is equal to the osmotic pressure of blood (always 21 mmHg) and there is no net movement of fluid from blood to the tissues. In this area, nutrients and wastes move with their concentration gradients. Oxygen gas (from the lungs) and nutrients (from the liver) are in high concentration in the blood and diffuse into the tissue fluid through the walls of the capillary. Carbon dioxide (produced by cellular respiration) and other cellular waste products are in high concentration in cells and tissue fluid and diffuse into the blood through the walls of the capillary.

At the venous end of the capillary bed, the net pressure favours the movement of fluid into the blood. The osmotic pressure of the blood (still 21 mmHg) is greater than blood pressure (now 15 mmHg) and there is a net movement of tissue fluid back into the blood. The blood is hypertonic to tissue fluid and pulls water from the tissues into the blood along with carbon dioxide and wastes.

Any excess fluid left in the tissues is taken up by the lymph capillaries and returned to the blood. This is a homeostatic mechanism and a main function of the lymphatic system. The lymphatic system is the topic of the next lessons.

VIDEO: CAPILLARY EXCHANGE

LINK: [https://youtu.be/-qY17G\\_n-WA](https://youtu.be/-qY17G_n-WA)

## **The Lymphatic System**

The lymphatic system is a network of lymph vessels and lymphoid organs found throughout the body. This system of lymphatic veins and nodes has the following three main functions. It drains excess fluid (lymph) from the tissues and moves it back into the circulatory system at the right and left subclavian veins. It collects lipids in lacteals found in the villi of the small intestine and transports them to the bloodstream. It aids the immune system to help protect the body from pathogens.

### ***The Lymphatic System***

The lymphatic system is made up of lymph capillaries, lymph vessels, and lymph nodes. Other organs involved in immune function are now the tonsils, thymus, liver, spleen, appendix, and bone marrow. They work cooperatively with lymphatic vessels and nodes to fight infections and disease.

### ***Lymph Capillaries***

The lymph capillaries are the starting point of the one-way lymphatic system. Lymph capillaries originate in tissues and drain excess tissue fluid that has not been reabsorbed into the bloodstream and move it into lymph veins. This prevents swelling or edema (collection of fluid in the tissues).

### ***Lymph Veins***

The lymph veins collect lymph from many lymph capillaries and move it into lymph ducts for transport to the subclavian veins, where the fluid is returned to the bloodstream. The movement of fluid in the lymph veins relies on muscular movements to squeeze the fluid along. These veins, like those that make up the circulatory system, contain one-way valves that keep the fluid moving toward the thoracic cavity or chest where it is returned to the circulatory system.

### ***Lymph Nodes***

Lymph nodes are lymphoid organs, along with the tonsils, spleen, thymus and bone marrow. They are bean-shaped structures with a cortex and medulla, similar to many other body organs.

The cortex (outside) of a lymph node contains many lymphocytes (a type of white blood cell) that are activated to fight off pathogens. Lymphocytes produce antibodies (Y-shaped proteins) that combine with antigens (proteins or polysaccharides on foreign cells) to form inactive antigen-antibody complexes.

In the medullar (middle) of the lymph nodes, macrophages, another form of white blood cell, engulf (phagocytize) foreign debris and clean up lymph fluid. Lymph nodes are found along lymph vessels and are most numerous in the groin, neck, and armpits. Swollen lymph nodes are a sign that an infection is present.

## **Fetal Circulation**

A human fetus (Latin = offspring) resembles a small person by three months. Hair is appearing, some cartilage begins to harden into bone, and it may be possible to determine the sex of the fetus. By four months, the fetal heartbeat can be heard with a stethoscope. By five months, the movement of the fetus can be felt by the mother. This lesson discusses the specialized features of fetal circulation that make it different from adult circulation.

Fetal circulation is modified to allow it to develop in the mother's uterus. One of the main differences is the transport of oxygenated blood from the mother to the fetus via the placenta. The fetus does not use its own pulmonary circuit and lungs until birth.

There are four main differences between the circulatory system of a fetus and an adult human. Two of these – umbilical cord and venous duct – are related to the exchange of oxygen between and fetal and maternal blood supply via the placenta.

In the placenta, fetal capillary beds are in close proximity to maternal capillary beds. Carbon dioxide and wastes from the fetus moved through the umbilical arteries are exchanged for oxygen and nutrients supplied by the mother. Note that fetal and maternal blood do not mix, and this exchange occurs across membranes by the process of diffusion.

The other two differences – oval opening and arterial duct – are temporary structural changes in the heart and blood vessels that allow the fetal circulation to bypass the lungs because the fetus does not breathe while in the uterus.

### ***Umbilical Vein and Umbilical Arteries***

The umbilical vein and the umbilical arteries are inside the umbilical cord that attaches the placenta to the umbilicus (future belly button) of the fetus. The umbilical vein carries oxygenated blood with maternal nutrients from the placenta to the fetus. The umbilical arteries carry deoxygenated blood with fetal waste from the fetus to the placenta. The umbilical arteries receive blood from the fetal heart via the dorsal aorta and both iliac arteries of the legs where they branch off to the umbilical cord.

### ***Venous Duct***

The venous duct receives blood from the umbilical vein and directs it to the posterior/inferior vena cava. This venous duct acts as a liver bypass and moves blood into the fetal systemic circulation. The liver bypass means it is possible for harmful substances in the mother's blood to be passed on to the fetus.

### ***Oval Opening***

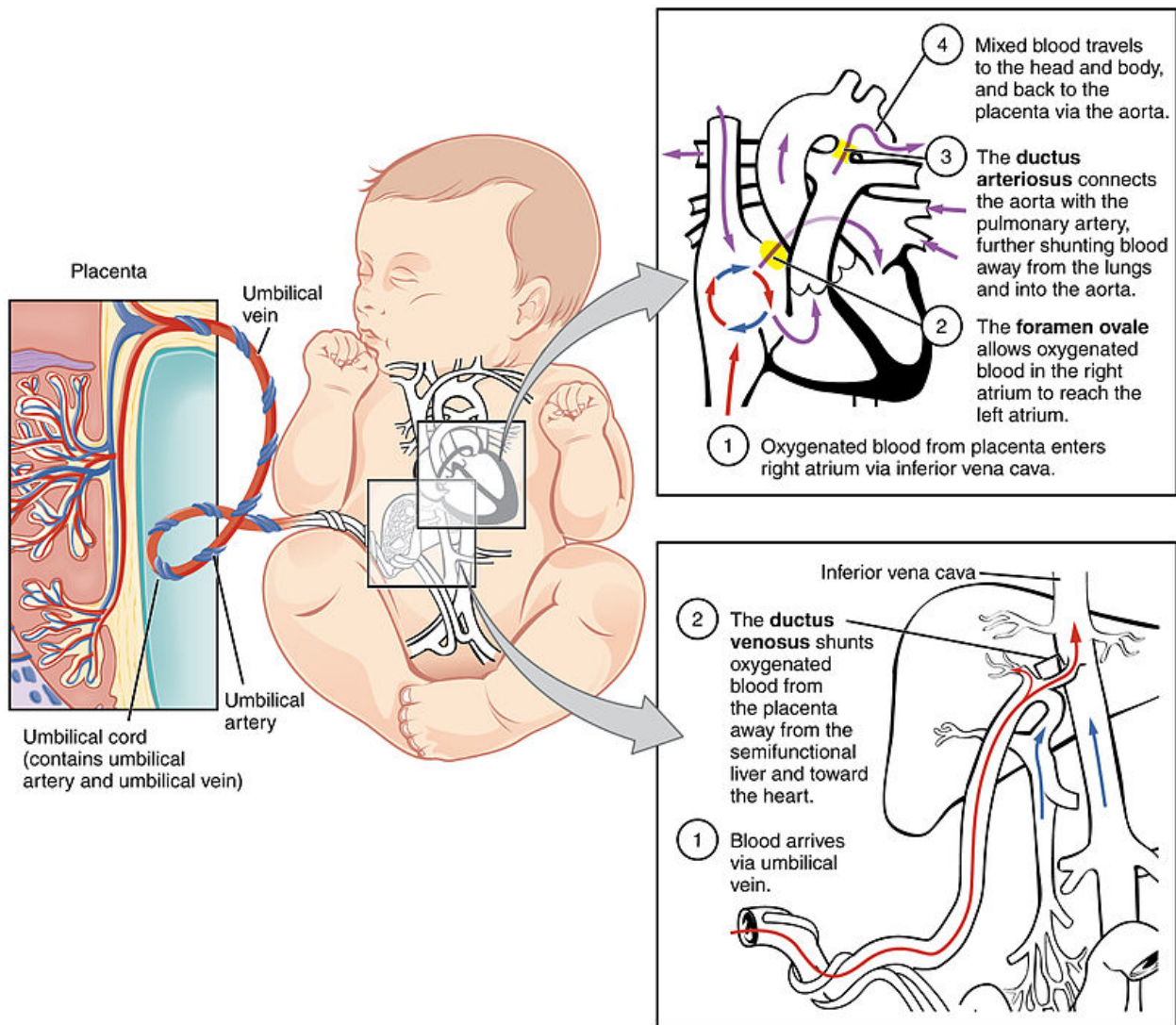
The oval opening is a passage between the right and left atria of the heart. This opening is covered with a flap that allows blood to move from the right atrium to the left atrium only. This movement is aided by higher blood pressure in the right atrium than in the left because little blood returns to the left atrium from the lungs. Movement of blood from the right atrium to the left atrium bypasses the lungs and delivers most of the oxygenated blood from the placenta directly to the body.

Following birth and cutting the umbilical cord, blood begins to flow in and out of the lungs. Blood returning from the lungs to the left atrium closes the flap between the two atria. In some cases, the flap

does not close and causes a “blue baby” whose lungs do not receive enough blood to be oxygenated. This condition may require surgery to be corrected.

### Arterial Duct

The arterial duct is a connection between the pulmonary artery and the aorta. This duct directs blood away from the lungs and into systemic circulation. At birth, cells grow over the opening to the arterial duct and it closes.



## **Blood**

Blood is composed of two main parts. The liquid components of blood, called plasma, is mainly water (92%) with many dissolved substances. Plasma makes up 55% of the volume of blood. The remaining 45% of the blood volumes is composed of formed elements or blood cells of various kinds. These are red blood cells, white blood cells, and platelets, which are actually cell fragments.

### ***Blood Plasma***

Blood plasma is mainly water, which acts as the solvent the substances dissolved in it. These dissolved substances include:

- Plasma proteins – albumin (maintains blood volume), immunoglobulins (fight infection), and fibrinogen (blood clotting)
- Salts – sodium ions, potassium ions, chloride ions, calcium ions, etc
- Nutrients – glucose, amino acids, fatty acids, certain vitamins
- Gases – mainly carbon dioxide, in the form of bicarbonate ion, from the tissues
- Waste – urea from the liver
- Hormones – many are found in plasma, ex, thyroxin, insulin, adrenalin, estrogen

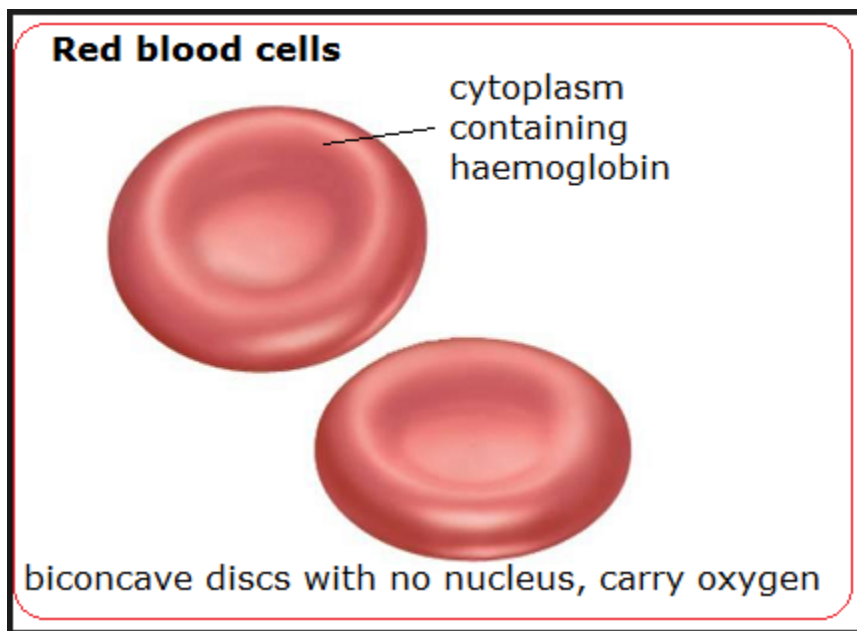
### ***Blood Cells***

All of the following types of blood cell are produced in red bone marrow. Red bone marrow is located in the ribs, vertebrae, skull, and the ends of long bones in the arms and legs.

VIDEO: The Components of Blood and Their Importance

LINK: <https://youtu.be/VSVYgivfs9c>

### ***Red Blood Cells – Erythrocytes***



<http://physiologyplus.com/describe-the-structure-and-functions-of-erythrocytes/>

Red blood cells have a biconcave shape, contain hemoglobin that carries oxygen, and are produced in bone marrow.

The majority of cells found in the blood are red blood cells or erythrocytes. RBCs are shaped like biconcave disks and have no nuclei. The flattened shape increases the surface area for gas exchange and aids in transport through the capillaries. A single milliliter of blood will normally contain 4 to 6 billion RBCs. RBCs function in the blood for up to four months. New RBCs are continually being produced from stem cells in the red bone marrow to replace worn out ones. As mentioned previously, the liver plays a role in recycling iron and breaking down of the heme groups to make bile.

RBCs carry oxygen from the lungs and deliver it to the body tissues in the capillaries. They contain protein called hemoglobin, and each hemoglobin molecule is composed of four polypeptide chains (an example of quaternary protein structure). Each of the four polypeptides has a heme group that contains iron. The heme group binds to oxygen and releases it to the tissues of the body. If hemoglobin levels in the blood decrease – a condition called anemia – more of the hormone erythropoietin is produced, which increases the number of RBCs produced in the bone marrow. Recombinant forms of this hormone (EPO, which is created to treat patients with anemia from many different causes) are now misused by athletes to increase the oxygen carrying capacity of the blood.

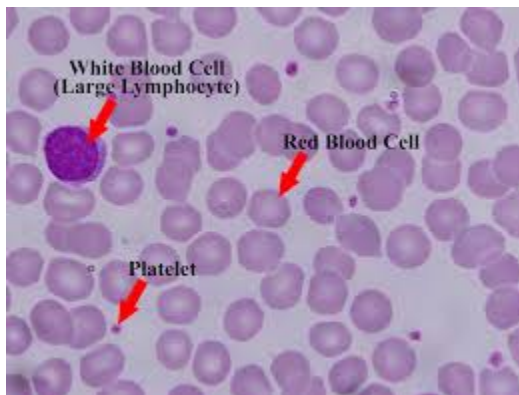
### ***White Blood Cells – Leukocytes***

White blood cells are large cells that vary in colour and contain nuclei. WBCs are spherical in shape.

White blood cells:

- Fight infection
- Develop immunity
- Phagocytize foreign particles

There are many different kinds of WBCs, each with a specific function. The size and appearance of WBCs vary greatly, so can be recognized under a microscope. The life span of a specific type of WBC ranges from several days to years, depending on the type of cell and its location. Like RBCs, all WBCs are produced in the red bone marrow from stem cells that differentiate into the many different types of blood cells.



[http://www.mt.mahidol.ac.th/e-learning/BHL/R\\_B\\_C.html](http://www.mt.mahidol.ac.th/e-learning/BHL/R_B_C.html)

Neutrophils, the most common WBC, have a multi-lobed nucleus. They are phagocytic, meaning they engulf and ingest foreign substances or invaders, such as like bacteria and other pathogens, and destroy them.

Lymphocytes mature in lymphatic tissues, such as the thymus and spleen. There are two main types – B lymphocytes and T lymphocytes. Both produce antibodies and provide secondary immunity.

Antibodies are Y-shaped protein molecules that travel in blood and lymph, and attach to specific foreign antigens with a lock and key mechanism similar to enzymes. Antibodies help to prevent disease. They are produced to recognize a specific antigens – a foreign substance that is recognized by the immune system as non-self and needs to be destroyed. Antibodies attach to foreign antigens by and promoting phagocytosis by other WBCs, clump pathogens together, or form complexes with pathogens and prevent them from attaching to cells in the respiratory tract and digestive tract.

Monocytes, the largest WBCs, develop into large macrophages in the body tissues and have the ability to phagocytize pathogens during infection. Eosinophils are involved in the control of allergic and inflammatory responses. Basophils release histamine that increases blood flow to sites of tissue injury.

### ***Platelets – Thrombocytes***

Platelets are cell fragments that break away from larger cells in the red bone marrow. A milliliter of blood contains up to 300 million platelets. Platelets are involved in blood clotting following tissue injury. Blood clotting is a complex process involving platelets, many clotting factors, the proteins fibrinogen and prothrombin, vitamin K found in green vegetables and produced by bacteria in the large intestine, and calcium ions. In the clotting process following an injury, platelets act as a first line of defense by forming a platelet plug that seals the leak. Later, a complex series of events form a protein net that traps RBCs around the platelet plug. As tissue repair takes place, the plug is dissolved and blood flow resumes.

VIDEO: Blood, Part 1 - True Blood: Crash Course A&P #29

LINK: <https://youtu.be/HQWlcSp9SIs>