

Transport In Mammals

8.1 The Circulatory System

- Larger organisms, are made up of many layers of cells, meaning that the time taken for substances such as glucose and oxygen to diffuse to every cell in the body would be far too long. The diffusion distances involved are too great. To solve this problem their exchange surfaces are connected to a mass transport system. Mass transport is the bulk movement of gases or liquids in one direction, usually via a system of vessels and tubes. The one-way flow of blood within the blood vessels carries essential nutrients and gases to all the cells of the body.
- In a closed circulatory system, blood is pumped around the body and is always contained within a network of blood vessels. In an open circulatory system, blood is not contained within blood vessels but is pumped directly into body cavities.
- Humans have a closed double circulatory system: in one complete circuit of the body blood passes through the heart (the pump) twice. Double circulation provides a low-pressure circulation to the lungs and a high-pressure circulation to the body tissues.
- The right side of the heart pumps deoxygenated blood to the lungs for gas exchange; this is the pulmonary circulatory system. Blood then returns to the left side of the heart, so that oxygenated blood can be pumped efficiently (at high pressure) around the body; this is the systemic circulatory system.

Structure	Function
Heart	A hollow, muscular organ located in the chest cavity which pumps blood. Cardiac muscle tissue is specialized for repeated involuntary contraction without rest.
Arteries	Blood vessels which carry blood away from the heart. The walls of the arteries contain lots of muscle and elastic tissue and a narrow lumen to maintain high blood pressure. 4 - 25mm in diameter.
Arterioles	Small Arteries which branch from larger arteries and connect to capillaries. 0.03mm.
Capillaries	Tiny blood vessels connecting arterioles and venules. Their size means they pass directly past cells and tissues and perform gas exchange and exchange of substances such as glucose. 0.005 - 0.01mm.
Venules	Small veins which join capillaries to larger veins. 0.007 - 1mm.

Veins	Blood vessels which carry blood back towards the heart. The walls of veins are thin in comparison to arteries, having less muscle and elastic tissue but a wider lumen. Valves help maintain blood flow back to the heart. 0.007 - 1mm.
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<u>Blood Vessel</u>	<u>Systemic/Pulmonary Circulation</u>	<u>Organ</u>	<u>Blood</u>
Aorta	Systemic	Blood from the heart to the body	Oxygenated
Vena Cava	Systemic	Blood to the heart from the body	Deoxygenated
Pulmonary Artery	Pulmonary	Blood from the heart to the lungs	Deoxygenated
Pulmonary Vein	Pulmonary	Blood to the heart from the lungs	Oxygenated
Hepatic Artery		Blood from the heart to the liver	Oxygenated
Hepatic Vein		Blood to the heart from the liver	Deoxygenated
Hepatic Portal Vein		Blood to the liver from other organs.	Partially Oxygenated
Renal Artery		Blood from the heart to the kidneys	Oxygenated
Renal Vein		Blood to the heart from the kidneys	Deoxygenated

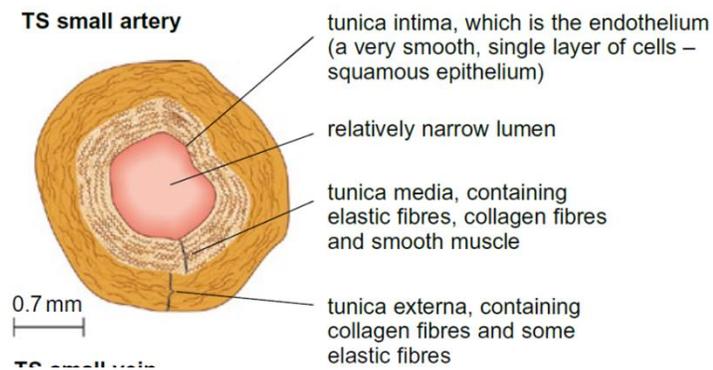
Arteries: The function of arteries is to transport blood, swiftly and at high pressure, to the tissues. The structure of the wall of an artery enables it to perform this function efficiently. Arteries and veins both have walls made up of three layers.

- Inner endothelium called the tunica intima.
- Middle layer called the tunica media.
- Outer layer called the tunica externa.

The distinctive characteristics of an artery wall are its strength and elasticity. Arteries have the thickest walls of any blood vessel. The aorta is the largest artery. The tunica media,

which is by far the thickest part of the wall, contains large amounts of elastic fibers. As arteries reach the tissue to which they are transporting blood, they branch into smaller and smaller vessels called arterioles.

The walls of arterioles are similar to those of arteries, but they have a greater proportion of smooth muscle.



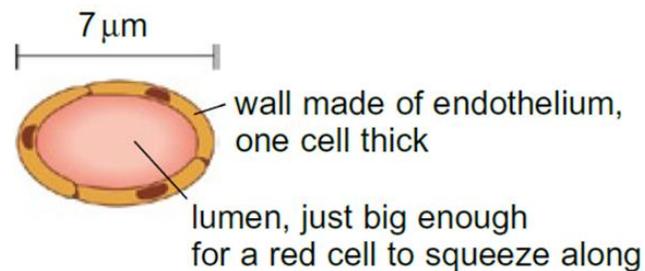
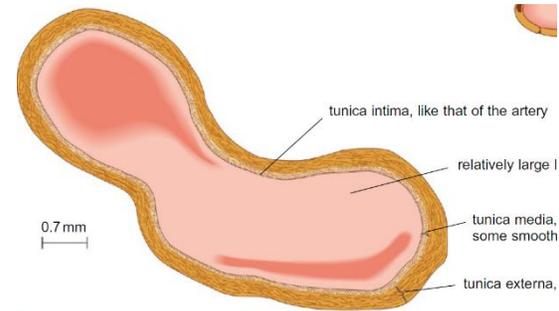
This muscle can contract, narrowing the diameter of the arteriole and so reducing blood flow. This helps to control the volume of blood flowing into a tissue at different times.

Elastic Artery: Large arteries with more elastic fibers & fewer smooth muscles. These are located near the heart and receive blood from the heart.

Muscle Artery: Medium Sized arteries with tunica media composed of more smooth muscle and less elastic fibers. Muscular arteries branch off from elastic arteries and carry blood to the body's tissues.

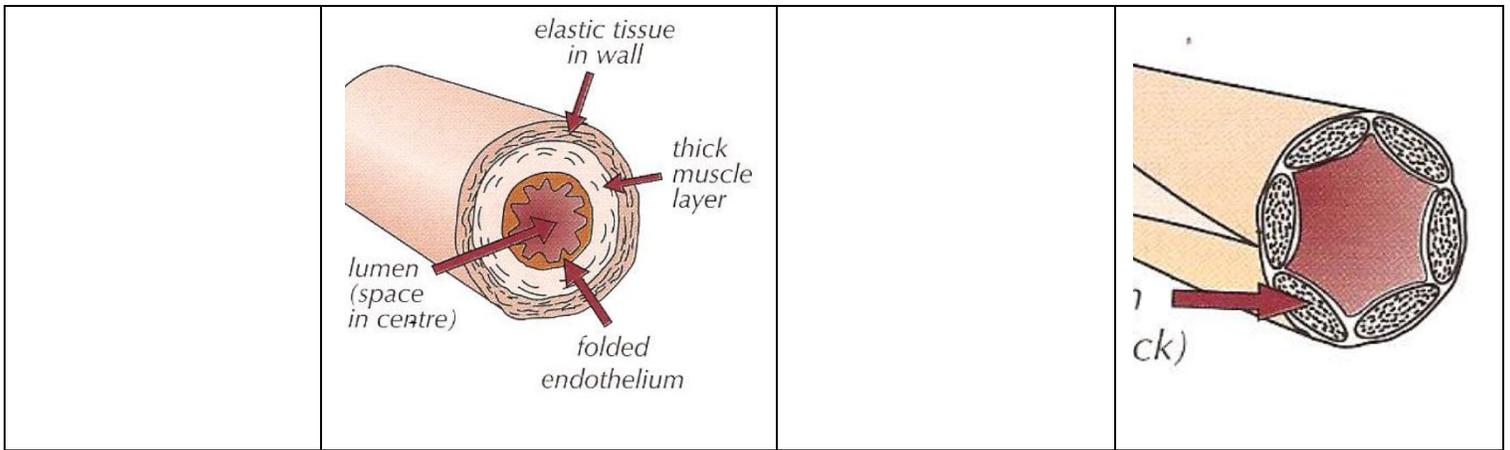
Veins: As blood leaves a capillary bed, the capillaries gradually join with one another, forming larger vessels called venules. These join to form veins. The function of veins is to return blood to the heart.

Capillaries: The arterioles themselves continue to branch, eventually forming the tiniest of all blood vessels, capillaries. The function of capillaries is to take blood as close as possible to all cells, allowing rapid transfer of substances between cells and blood. Capillaries form a network throughout every tissue in the body except the cornea and cartilage. Such networks are sometimes called capillary beds.



	<u>Arteries</u>	<u>Veins</u>	<u>Capillaries</u>
Relative thickness of wall	Thick layer of muscle	Thin layer of muscle	Single layer of cells
Composition of wall (muscle & elastic tissue)	Thick layer of elastic & muscle tissue. Tunica media composed of smooth muscle in muscular artery. Fewer smooth muscle in elastic artery.	Thin layer of elastic & muscle tissue. Tough layer mainly composed of collagen fibers.	Thin layer of flattened cells. No elastic, smooth muscle or collagen.
Endothelium Wall			one-cell thick, which ensures that substances can diffuse easily between the capillary & neighboring cells.

Elastic Fibers	High proportion making them able to stretch and recoil to accommodate blood surging through, preventing them from bursting or from the blood pressure dropping.	Low proportion as the blood flowing through veins is under very low pressures so the walls of the veins do not have to stretch and recoil to accommodate blood flow.	
Other Structures & Function	Arteries further from the heart contain less elastic & more smooth muscle tissue. The diameter of these arteries can be adjusted to alter the blood flowing to different tissues.	Skeletal muscle contraction helps raise blood pressure temporarily within the veins, and the presence of one-way valves keeps blood moving back towards the heart.	The walls are also "leaky" - there are small gaps b/w individual squamous epithelial cells that form the wall to allow small substances to leak out of the blood into the fluid surrounding the cells of the body.
Diameter of lumen	Narrow (4mm - 25mm) ensuring that blood remains at relatively high pressure for efficient delivery to the tissues whilst also providing resistance to blood flow to allow gas exchange as blood passes through the tissues.	Wide (7µm - 1mm)	1 cell (7.5µm - 8.7µm)
Presence of valves	No valves	Valves	No valves
Pressure	High Pressure	Low Pressure	Low to several organs.



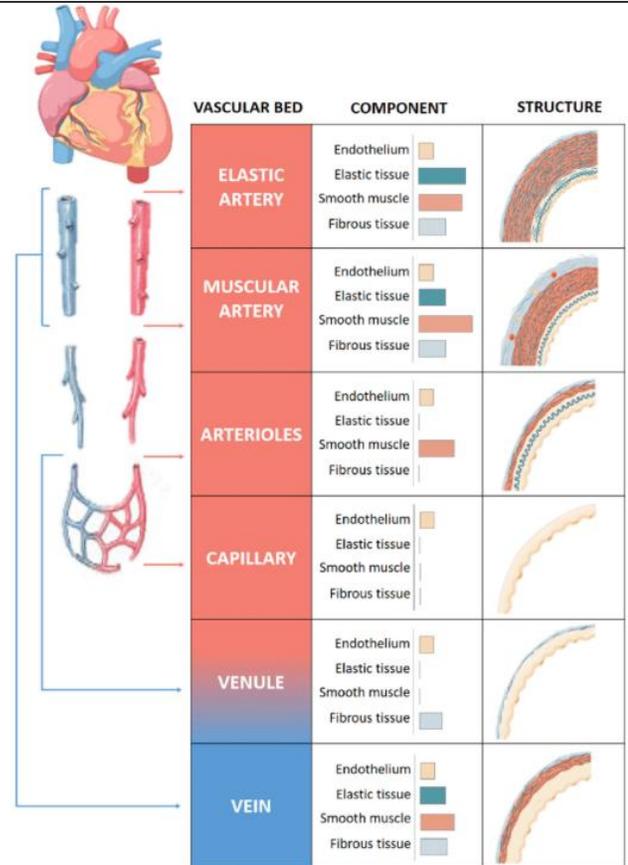
	Structure	Explanation
<u>Muscular artery</u>	Thicker tunica media mainly composed of smooth muscle	Able to perform vasoconstriction and vasodilation
	Much less elastin than elastic arteries	Cannot stretch and recoil
	Narrow lumen	Blood flows under high pressure
<u>Elastic artery</u>	Thinner tunica media (compared to muscular artery) mainly composed of elastin and collagen	Gives artery the ability to stretch in response to each pulse
	Relatively few smooth muscle fibers	Cannot perform vasoconstriction or vasodilation
	Narrow lumen	Blood flows under high pressure
<u>Vein</u>	One-way valves	Close to prevent the backow of blood
	Wide lumen	Blood pressure is reduced in veins with no surges
	Less smooth muscle and elastin	No need for veins to stretch and recoil
	Lots of collagen	Increased strength and structure

<u>Capillary</u>	Very small diameter	Blood travels relatively slowly, giving more opportunity for diffusion to occur
	Capillaries branch between cells	Substances can diffuse quickly between cells and the blood quickly
	Thin walls, no elastic, smooth muscle or collagen	Capillaries can't between individual cells and diffusion is rapid

Blood:

Composition of the blood: blood is a complex tissue and specialized transport medium that is also considered a special type of connective tissue. An average adult has 4-6 liters of blood consisting of various cell types suspended in a watery fluid called plasma.

1. Transport of substances around the body.
2. Protection against disease-causing organisms (pathogens).
3. Clotting to prevent excessive loss of blood & the entry of Pathogens.
4. Thermoregulation.
5. Maintaining pH of the body fluids.



Total Volume of Blood in the Human Body	5 dm ³
Average Number of RBCs	2.5 × 10 ⁵
Average Number of WBSs	5.0 × 10 ¹¹
Average Number of Platelets	6.0 × 10 ¹²

<u>Component</u>	<u>Function</u>
Red Blood Cell	Oxygen transport.
White Blood Cell	Phagocytes: engulf and destroy bacteria. Lymphocytes: produce antibodies.

Platelets	Clotting by converting soluble fibrinogen to insoluble fibrin to prevent blood loss and the entry of pathogens.
Plasma	Transport, limited to: blood cells, ions, glucose, amino acids, hormones, carbon dioxide, urea, vitamins and plasma proteins.

Plasma: Blood is composed of cells floating in a pale yellow liquid called plasma. Blood plasma is mostly water, with a variety of substances dissolved in it. These solutes include nutrients such as glucose and waste products such as urea that are being transported from one place to another in the body. Solutes also include protein molecules, called plasma proteins, that remain in the blood all the time. Plasma comes forth blood cells, contained dissolved substances such as nutrients, hormones, carbon dioxide, urea, and heat around the body.

- Nutrients: Glucose, Amino Acids, Ions, and Vitamins from the gut to the cells.
- Lipids from digested food, attached to the certain soluble proteins.
- Soluble proteins for; Fibrinogen (in blood clotting).
- Antibodies against pathogens and 'other foreign cells.'
- Main Nitrogenous excretory product urea-kidneys for excretion.
- Hormones from the glands where they are made to target organs where they have their effect.
- Carbon dioxide from tissues to the lungs for excretion. Mixes not chemically combines. Plasma pick blood carbon dioxide and gives to the lungs to exhale. Hemoglobin is only responsible for oxygen transfer.

10% of carbon dioxide is carried inside red blood cells attached to HB as Carbaminohemoglobin and 5% in solution in plasma. Most carbon dioxide is transported by the plasma as hydrogen carbonate ions (HCO_3^-). Carbon dioxide reacts with water in plasma to form carbonic acid, which dissociate into hydrogen ions and hydrogen carbonate ions.



Some tissues, such as the muscles and liver, are metabolically active and produce much heat. This is transported to other less active tissues to help maintain a constant temperature throughout the body.

Tissue Fluid: As blood flows through capillaries within tissues, hydrostatic pressure causes some of the plasma to leak out through the gaps between the cells in the walls of the capillary, and seeps into the spaces between the cells of the tissues.

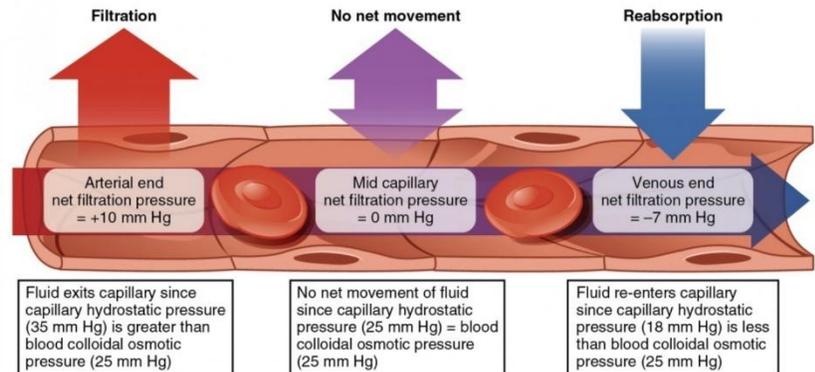
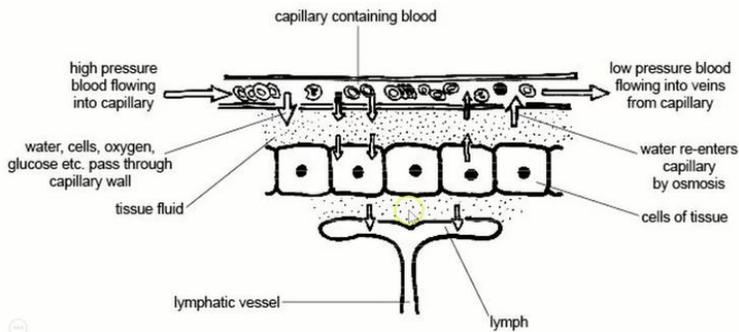
Tissue fluid allows the body to easily and quickly move dissolved molecules onto the body cells, and take away waste materials back into the blood. Almost one-sixth of your body consists of spaces between your cells. These spaces are filled with this leaked plasma, which is known as tissue fluid. In the formation of tissue fluid blood plasma and the dissolved substances moves out into the body cells. Water has a 1.0 permeability of capillary wall, while sodium has 0.96, urea has 0.6, glucose has 0.6, and albumin has only 0.00001 permeability of capillary wall. About 8% of blood plasma consists of plasma proteins, of which about half may be albumins. These are a group of small proteins involved in the transport of other substances (e.g. fatty acids, hormones) and which help regulate the osmotic pressure of blood. RBC's, large proteins and platelets are left in the blood. The balance between the hydrostatic pressure of blood ('blood pressure') and the osmotic pressure of blood is important in the formation of tissue fluid.

Hydrostatic Pressure	Oncotic Pressure
This high blood pressure inside the capillaries, forcing blood plasma out of the capillaries, through the endothelium onto the body cells (arterial end of the capillaries).	The removal of the blood plasma, causes a decrease in the water potential of the blood, as a result water moves back into the capillaries by osmosis (venous end).
They are force exerted by the fluid present within the blood capillaries against the capillary wall.	They are also known as colloid osmotic pressure which is exerted by proteins like albumin in the blood plasma.
This helps to push the blood out of the blood capillaries.	This helps to push the fluid into the blood capillaries.
This helps to increase filtration.	This helps to prevent the movement of fluid from blood capillaries.
This mostly occurs at the arterial end.	This mostly occurs at the venular end.

- Water solvent make it ideal for the transport in mammals. Glucose is transported in solution from the small intestine to every cell of the body for respiration. Urea is also transported in solution from liver to kidneys.
- Water having a high specific heat capacity allows it to absorb a lot of heat without big temperature fluctuations. This is vital in maintaining temperatures that are optimal for enzyme activity. Water in blood plasma is also vital for transferring heat around the body helping to maintain a fairly constant temperature in a process called homeostasis. As blood passes through the more active regions of the body, heat energies absorbed but water remains fairly constant.

- Group attention is a combination of solute potential and pressure potential.

$$\Psi = \Psi_S + \Psi_P$$



Lymph: About 90% of the fluid that leaks from capillaries eventually seeps back into them. The remaining 10% is collected up and returned to the blood system by means of a series of tubes known as lymph vessels or lymphatics. Lymphatics are tiny, blind-ending vessels, which are found in almost all tissues of the body. Lymphatics contain tiny valves, which allow the tissue fluid to flow in but stop it from leaking out.

- The fluid inside lymphatics is called lymph. Lymph is virtually identical to tissue fluid; it has a different name more because it is in a different place than because it is different in composition.
- Not all tissue fluid returns to the capillaries. About 90% of the tissue fluid returns.
- The excess, 10%, drains into the lymphatic system, where it forms lymph.
- Lymph is a colorless/pale yellow fluid similar to tissue fluid but containing more lipids.
- The lymphatic system drains into the circulatory system near the vena cava via the thoracic duct.
- Any plasma proteins that have escaped from the blood are returned to the blood via the lymph capillaries
- If plasma proteins were not removed from tissue fluid they could lower the water potential (of the tissue fluid) and prevent the reabsorption of water into the blood in the capillaries
- After digestion lipids are transported from the intestines to the bloodstream by the lymph system

The lymphatic system is a secondary circulatory system and a major part of the immune system. It consists of:

- lymphatic capillaries and vein-like lymph vessels, containing valves.

- lymph nodes - sac-like organs that trap pathogens and foreign substances, and which contain large numbers of white blood cells.
- lymphatic tissue in the spleen, thymus and tonsils - these also contain large amounts of white blood cells and are involved in their development.

The Importance of Lymph:

- Tissue fluid flows into the lymph system through valves and nodes
- These valves are even large enough to allow large protein molecules to pass through
- With the lymph system you would die within 24 hours, as the rate of water loss in the blood would be too large
- This would lead to a build up of tissue fluid in the tissues, this is called oedema.

The defense mechanism of the lymph system:

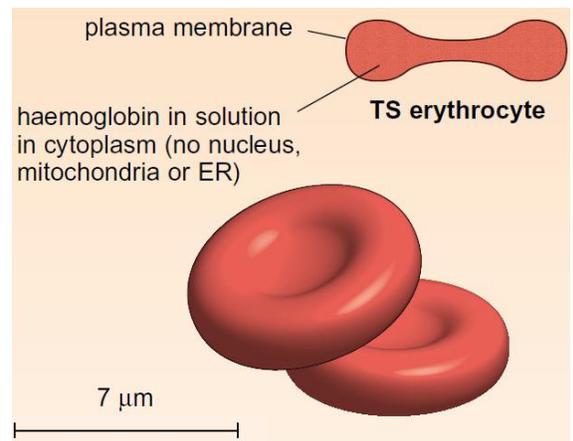
- The lymph system contains white blood cells, phagocytes and lymphocytes.
- As well as transporting water/plasma, the lymphatic system plays an important role in the secondary defense system.

Red blood Cells (Erythrocytes): Specialized cells made in the bone marrow. The bone marrow is the soft, fatty tissue inside the bones in your body. Bone marrow contains cells that produce blood cells and platelets and make millions of RBC's every day. They have a lifespan about of about 100 days and are then broken by the spleen so they can be constantly replaced. They lack a nucleus lost during the development and transports oxygen around the body.

- Red pigment hemoglobin a protein with a quaternary structure that contains haem iron enabling them to be recognized on microscope slides, that chemically and reversibly combines with oxygen.
- Lack of nucleus more oxyhemoglobin is packed in each cell.
- Biconcave disc shape which provides a large. S.A: Volume for absorption of oxygen. Transport of oxygen from lungs to tissues. This helps with diffusion.
- The red color is caused by the red pigment, hemoglobin or 'Hb'.
- This is a globular protein.
- The main function of hemoglobin is to transport oxygen and carbon dioxide.
- from the lungs to the respiring cells of the body
- The flattened disc shape means that there is only a short distance for oxygen to diffuse to the middle of the cell.
- Flexible cells allowing them to squeeze through narrow blood capillaries & vessels.

Structure:

- Erythrocytes have a diameter of $7\mu\text{m}$.
- This is small - the average cell is $40\mu\text{m}$ in diameter.
- Therefore the hemoglobin is very close to the plasma membrane - as a result oxygen is loaded and unloaded very quickly in and out of the cell.
- Capillaries are $8\mu\text{m}$ wide - only allowing 1 Erythrocyte through at a time.
- Erythrocytes are shaped like a biconcave disc.



The dent in each side of the cell, like its small size, increases its surface area to volume ratio. This means that oxygen can diffuse rapidly into and out of the cell. Erythrocytes have no nucleus no mitochondria and no endoplasmic reticulum this leaves more room for hemoglobin.

White blood cells: protects body against disease causing microorganisms, bacteria and virus:

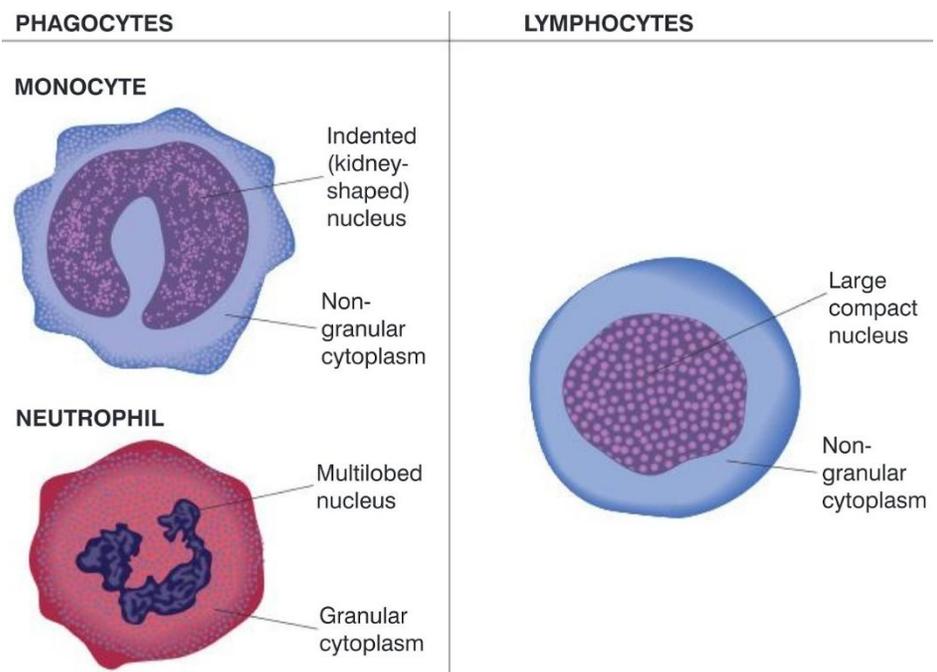
Phagocytosis and Antibodies: Phagocytosis is where white cells take in (ingest) pathogens such as bacteria, and destroy them. 60 to 70% of WBC's are phagocytes. Unusual irregular, irregular lobe shaped nucleus. Cells move around like an Amoeba and change their shape, producing extension of cytoplasm called pseudopodia:

Surrounds and engulfs bacteria, into enclosing it inside the cell.

- The Phagocyte secretes digestive enzymes into the vacuole and breaks down the bacterium wall (peptidoglycan). Phagocytes can leave capillaries, squeezing below the cell of the capillary wall to enter tissues. Phagocytes must be able to recognize foreign cells to deal with them. They respond to chemicals on the surface membranes of the pathogen. These 'Chemical Markers' are called antigens.
 - Monocytes are identifiable by their size, they are the largest of the leukocytes and have a nucleus shaped like a kidney or bean. The nucleus of monocytes tends to appear lighter after staining than other leukocytes. The nucleus should appear a light blue color while the chromatin inside is distinct.
 - Neutrophils are distinguished by their multi lobed nuclei. Up to 70% of all leukocytes are neutrophils making them easy to spot on a micrograph. The granules of neutrophils typically stain pink or purple-blue.

- Lymphocytes are 20-25% of WBC's and they recognize antigens. They have a diameter of 7µm. Large nucleus. When it detects foreign antigens it makes antibodies, which it secretes into plasma. Antibodies stick to surface antigens, on the pathogen and destroy it.
 - Causing bacteria to burst open.
 - Making bacteria stick together in clumps so it is easier for the phagocytosis.
 - Acting as a label on packages for recognition.
 - Neutralizing toxins produced by pathogens.

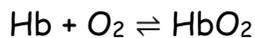
Sometimes lymphocytes develop into memory cells. On exposure later, the memory cells respond by dividing to produce more antibody producing cells so infection is dealt quickly. This is immunity or immune response.



8.2 Transport of Oxygen & Carbon Dioxide

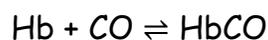
Each molecule of hemoglobin contains 4 haem groups, each able to bond with one molecule of oxygen. This means that each molecule of hemoglobin can carry 4 oxygen molecules or 8 oxygen atoms in total.

Hemoglobin is an iron-containing protein that has a high affinity for oxygen. At partial pressure (different concentrations) of oxygen the hemoglobin will bind forming oxyhemoglobin. The saturation of hemoglobin is measured in percent (%) - 100% being fully saturated. The binding of the first oxygen molecule results in a conformational change in the structure of the hemoglobin molecule, making it easier for each successive oxygen molecule to bind; this is cooperative binding.

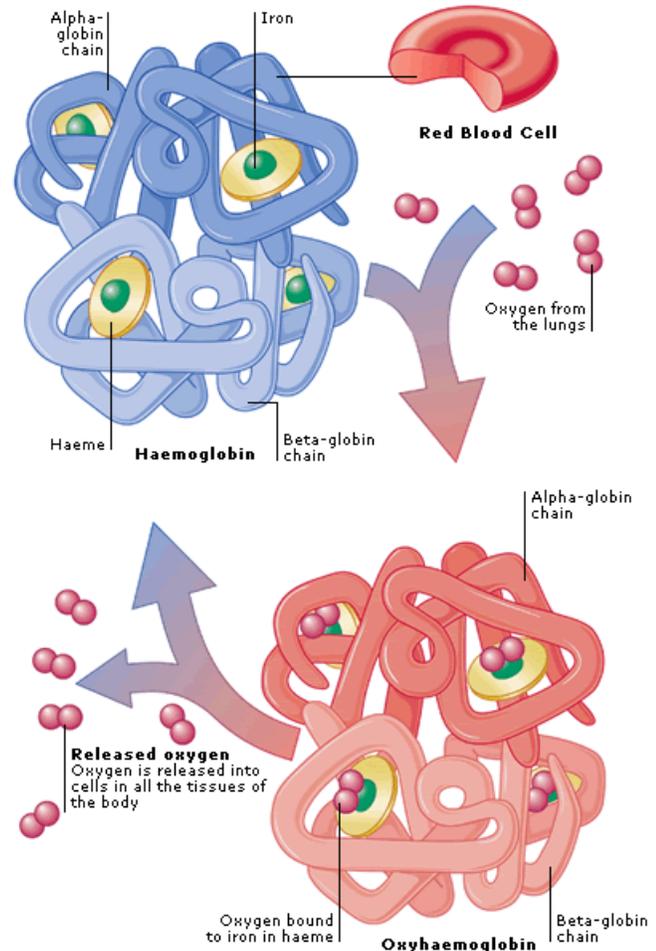


In the lungs, where there is a high concentration of oxygen, oxygen & hemoglobin are chemically combined & packed forming oxyhemoglobin and are transported around the body through blood vessels & capillaries. In tissues, where oxygen is at low concentration the chemical reaction of oxyhemoglobin dissociates or is reversed diffusing out & giving up its oxygen to that part of the body for respiration. Red blood cells load oxygen as they pass through capillaries & unload it as they pass through capillaries in tissues such as muscles. Active organisms having a high demand for oxygen possess hemoglobin with a lower affinity towards oxygen than humans.

Carbon monoxide however is an odorless poisonous gas & in a case where you inhale carbon monoxide, the hemoglobin gets chemically combined with it forming oxyhemoglobin & begins transport around the body in the form of carboxyhemoglobin.



Carbon monoxide is difficult to remove from the body that so you can die. As more carbon monoxide is packed, there is less space for oxygen and you are most likely to suffer from a cardiac arrest.



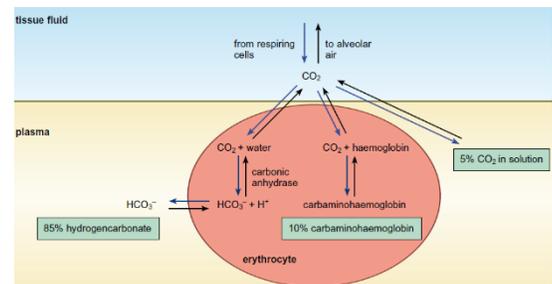
Hemoglobin Acid: H^+ ions produced by the dissociation reactions bind readily with the hemoglobin in the red blood cells. This forms Hemoglobin acid, HHb. This causes the hemoglobin to release all the oxygen it has carrying. The hydrogen carbonate diffuses out of the red blood cell into the plasma - 85% is carried this way.

The net result of this reaction is two fold. The hemoglobin 'mops up' the hydrogen ions which are formed when carbon dioxide dissolves and dissociates. A high concentration of hydrogen ions means a low pH; if the hydrogen ions were left in solution, the blood would be very acidic. By removing the hydrogen ions from solution, hemoglobin helps to maintain the pH of the blood close to neutral. It is acting as a buffer.

The presence of a high partial pressure of carbon dioxide causes hemoglobin to release oxygen. This is called the Bohr effect, after Christian Bohr who discovered it in 1904.

Carbaminohemoglobin: Some of the carbon dioxide on entering the Erythrocytes escapes being broken down by the carbonic anhydrase enzyme. This binds directly with the amino group in hemoglobin. This forms Carbaminohemoglobin. About 10% of carbon dioxide is carried this way.

In the lungs all the carbon dioxide in various forms leaves the plasma and hemoglobin and enters the lungs.



Q. How is hemoglobin F different from adult hemoglobin?

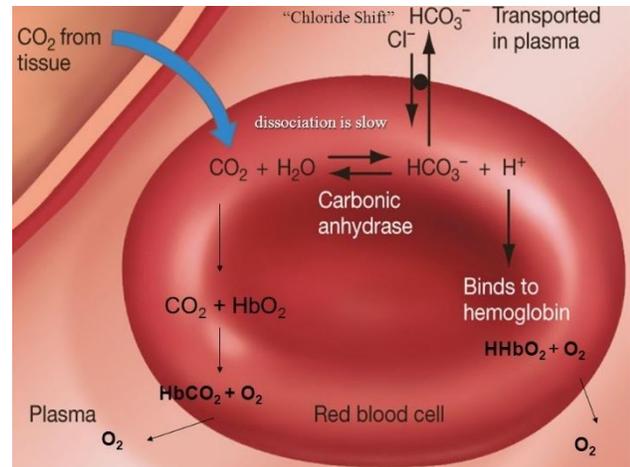
Ans. Fetal hemoglobin binds to oxygen more strongly than adult hemoglobin, enabling the transfer of oxygen from mother to fetus prenatally. Oxygen exchange within the tissue is thus affected by the strength of the binding between hemoglobin and oxygen.

Q. What is the main difference between hemoglobin and myoglobin?

Ans. The main difference between hemoglobin and myoglobin is in their structure and function. Hemoglobin has four polypeptide chains, and its function is to transport oxygen. Myoglobin has only one polypeptide chain, and its function is to store oxygen for use by muscle tissue.

The Chloride Shift:

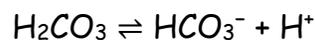
The chloride shift is the movement of chloride ions into red blood cells that occurs when hydrogen carbonate ions are formed. Carbonic Acid formed dissociates into hydrogen and bicarbonate ions. The bicarbonate ion moves into the blood plasma to exchange itself with chloride ions to diffuse into the RBCs with the hydrogen ions. Hydrogen carbonate ions are formed by the following process: Carbon dioxide diffuses into red blood cells.



The enzyme carbonic anhydrase catalyzes the combining of carbon dioxide and water to form carbonic acid (H₂CO₃)



Carbonic acid dissociates to form hydrogen carbonate ions and hydrogen ions.



Negatively charged hydrogen carbonate ions formed from the dissociation of carbonic acid are transported out of red blood cells via a transport protein in the membrane.

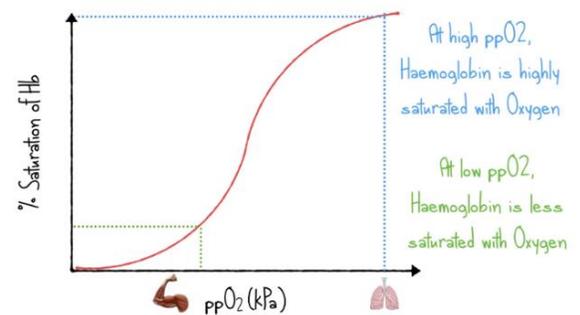
To prevent an electrical imbalance, negatively charged chloride ions are transported into the red blood cells via the same transport protein.

If this did not occur then red blood cells would become positively charged as a result of a build up of hydrogen ions formed from the dissociation of carbonic acid.

Oxygen Dissociation Curve:

The oxygen-hemoglobin dissociation curve shows how the hemoglobin saturation with oxygen (SO₂), is related to the partial pressure of oxygen in the blood (PO₂).

A molecule whose function is to transport oxygen from one part of the body to another must be able not only to pick up oxygen at the lungs, but also to release oxygen within respiring tissues. Hemoglobin performs this task in an excellent manner.



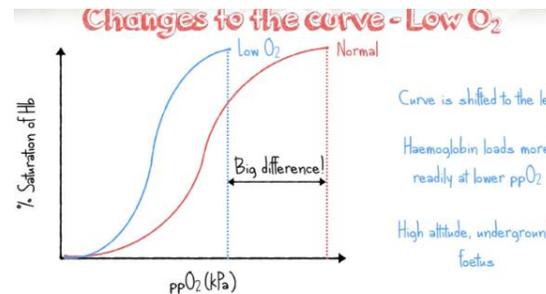
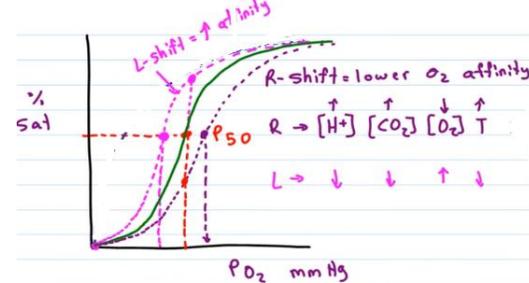
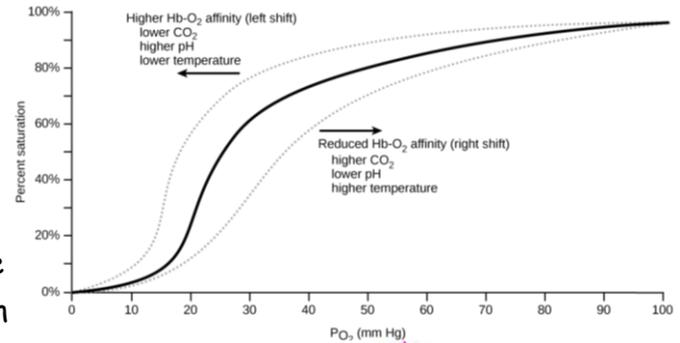
To investigate how hemoglobin behaves, samples are extracted from blood and exposed to different concentrations, or partial pressures, of oxygen. The amount of oxygen which combines with each sample of hemoglobin is then measured. The maximum amount of oxygen with which a sample can possibly combine is given a value of 100%.

A sample of hemoglobin which has combined with this maximum amount of oxygen is said to be saturated. The amounts of oxygen with which identical samples of hemoglobin combine at lower oxygen partial pressures are then expressed as a percentage of this maximum value.

The percentage saturation of each sample can be plotted against the partial pressure of oxygen to obtain a curve known as a dissociation curve. The curve shows that at low partial pressures of oxygen for example; at the tissue level or muscles, the percentage saturation of hemoglobin is very low- that is, the hemoglobin is combined with only a very little oxygen. At high partial pressures of oxygen i.e., the lungs, the percentage saturation of hemoglobin is very high; it is combined with large amounts of oxygen.

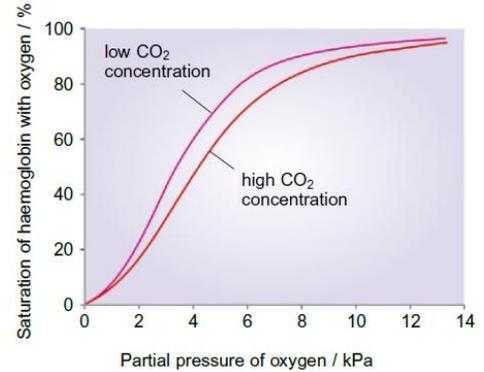
The sigmoid shape of the haemoglobin dissociation curve can be explained by the behavior of a hemoglobin molecule as it combines with or loses oxygen molecules.

Oxygen molecules combine with the iron atoms in the haem groups of a hemoglobin molecule. When an oxygen molecule combines with one haem group, the whole hemoglobin molecule is slightly distorted as the protein changes shape or conformation. The distortion makes it easier for a second oxygen molecule to combine with a second haem group. This in turn makes it easier for a third oxygen molecule to combine with a third haem group. It is still then easier for the fourth and the final oxygen molecule to combine.

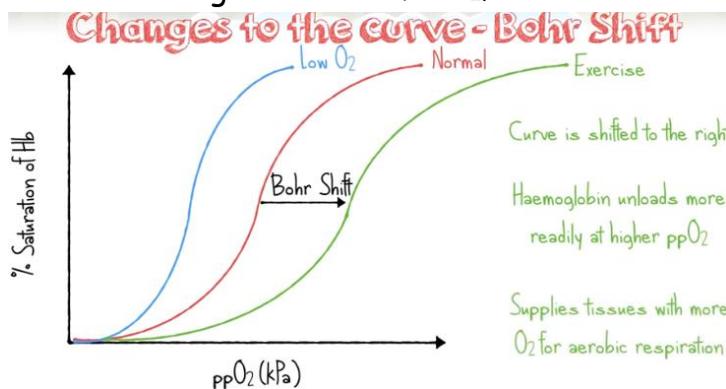
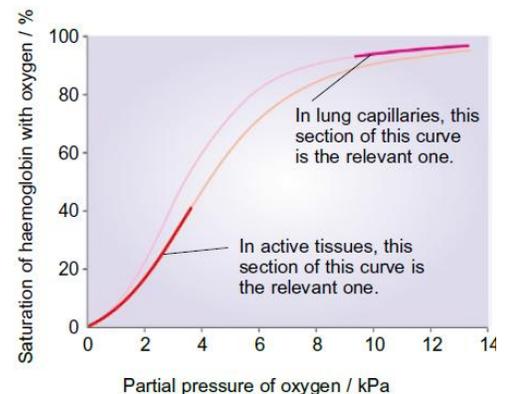


The Bohr Shift: The Bohr shift describes the affect of high carbon dioxide concentration on hemoglobin's affinity for oxygen. When the partial pressure of carbon dioxide in the blood is high, hemoglobin's affinity for oxygen is reduced. This is the case in respiring tissues, where cells are producing carbon dioxide as a waste product of respiration. This occurs because CO_2 lowers the pH of the blood. This is a helpful change because it means that hemoglobin gives up its oxygen more readily in the respiring tissues where it is needed. On a graph showing the dissociation curve, the curve shifts to the right when CO_2 levels increase. A second line is drawn to the right of and below the standard curve. This means that at any given partial pressure of oxygen, the percentage saturation of hemoglobin is lower at higher levels of CO_2 .

The effect of changes in carbon dioxide concentration on haemoglobin saturation



The effect of changes in carbon dioxide concentration on oxygen transport



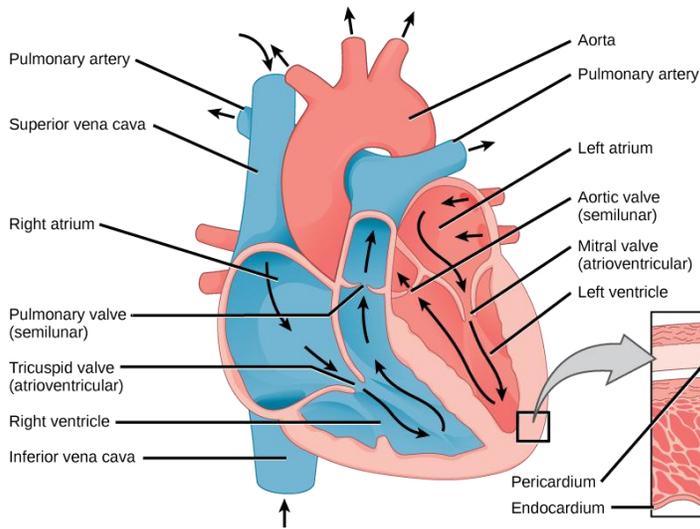
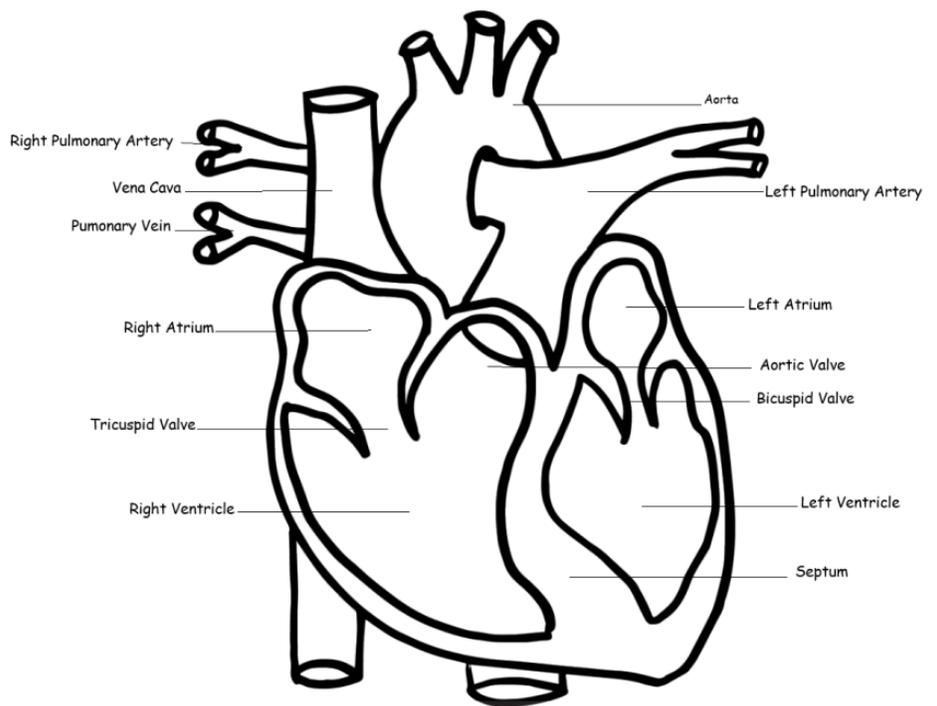
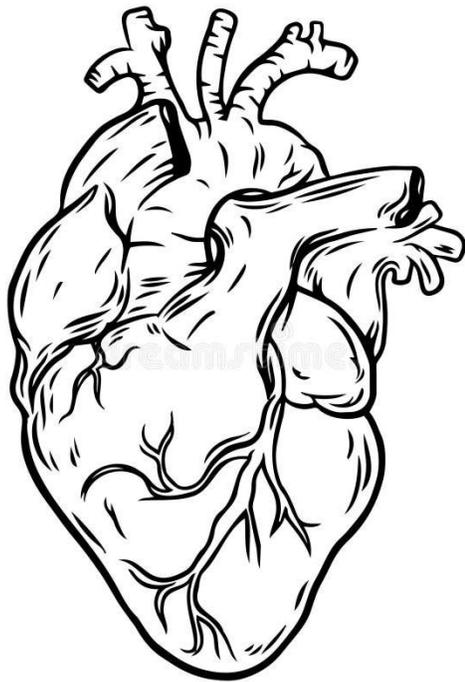
Significance of High RBC count at High altitude:

- If someone travels quickly, over a period of just a few days, from sea level to a very high altitude, the body does not have enough time to adjust to this drop in oxygen availability, and the person may suffer from altitude sickness.
- However, if the body is given plenty of time to adapt, then most people can cope well at altitudes up to at least 5000 meters.
- As the body gradually acclimatizes to high altitude, a number of changes take place. Perhaps the most significant of these is that the number of red blood cells increases. Whereas red blood cells normally make up about 40-50% of the blood, after a few months at high altitude this rises to as much as 50-70%. However, this does take a long time to happen.

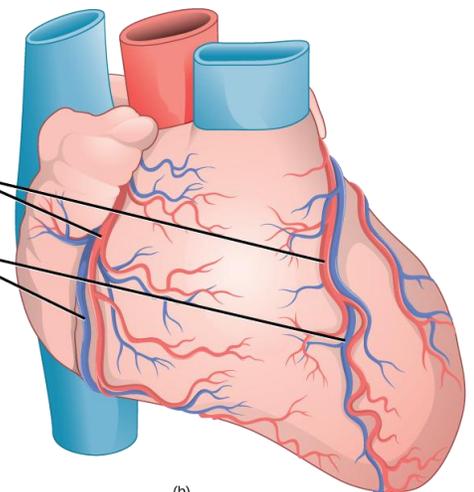
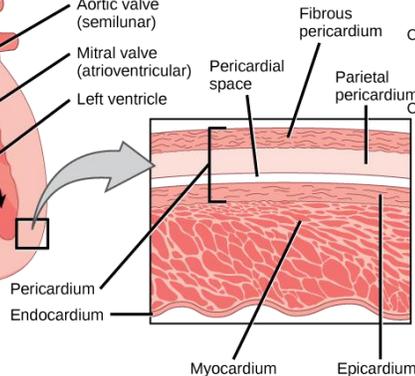
- People who live permanently at high altitude, such as the Andes or Himalayas, show a number of adaptations to their low-oxygen environment. For example, broad chest, larger heart (specifically the right side) and more hemoglobin in their blood.

8.3 The Heart

A contractile device whose main purpose in a circulatory system is to facilitate the rapid mass flow of materials from one part of the body to another over a distance. The mammalian circulatory system is divided into three circuits: the systemic circuit, the pulmonary circuit, and the coronary circuit.

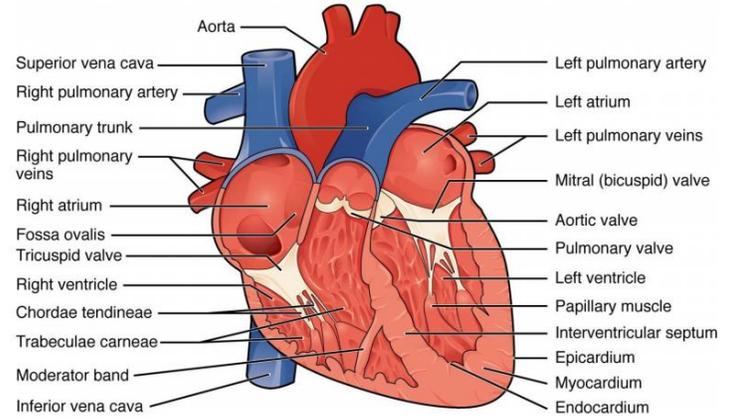


(a)



(b)

Structure of the Heart: The heart of mass 300g made of myocardium (cardiac muscle), is situated in the mediastinum placed in a tough, 2-layered sac called the pericardium is behind the sternum in the thorax. The heart is a hollow, muscular organ located in the chest cavity. The oxygenated left side is separated from the deoxygenated right through a tissue called the atrioventricular septum. The heart is made of 2 lower chambers called the ventricles that pump blood out of the heart through the arteries, and 2 upper chambers called the atria which receive blood through the veins. Blood is pumped away from the heart in arteries and returns to the heart in veins.



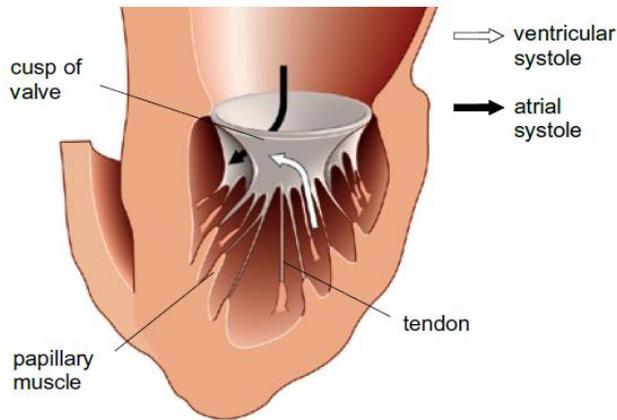
Right Atrium	Made out of less muscular wall. Superior vena cava and inferior vena cava open into this chamber. Hence it has two openings. Right atrium opens into the right ventricle. The opening is guarded by an atrioventricular valve known as the tricuspid valve.
Left Atrium	The wall is thin and less muscular. Four pulmonary veins open into this chamber. Hence there are four openings on the wall. This opens into the left ventricle through a ventricular valve known as mitral or bicuspid valve.
Right Ventricle	The wall is thicker than the atrium. The wall has got cone shaped projections called papillary muscles. Chordae tendinae connects the valves to papillary muscles. Pulmonary artery arise from the right ventricle. Opening of the artery is guarded by semilunar valves (pulmonary valves). This valve is made out of 3 cusps. Pulmonary artery move towards the superior side in front of the atria and bifurcates forming the left and the right pulmonary arteries.
Left Ventricle	The wall is thicker than the right ventricle. Aorta arises from the left ventricle. Opening of the aorta is guarded by 3 semilunar valves. Coronary arteries are present on the wall of the ventricle.
Septum	Separates the left & right side of the heart. Interatrial-top part of the septum. Interventricular- bottom part of the septum.

Valves Valves are important to control the flow of blood from one chamber of the heart to another. Valves allow blood to flow in only One Direction. Valves are controlled by pressure changes in the heart chambers:

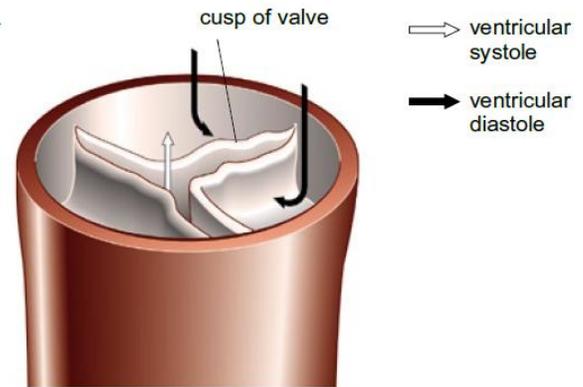
- High pressure begins the valves forces it to open.
- High pressure in front of the valve closes it.

Tricuspid Valve	opening between right atrium and right ventricle. It has 3 flaps, preventing blood from flowing back into the right atrium.
Pulmonary Semilunar Valve	opening between right ventricle and pulmonary artery. It prevents blood from flowing back into the right ventricle.
Mitral/Bicuspid Valve	opening between left atrium and left ventricle. It prevents blood from flowing back into the left atrium.
Aortic Semilunar Valves	opening between left ventricle and aorta. It prevents blood from flowing back into the left ventricle.

Atrio-ventricular valve



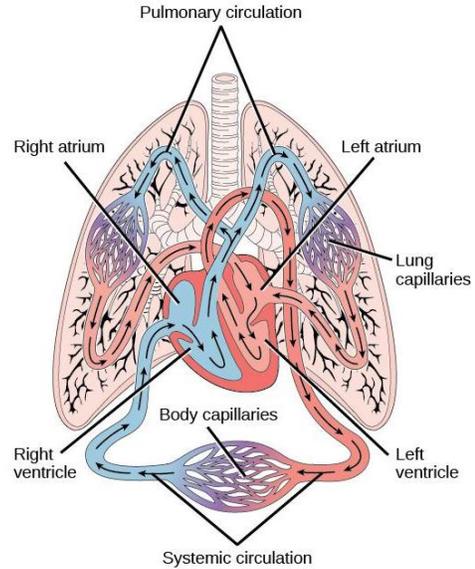
Semilunar valve in the aorta and pulmonary arteries



Chordae Tendineae

Threads, keeping the valve flaps from flipping up into the atria.

- Between the Atria and ventricles are atrioventricular valves to prevent backflow of blood into the atrium when the ventricles contract. The bicuspid valve has two flaps while the tricuspid valve has three.
- The valve flaps are attached to the muscle of the wall of the ventricle by a tough string like structure called tendons which prevent the valve-flaps from flipping backward into the atria when the ventricles contract.
- Arteries carrying blood away from the heart also have valves called semilunar valves. They prevent the backflow when ventricle relax.

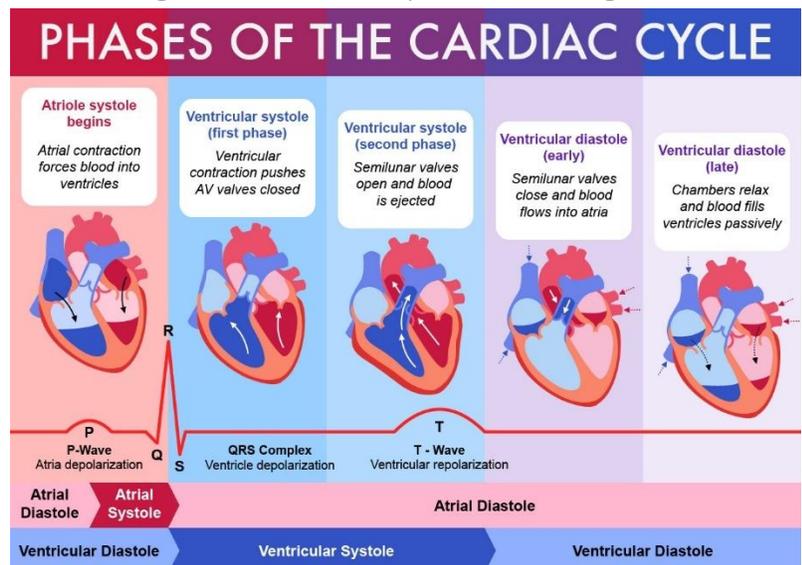


Relative Thickness: The left ventricle is much thicker than the right as it pumps high pressure blood to the body so a high pressure developed in the systemic circulation requiring a thicker muscle wall. Atria are situated superior to the ventricles. The atria's walls are much thinner and elastic, because the blood flow is of low pressure. The wall of the heart consists of 3 layers.

- Endocardium
- Myocardium
- Pericardium: that secretes the pericardial fluid which reduces the friction when the heart beats.

Cardiac Cycle: events which take place within a single heartbeat to perform a single cardiac output is known as the cardiac cycle.

- Cardiac Diastole
 - Atrial Systole
 - Ventricular Systole
1. **Diastole:** Both the atria and ventricles are relaxed and the valves closed. Deoxygenated blood from the body enters the right atrium through the vena cava. Oxygenated blood from the



lungs enters the left atrium through the pulmonary veins. Both atria fill up with blood.

2. Systole: Atria contract so the blood is squeezed which causes the atrioventricular valves to open leading the blood to the ventricles. The valves between the atria and ventricles close preventing any backflow to the atria.
3. Every 1/10 second the ventricles contract and the blood is squeezed again. The increase of blood pressure forces open the valves.
4. The ventricles pressure becomes higher than the atria's pressure, and the pressure in the right ventricles exceed that in the pulmonary artery the semi-lunar valves open and oxygenated blood flows out of the body.
5. When the ventricles are empty, the valves leading the blood out of the heart close and the heart muscles relax completing the sequence of contraction & relaxation in one heartbeat.
6. The atria fill up with blood as the heartbeat sequence begins again.

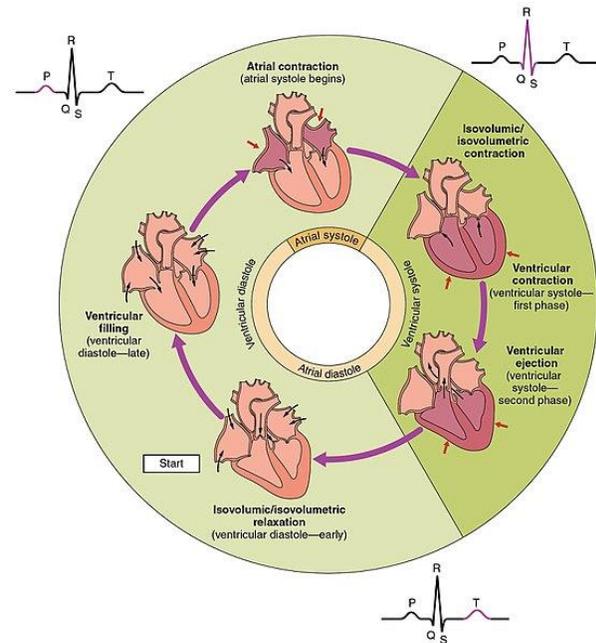
<u>Cardiac Diastole</u>	<u>Atrial Systole</u>	<u>Ventricular Systole</u>
<p>Pressure in the ventricles decreases thus increasing the volume.</p> <p>The semi-lunar valves in the aorta and the pulmonary arteries close.</p> <p>All the heart muscles relax.</p> <p>Blood flows into the atria from the vena cava and pulmonary vein.</p> <p>Blood pressure remains low inside the atria and ventricles.</p>	<p>The muscles of the atria (plural for atrium) contracts thus decreasing the volume.</p> <p>The pressure inside of the atria increases.</p> <p>The semi-lunar valves in the vena cava and the pulmonary vein close.</p> <p>The tricuspid & bicuspid atrioventricular valves opens, allowing blood into the ventricles.</p> <p>Pressure decreases.</p> <p>This lasts about 0.1 seconds.</p>	<p>The muscles of the ventricles contract thus decreasing the volume.</p> <p>The pressure inside the ventricles increases.</p> <p>The tricuspid & bicuspid atrioventricular valves close.</p> <p>The semi-lunar valves in the aorta and the pulmonary arteries open.</p> <p>Pressure decreases.</p> <p>This lasts about 0.3 seconds.</p>
<p><u>Ventricular Diastole</u>: Both Atria & ventricles relax. The semilunar valves in the aorta and pulmonary artery are pushed shut. Blood flows from veins through the atria and into the ventricles.</p>	<p><u>Atrial Systole</u>: Both Atria contract. Blood flows from the Atria into the ventricles. Back flow of blood into the vein is prevented by closure of the valves in the veins.</p>	<p><u>Ventricular Systole</u>: Both ventricles contract. The atrioventricular valves are pushed shut by the pressurized blood in the ventricles. The semilunar valves in the aorta and pulmonary artery are pushed open. Blood</p>

		flows from the ventricles into the arteries.
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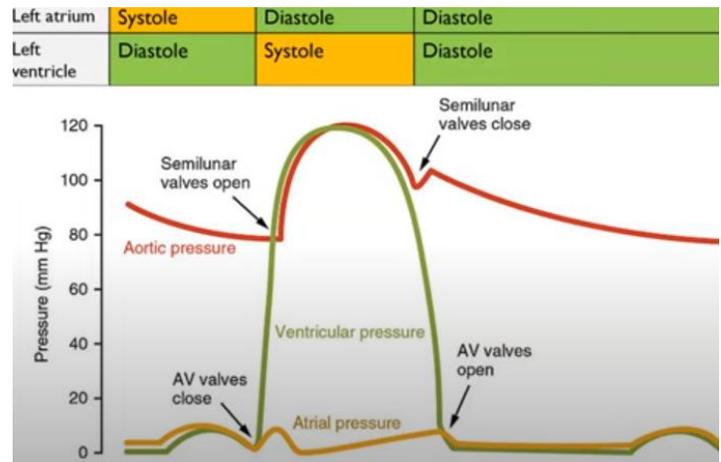
	<u>Atrial Systole</u>	<u>Ventricle Systole</u>	<u>Diastole</u>
<u>Description</u>	Atria Contracts	Ventricle Contracts	Both Chambers Relax
<u>Volume of Atria</u>	Decreases	No Change	Increases
<u>Pressure in Atria</u>	Increases	No Change	Increases
<u>Volume of Ventricles</u>	Increases	Decreases	Slow Increase
<u>Pressure in Ventricles</u>	Decreases	Increases	Slow Increase

Changes in the Pressure (mmHG) & Volume (ml) during the Cardiac Cycle:

- **Both ventricles and atria relax:**
 - Semilunar Valves close producing second heart sound 'dubb'.
 - Ventricular pressure decreases due to relaxation.
 - Atrial pressure starts increasing due to entry of blood.
 - Again pressure of atria decreases as some blood move into ventricles passively.
 - Pressure increases slowly in both atria and ventricles as blood is filling.
 - Volume increases in both atria and ventricles due to filling of blood and extension of heart muscles.
- **Atria contract and ventricles relax:**



- Atrial pressure increases gradually due to contraction and slight increase in ventricular pressure due to passive filling or slow filling of blood from atrium to ventricle.
- Bicuspid and tricuspid valves open.
- Volume decreases because of contraction and stretching of ventricles.
- **Ventricles contract and atria relax:**
 - Bicuspid and tricuspid valves close producing the first heart sound 'lub'.
 - Ventricular pressure increases gradually due to contraction and pressure decrease in atria due to relaxation.
 - Semilunar valves open.
 - Volume decreases because of contraction and expansion of atria.



Cardiac Output: the amount of blood pumped around the body is called a cardiac output and it depends on two factors:

- The stroke volume: the volume of blood pumped by the left ventricle in each heart beat. A typical value for an adult at rest is 75 ml.
- The heart rate: the number of times the heart beats per minute. A typical value for an adult at rest is 70 bpm.

$$\text{Cardiac Output} = \text{Stroke Volume} \times \text{Heart Rate}$$

A typical resting cardiac output is 4-6 litres per minute. This can rise to as much as 40 litres per minute in highly trained endurance athletes.

Single Circulation	Double Circulation
<p>There are three circuits from the heart:</p> <ul style="list-style-type: none"> • blood passes from the heart to the lungs - where it absorbs oxygen and releases carbon dioxide - then back to the heart • blood passes from the heart to the organs and tissues in the body, and back to the heart. • Blood is supplied to the heart muscle and then returned to the heart. 	<p>In a single circulation of a fish blood travels from the heart to the gills, where it absorbs oxygen and releases carbon dioxide. It then flows from the gills to the organs and tissues in the rest of the body, and back to the heart.</p>

Q. Why do you think a double circulatory system has evolved?

Ans. The ability to create more pressure to pump blood round the system. The separation of oxygen-rich and oxygen-poor blood.

Q. How is the heart coordinated?

Ans. The muscles in the heart are described as myogenic. These muscles respond to changes in electrical charge in the heart - automatically contracts and relaxes. It does not require impulse stimulation from the brain. This should contract rhythmically.

Nodes:

The cardiac cycle is controlled by a small patch of myogenic muscle in the walls of the right atrium - often 'pacemakers.'

There are two nodes in the heart

- Sino-atrial node (SAN)
- Atrio-ventricular Node (AVN)

Electrical impulses are sent from the SAN to the AVN coordinating heart muscle contractions.

Polarization & Depolarization:

The membranes around the two nodes, allow a charge to be maintained across the membrane. At rest the nodes in the heart become polarized. A positive charge builds up on the inside of the node, and a negative on the outside. This is caused by ions building up. When a contraction occurs, the nodes are depolarized. Positively charged ions move out of the nodes stimulating a wave in electrical electricity in the heart.

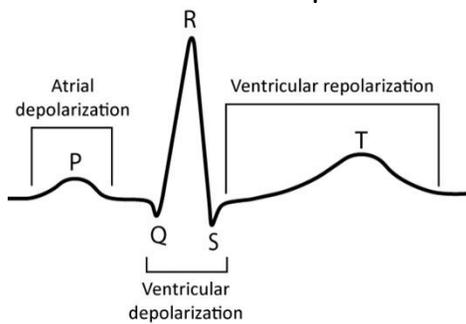
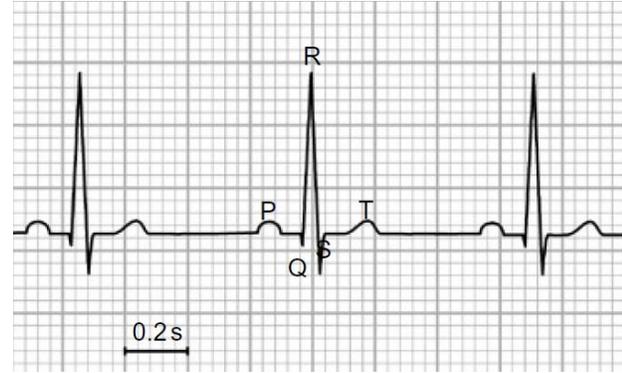
Control of the Cardiac Cycle:

Atrial Systole: The Sino-atrial node in the upper left wall of the right atrium sends a wave of electrical activity (depolarization) throughout the atria. This causes the walls of the atria to contract almost simultaneously. Blood is forced through the bicuspid (mitral) and tricuspid valves into the ventricles.

Ventricular systole: The Atrio-ventricular Node, picks up the wave from the SAN and sends its own wave of depolarization down the bundle of His, then into the Purkyne tissues. This causes the ventricular walls to contract. These forces blood out of the aorta and the pulmonary (semi-lunar) valves.

Electrocardiogram (ECG):

The activity of the heart may be monitored by electrocardiogram (ECG). It is a simple test that can be used to check your hearts rhythm and electrical activity. Sensors (electrodes) are attached to specific places on the skin are used to detect changes in polarization in the heart by measuring current at the skin surface. They can detect a possible heart problem such as coronary artery disease. An echocardiogram (ECG) or an echo is used to look at the heart and nearby blood vessels. An ECG may be used to listen to the sounds of valves closing. When the ventricles contract, the bi and tricuspid valves close, which produces a 'lub' sound which can be heard during a heartbeat. While when the ventricles relax, blood in the arteries try to flow back into the ventricles, but this is prevented by the semi-lunar valves. This produces a 'dub' sound.



- The part labelled P represents the wave of excitation sweeping over the atrial walls.
- The parts labelled Q, R and S represent the wave of excitation in the ventricle walls.
- The T section indicates the recovery of the ventricle walls

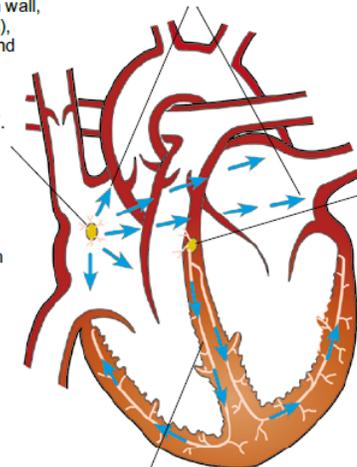
ECGs are used to diagnose problems with the heart, as variations in different components of the trace can indicate a disease or other abnormality. An ECG may be taken while the patient is relaxed or it may be taken before, during and after exercise. A 'stress test' usually involves the patient exercising on a treadmill while attached to an ECG machine.

1 Each cardiac cycle begins in the right atrium. There is a small patch of muscle tissue in the right atrium wall, called the sino-atrial node (SAN), which automatically contracts and relaxes all the time. It doesn't need a nerve impulse to start it off, so it is said to be myogenic – that is, 'started by the muscle'. The SAN is often called the pacemaker, because it sets the pace at which the whole heart beats. However, the pacemaker's rate can be adjusted by nerves transmitting impulses to the pacemaker from the brain.

5 The ventricles then relax, indicated by the T wave. Then the muscle in the SAN contracts again, and the whole sequence runs through once more.



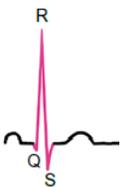
2 As the muscle in the SAN contracts, it produces an electrical impulse which sweeps through all of the muscle in the atria of the heart. This impulse makes the muscle in the atrial walls contract. The impulse shows up on the ECG as the P wave. So the P wave represents the electrical activity just before atrial systole.



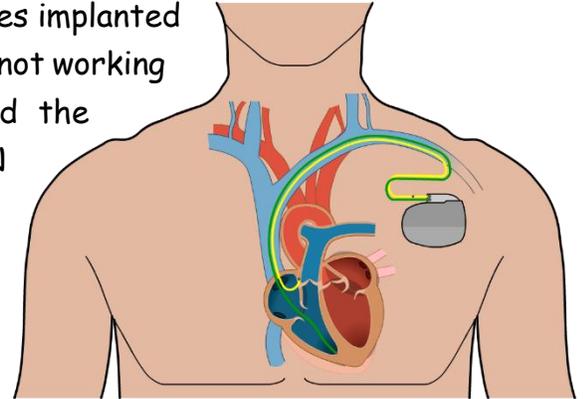
3 The impulse sweeps onwards and reaches another patch of cells called the atrio-ventricular node (AVN). This node is the only way in which the electrical impulse can get down to the ventricles. The AVN delays the impulse for a fraction of a second, before it travels down into the ventricles. This delay means that the ventricles receive the signal to contract after the atria.



4 The impulse moves swiftly down through the septum of the heart, along fibres known as Purkyne tissue. Once the impulse arrives at the base of the ventricles it sweeps upwards, through the ventricle walls. This is shown by the Q, R and S part of the ECG. The ventricles then contract.



Artificial Pacemakers: Artificial pacemakers are devices implanted in people whose heart's electrical conduction system is not working properly. Problems include the SAN not firing, and the blockage or disruption of impulses between the SAN and AVN, or in the bundle of His. Pacemakers monitor the heart's electrical activity and stimulate the ventricles or atria to contract when necessary. Impulses are transmitted down electrodes implanted in the muscular walls.

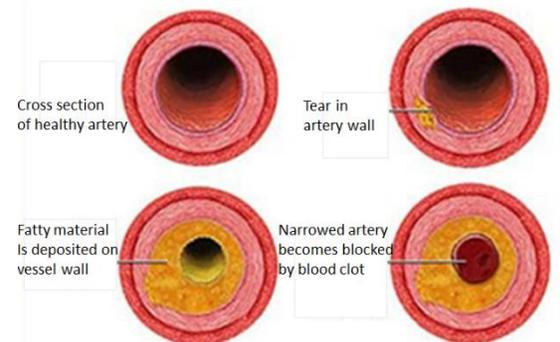


Cardiovascular Disease:

The inner lining of the wall of an artery (endothelium) is generally smooth and unbroken. If it damages, lipids and white blood cells from the blood clump together and form fatty streaks under the lining. As time passes, more lipids, white blood cells and connective tissue build up and harden to form an atheroma, a fibrous plaque. The lumen of the artery will get partially blocked due to this plaque which also restricts the blood flow resulting in the increase of blood pressure.

Myocardial infarction is commonly known as a heart attack.

Coronary heart disease (CHD) is the blockage of the coronary arteries. It's a cardiovascular disease happens when there are more atheromas within the coronary arteries. This restricts the blood flow towards the heart which may lead to myocardial infarction. The narrow blood vessel coronary artery spreads out over the heart surface. These vessels can become blocked by fatty deposits called an atheroma resulting in vessel



occlusion. If this happens the oxygen supply to the heart is reduced resulting in coronary heart disease symptoms include angina, chest pain. Atheroma affects the walls of the artery causing them to harden called atherosclerosis. It increases the risk of blood clots and blocks the artery. The risk factors:

- Aneurysm: swelling of the artery in the shape of a balloon
- Thrombosis: blood clot formation
- Genetic Predisposition: genes have made some individuals more likely to suffer from coronary heart disease.
- Diet: a diet especially rich in saturated fat & salts causes raised blood cholesterol. It combines with other fatty substances forming atheroma.

- Hypertension: the heart has to work harder to pump blood around the body putting more strain on the heart muscle.
- Increased stress: causes a release of hormones constricting the blood vessels.
- Smoking: the drug nicotine in tobacco smoke has a number of effects. It constricts arterioles raising the blood pressure. The deposit of tar ruins the lungs and increases buildup of cholesterol. Smoking contains carbon monoxide which lowers the ability of hemoglobin to carry oxygen.
- Age and gender: may too play a vital role in increasing the chances of coronary artery disease. With an increasing age the heart muscle weakens and the heart rate slows down hindering with the amount of oxygen transported to the heart.
- Sedentary lifestyle: a person spending several hours sitting with lack or exercise, increases obesity and therefore the deposit of fats in the coronary artery causing a greater viability to the disease.

Reducing the risks of CHD:

- Diet: a healthy diet consisting of vegetables and low fats, decrease the likelihood of the disease as little to no fat is deposited in parts of the body.
- Exercising strengthens the heart muscle as with an increased heart rate, a good oxygen supply reaches the heart. Moreover, exercising allows a person to burn fats, decreasing the cholesterol levels in the blood.