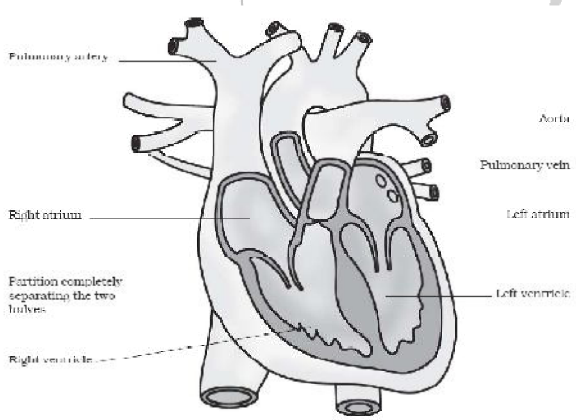
The cardiovascular system consists of the heart, blood vessels, and the approximately 5 liters of blood that the blood vessels transport. Responsible for transporting oxygen, nutrients, hormones, and cellular waste products throughout the body, the cardiovascular system is powered by the body's hardest-working organ — the heart, which is only about the size of a closed fist. Even at rest, the average heart easily pumps over 5 liters of blood throughout the body every minute.

ANATOMY

The Heart



The heart is a muscular pumping organ located medial to the lungs along the body's midline in the thoracic region. The bottom tip of the heart, known as its apex, is turned to the left, so that about 2/3 of the heart is located on the body's left side with the other 1/3 on right. The top of the heart, known as the heart's base, connects to the great blood vessels of the body: the aorta, vena cava, pulmonary trunk, and pulmonary veins.

Circulatory Loops

There are 2 primary circulatory loops in the human body:

Pulmonary circulation transports deoxygenated blood from the right side of the heart to the lungs, where the blood picks up oxygen and returns to the left side of the heart. The pumping chambers of the heart that support the pulmonary circulation loop are the right atrium and right ventricle.

Systemic circulation carries highly oxygenated blood from the left side of the heart to all of the tissues of the body (with the exception of the heart and lungs). Systemic circulation removes wastes from body tissues and returns deoxygenated blood to the right side of the heart. The left atrium and left ventricle of the heart are the pumping chambers for the systemic circulation loop.

Blood Vessels

Blood vessels are the body's highways that allow blood to flow quickly and efficiently from the heart to every region of the body and back again. The size of blood vessels corresponds with the amount of blood that passes through the vessel. All blood vessels contain a hollow area called the lumen through which blood is able to flow. Around the lumen is the wall of the vessel, which may be thin in the case of capillaries or very thick in the case of arteries.

All blood vessels are lined with a thin layer of simple squamous epithelium known as the endothelium that keeps blood cells inside of the blood vessels and prevents clots from forming. The endothelium lines the entire circulatory system, all the way to the interior of the heart, where it is called the endocardium.

There are three major types of blood vessels: arteries, capillaries and veins. Blood vessels are often named after either the region of the body through which they carry blood or for nearby structures. For example, the brachiocephalic artery carries blood into the brachial (arm) and cephalic (head) regions. One of its branches, the subclavian artery, runs under the clavicle; hence the name subclavian. The subclavian artery runs into the axillary region where it becomes known as the axillary artery.

Arteries are blood vessels that carry blood away from the heart. Blood carried by arteries is usually highly oxygenated, having just left the lungs on its way to the body's tissues. The pulmonary trunk and arteries of the pulmonary circulation loop provide an exception to this rule – these arteries carry deoxygenated blood from the heart to the lungs to be oxygenated. Arteries face high levels of blood pressure as they carry blood being pushed from the heart under great force. To withstand this pressure, the walls of the arteries are thicker, more elastic, and more muscular than those of other vessels. The largest arteries of the body contain a high percentage of elastic tissue that allows them to stretch and accommodate the pressure of the heart.

Smaller arteries are more muscular in the structure of their walls. The smooth muscles of the arterial walls of these smaller arteries contract or expand to regulate the flow of blood through their lumen. In this way, the body controls how much blood flows to different parts of the body under varying circumstances. The regulation of blood flow also affects blood pressure, as smaller arteries give blood less area to flow through and therefore increases the pressure of the blood on arterial walls.

Arterioles are narrower arteries that branch off from the ends of arteries and carry blood to capillaries. They face much lower blood pressures than arteries due to their greater number, decreased blood volume, and distance from the direct pressure of the heart. Thus arteriole walls are much thinner than those of arteries. Arterioles, like arteries, are able to use smooth muscle to control their aperture and regulate blood flow and blood pressure.

Capillaries are the smallest and thinnest of the blood vessels in the body and also the most common. They can be found running throughout almost every tissue of the body and border the edges of the body's avascular tissues. Capillaries connect to arterioles on one end and venules on the other. Capillaries carry blood very close to the cells of the tissues of the body in order to exchange gases, nutrients, and waste products. The walls of capillaries consist of only a thin layer of endothelium so that there is the minimum amount of structure possible between the blood and the tissues. The endothelium acts as a filter to keep blood cells inside of the vessels while allowing liquids, dissolved gases, and other chemicals to diffuse along their concentration gradients into or out of tissues.

Pre-capillary sphincters are bands of smooth muscle found at the arteriole ends of capillaries. These sphincters regulate blood flow into the capillaries. Since there is a limited supply of blood, and not all tissues have the same energy and oxygen requirements, the pre-capillary sphincters reduce blood flow to inactive tissues and allow free flow into active tissues.

Veins are the large return vessels of the body and act as the blood return counterparts of arteries. Because the arteries, arterioles, and capillaries absorb most of the force of the heart's contractions, veins and venules are subjected to very low blood pressures. This lack of pressure allows the walls of veins to be much thinner, less elastic, and less muscular than the walls of arteries. Veins rely on gravity, inertia, and the force of skeletal muscle contractions to help push blood back to the heart. To facilitate the movement of blood, some veins contain many one-way valves that prevent blood from flowing away from the heart. As skeletal muscles in the body contract, they squeeze nearby veins and push blood through valves closer to the heart. When the muscle relaxes, the valve traps the blood until another contraction pushes the blood closer to the heart.

Venules are similar to arterioles as they are small vessels that connect capillaries, but unlike arterioles, venules connect to veins instead of arteries. It picks up blood from many capillaries and deposit it into larger veins for transport back to the heart.

Coronary Circulation

The heart has its own set of blood vessels that provide the myocardium with the oxygen and nutrients necessary to pump blood throughout the body. The left and right coronary arteries branch off from the aorta and provide blood to the left and right sides of the heart. The coronary sinus is a vein on the posterior side of the heart that returns deoxygenated blood from the myocardium to the vena cava.

Hepatic Portal Circulation

The veins of the stomach and intestines perform a unique function: instead of carrying blood directly back to the heart, they carry blood to the liver through the hepatic portal vein. Blood leaving the digestive organs is rich in nutrients and other chemicals absorbed from food. The liver removes toxins, stores sugars, and processes the products of digestion before they reach the other body tissues. Blood from the liver then returns to the heart through the inferior vena cava.

PHYSIOLOGY

Functions

The cardiovascular system has three major functions:

- **Transportation:** The cardiovascular system transports blood to almost all of the body's tissues. The blood delivers essential nutrients and oxygen and removes wastes and carbon dioxide to be processed or removed from the body. Hormones are transported throughout the body via the blood's liquid plasma.
- **Protection:** The cardiovascular system protects the body through its white blood cells. White blood cells clean up cellular debris and fight pathogens that have entered the body. Platelets and red blood cells form scabs to seal wounds and prevent pathogens from entering the body and liquids from leaking out. Blood also carries antibodies that provide specific immunity to pathogens that the body has previously been exposed to or has been vaccinated against.
- **Regulation:** The cardiovascular system is instrumental in the body's ability to maintain homeostatic control of several internal conditions. Blood vessels help maintain a stable body temperature by controlling the blood flow to the surface of the skin. Blood vessels near the skin's surface open during times of overheating to allow hot blood to dump its heat into the body's surroundings. In the case of hypothermia, these blood vessels constrict to keep blood flowing only to vital organs in the body's core. Blood also helps balance the body's pH due to the presence of bicarbonate

ions, which act as a buffer solution. Finally, the albumins in blood plasma help to balance the osmotic concentration of the body's cells by maintaining an isotonic environment.

The Circulatory Pump

The heart is a four-chambered "double pump," where each side (left and right) operates as a separate pump. The left and right sides of the heart are separated by a muscular wall of tissue known as the septum of the heart. The right side of the heart receives deoxygenated blood from the systemic veins and pumps it to the lungs for oxygenation. The left side of the heart receives oxygenated blood from the lungs and pumps it through the systemic arteries to the tissues of the body. Each heartbeat results in the simultaneous pumping of both sides of the heart, making the heart a very efficient pump.

Regulation of Blood Pressure

Several functions of the cardiovascular system can control blood pressure. Certain hormones along with autonomic nerve signals from the brain affect the rate and strength of heart contractions. Greater contractile force and heart rate lead to an increase in blood pressure. Blood vessels can also affect blood pressure. Vasoconstriction decreases the diameter of an artery by contracting the smooth muscle in the arterial wall. The sympathetic (fight or flight) division of the autonomic nervous system causes vasoconstriction, which leads to increases in blood pressure and decreases in blood flow in the constricted region. Vasodilation is the expansion of an artery as the smooth muscle in the arterial wall relaxes after the fight-or-flight response wears off or under the effect of certain hormones or chemicals in the blood. The volume of blood in the body also affects blood pressure. A higher volume of blood in the body raises blood pressure by increasing the amount of blood pumped by each heartbeat. Thicker, more viscous blood from clotting disorders can also raise blood pressure.

Haemostasis

Haemostasis, or the clotting of blood and formation of scabs, is managed by the platelets of the blood. Platelets normally remain inactive in the blood until they reach damaged tissue or leak out of the blood vessels through a wound. Once active, platelets change into a spiny ball shape and become very sticky in order to latch on to damaged tissues. Platelets next release chemical clotting factors and begin to produce the protein fibrin to act as structure for the blood clot. Platelets also begin sticking together to form a platelet plug. The platelet plug will serve as a temporary seal to keep blood in the vessel and foreign material out of the vessel until the cells of the blood vessel can repair the damage to the vessel wall.

Blood Typing

People have different blood types. Blood type is determined by whether certain proteins (Rh factor and blood group antigens A and B) are present on the surface of red blood cells. These proteins are considered antigens because they can trigger an immune response.

ABO Blood Groups

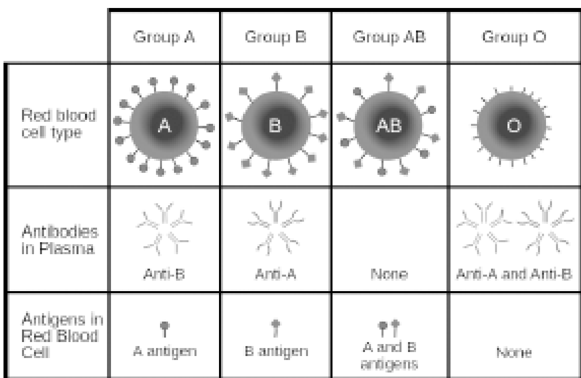
In the 1901, Karl Landsteiner discovered the ABO blood group antigens. The ABO blood groups are defined by the presence of two alternative antigens on red blood Cells. Two basic rules governing this system are as follows:

(1) The blood "type" is defined by the presence of two red blood cell antigens, "A" and "B". RBCs of type A have the A antigen on their surface, those of type B have antigen B, type

AB red cells bear both antigens, while type O cells bear neither antigen.

(2) "Natural" antibodies called isoagglutinins exist in an individual's serum, directed against whichever of the A and B antigens is not present on that person's red cells

The four main blood types are A, B, AB, and O



A: Antigen A (but not B) is present.

B: Antigen B (but not A) is present.

AB: Antigens A and B are present.

O: Neither antigen A nor B is present.

Rh grouping

The Rh antigen similar to one present in Rhesus monkeys (hence Rh), is also observed on the surface of RBCs of majority (nearly 80per cent) of humans. Such individuals are called Rh positive (Rh+ve) and those in whom this antigen is absent are called Rh negative (Rh-ve).

An Rh-ve person, if exposed to Rh+ve blood, will form specific antibodies against the Rh antigens. Therefore, Rh group should also be matched before transfusions. A special case of Rh incompatibility (mismatching) has been observed between the Rh-ve blood of a pregnant mother with Rh+ve blood of the foetus. In such cases, the mother starts preparing antibodies against Rh antigen in her blood. In case of her subsequent pregnancies, the Rh antibodies from the mother (Rh-ve) can leak into the blood of the foetus (Rh+ve) and destroy the foetal RBCs. This could be fatal to the foetus or could cause severe anaemia and jaundice to the baby. This condition is called erythroblastosisfoetalis. This can be avoided by administering anti-Rh antibodies to the motherimmediately after the delivery of the first child. Rh INCOMPATIBILITY between mother and infant may result in ERYTHROBLASTOSIS FETALIS, which can be prevented by passive immunization of the mother with anti-Rh antibodies(RHOGAM).

Blood Transfusion

A blood transfusion is the transfer of blood or a blood component from one person (a donor) to another (a recipient). A blood transfusion is safest when the blood type of the transfused blood matches the recipient's blood type and Rh status. However, in an emergency, anyone can receive type O red blood cells. Thus, people with type O blood are known as universal donors. People with type AB blood can receive red blood cells from a donor of any blood type and are known as universal recipients.

Recipients whose blood is Rh-negative must receive blood from Rh-negative donors (except in life-threatening emergencies), but recipients whose blood is Rh-positive may receive Rh-positive or Rh-negative blood.Also, blood may be Rh-positive (Rh factor is present on the surface of the red blood cells) or Rh-negative (Rh factor is absent).

Normally, if people lack an A and/or a B antigen, they have naturally occurring antibodies against the antigen or antigens that they lack. For example, people with blood type A have naturally occurring anti-B antibody, and people with blood type O (who lack both A and B antigens) have naturally occurring anti-A and anti-B antibodies. In addition to A and B antigens, there are several other blood group antigens also present on red blood cells. However, people do not have naturally occurring antibodies against these antigens. Such antibodies develop only if people are exposed to these antigens by transfusion.

ABO and Rh blood type donation showing matches between donor and recipient types

		Donors							
		O+	A+	B+	AB+	O−	A−	B−	AB−
Recipients	O+	✔				✔			
	A+	✔	✔			✔	✔		
	B+	✔		✔		✔		✔	
	AB+	✔	✔	✔	✔	✔	✔	✔	✔
	O−					✔			
	A−					✔	✔		
	B−					✔		✔	
	AB−					✔	✔	✔	✔

Bombay Phenotype

The h/h blood group, also known as Ohor the Bombay blood group, is a rare blood type. This blood phenotype was first discovered in Bombay, by Dr. Y. M. Bhende in 1952.Individuals with the rare Bombay phenotype (hh) do not express H antigen (also called substance H), the antigen which is present in blood group O. As a result, they cannot make A antigen (also called substance A) or B antigen (substance B) on their red blood cells, whatever alleles they may have of the A and B blood-group genes, because A antigen and B antigen are made from H antigen. For this reason people who have Bombay phenotype can donate red blood cells to any member of the ABO blood group system (unless some other blood factor gene, such as Rhesus, is incompatible), but they cannot receive blood from any member of the ABO blood group system (which always contains one or more of A and B and H antigens), but only from other people who have Bombay phenotype.The usual tests for ABO blood group system would show them as group O.

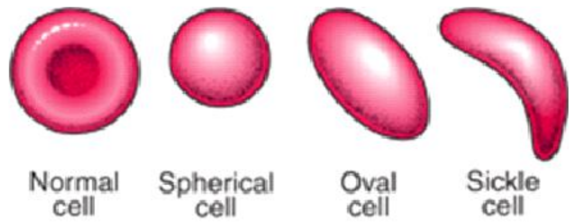
Blood Substitute

A blood substitute (also called artificial blood or blood surrogates) is a substance used to mimic and fulfill some functions of biological blood. It aims to provide an alternative to blood transfusion, which is transferring blood or blood-based products from one person into another. Thus far, there are no well-accepted oxygen-carrying blood substitutes, which is the typical objective of a red blood cell transfusion. However, there are widely available non-blood volume expanders for cases where only volume restoration is required. These are helping doctors and surgeons avoid the risks of disease transmission and immune suppression. The main categories of 'oxygen-carrying' blood substitutes being pursued are hemoglobin-based oxygen carriers (HBOC) and perfluorocarbon-based oxygen carriers (PFBOC).

DISEASES ASSOCIATED WITH BLOOD

SICKLE CELL DISEASE

Sickle cell disease is an inherited condition characterized by sickle (crescent)-shaped red blood cells and chronic anaemia caused by excessive destruction of red blood cells. A special blood test called electrophoresis can be used to determine whether people have sickle cell disease.



Red Blood Cell Shapes

Normal red blood cells are flexible and disk-shaped, thicker at the edges than in the middle. In several hereditary disorders, red blood cells become spherical (in hereditary spherocytosis), oval (in hereditary elliptocytosis), or sickle-shaped (in sickle cell disease). In sickle cell disease, the red blood cells contain an abnormal form of haemoglobin (the protein that carries oxygen). The abnormal form of haemoglobin is called haemoglobin S. When red blood cells contain a large amount of haemoglobin S, they can become deformed into a sickle shape. Not every red blood cell is sickle-shaped. The sickle-shaped cells become more numerous when people have infections or low levels of oxygen in the blood. The sickle cells are fragile and break apart easily. Because the sickle cells are stiff, they have difficulty travelling through the smallest blood vessels (capillaries), blocking blood flow and reducing oxygen supply to tissues in areas where capillaries are blocked. The blockage of blood flow can cause pain and, over time, cause damage to the spleen, kidneys, brain, bones, and other organs. Kidney failure and heart failure may occur.

ANAEMIA

Anaemia is a condition in which the number of red blood cells or the amount of hemoglobin (the protein that carries oxygen in them) is low. Red blood cells contain hemoglobin, a protein that enables them to carry oxygen from the lungs and deliver it to all parts of the body. When the number of red blood cells is reduced or the amount of hemoglobin in them is low, the blood cannot carry an adequate supply of oxygen. An inadequate supply of oxygen in the tissues produces the symptoms of anemia. Anemia may also result when the body does not produce enough red blood cells. Many nutrients are needed for red blood cell production. The most critical are iron, vitamin B_{12}, and foliate (folic acid), but the body also needs trace amounts of vitamin C, riboflavin, and copper, as well as a proper balance of hormones, especially erythropoietin (a hormone that stimulates red blood cell production). Without these nutrients and hormones, production of red blood cells is slow and inadequate, or the red blood cells may be deformed and unable to carry oxygen adequately. Chronic disease also may affect red blood cell production. In some circumstances, the bone marrow space may be invaded and replaced (for example, by leukemia, lymphoma, or metastatic cancer), resulting in decreased production of red blood cells.

Anemia may also result when too many red blood cells are destroyed. Normally, red blood cells live about 120 days. Scavenger cells in the bone marrow, spleen, and liver detect and destroy red blood cells that are near or beyond their usual life span. If red blood cells are destroyed prematurely (haemolysis), the bone marrow tries to compensate by producing new cells faster. When the destruction of red blood cells exceeds their production, hemolytic anemia results. Hemolytic anemia is relatively uncommon compared with the anemia caused by excessive bleeding and decreased red blood cell production.

THALASSEMIA

Thalassemias are a group of inherited disorders resulting from either a genetic mutation, or a deletion of certain key genes involved in haemoglobin production. The abnormal haemoglobin formed results in improper oxygen transport and destruction of red blood cells. Thalassemia can cause complications, including iron overload, bone deformities, mild or severe anaemia and cardiovascular illness. Haemoglobin is made up of two pairs of globin chains. The two main forms of thalassemia are alpha thalassemia and beta thalassemia. Normally, adults have one pair of alpha chains and one pair of beta chains. Sometimes one or more of these chains is abnormal. In alpha thalassemia, at least one of the alpha globin genes has a mutation or abnormality. In beta thalassemia, the beta globin genes are the ones affected.

This genetic defect is inherited from the parents. If only one of parents is a carrier for thalassemia, one may develop a form of the disease called "thalassemia minor", where one will only be a carrier of the disease. However, some people with thalassemia minor do develop minor symptoms. If both the parents are carriers of thalassemia, there is a 25 percent chance of inheriting a more serious form of the disease. Thalassemia is most common in people from Southeast and Central Asia, the Mediterranean, the Middle East, India, and North Africa.