TRANSPORT IN ANIMALS

Instruction: ***Copy the notes in your own hand writing and read them. We will discuss a few concepts when we return to school.***

NEED FOR A TRANSPORT SYSTEM

Many materials including oxygen, carbon dioxide, soluble food substances, hormones, urea among others need to be transported from one point to another using a transport network and medium

Multicellular animals have a smaller surface area to volume ratio, higher rate of metabolism, and the distance from the body surface to the center of the body is longer. Movement of materials through the many cells is difficult, so they develop transport systems.

The larger, compact and more active an organism is, the more the need for a transport system due to a small surface area to volume ratio which reduces the rate of diffusion of materials from the body surface to the cells in the middle of the organism.

Unicellular animals are smaller, have larger surface area to volume ratio, lower rate of metabolism, and the distance from the body surface to the center of the organisms is shorter. Therefore, materials move by simple diffusion with no need for specialized transport systems.

Multicellular animals may increase surface area to volume ratio by developing hollow Body cavities as in coelenterates, flattening of the body as in Platyhelminthes, to eliminate the need for transport systems.

IMPORTANCES OF A BLOOD CIRCULATORY SYSTEM (FUNCTIONS OF BLOOD)

- It enhances the formation of energy in the tissues by transporting oxygen and soluble food substances to the tissues to be used as raw materials for respiration. Carbon dioxide is also transported away from the tissues mainly in the form of hydrogen carbonate ions (HCO_3^-) as a by-product of respiration and then taken to the lungs for its removal from the body. Oxygen is transported in the form of oxyhaemoglobin from the respiratory surfaces to the tissues.
- Blood transports water from the gut to all tissues.
- Blood transports the soluble well digested food materials from the gut to the body tissues.
- Blood transports metabolic waste products from the tissues to the excretory organs for their removal from the body. For example, blood transports urea from the liver to the kidney in order for it to be removed from the body.
- Blood disStributes heat from the organs where it is mainly generated. For example, the liver and the muscles, uniformly throughout the body.
- Blood maintains a constant pH through the maintenance of circulation of the plasma proteins manufactured by the liver which act as buffers to maintain the pH of the body fluids constant. This enables enzymes to function efficiently as charges will denature the enzyme.

- Blood transports different metabolites such as glucose, amino acids and hormones needed for the growth and development of the body.
- Blood defends the body against diseases through the following ways;
- By using some white blood cells (leucocytes) which phagocytotically ingest and destroy pathogens that cause diseases.
- By formation of a blood clot around the wound so as to prevent entry of microbes or pathogens into the body.
- By use of the immune response mechanism towards infection for example, by use of the different types of antibodies to destroy the microbes

BLOOD

This is a highly specialized fluid tissue which consists of different types of cells suspended in a pale-yellow fluid known as the blood plasma.

BLOOD PLASMA

This is a pale-yellow fluid component of blood composed of the plasma proteins and blood serum where the blood cells are suspended. Blood plasma takes the biggest percentage of blood. It is in the blood serum that all the different soluble materials are dissolved. For example; urea, hormones, soluble food substances, bicarbonate ions among others.

The plasma proteins are manufactured by the liver and include the following;

- **Fibrinogen.** This protein is important for normal blood clotting by changing into fibrin in the presence of thrombin enzyme.
  Fibrinogen (soluble) ⟶ Fibrin (Insoluble)
- **Prothrombin.** This is the inactive form of the proteolytic enzyme, thrombin, used in converting fibrinogen to fibrin during the clotting of blood.
- **Globulin.** Both Prothrombin and globulin play important roles in the homeostasis. All the plasma proteins maintain pH of the body fluids constant by acting as buffers.

BLOOD CELLS

There are three main types of blood cells which include;

- Erythrocytes (Red blood cells)
- Leucocytes (White blood cells)
- Platelets

RED BLOOD CELLS (ERYTHROCYTES)

These are small numerous bi-concave disc shaped cells mainly important in transportation of oxygen as oxyhaemoglobin from the respiratory surfaces for example, lungs and gives it to the tissues.

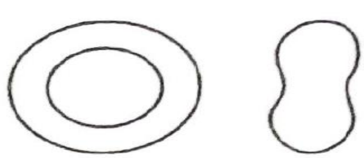
Erythrocytes are manufactured by the bone marrow in adult and by the liver in the foetus.

Adaptations of erythrocytes

- They have a bi-concave disc shape which provides a large surface area that enhances maximum diffusion of enough oxygen into them.
- They have a flexible membrane which can enable them change their original shape and squeeze themselves into the blood capillaries in order to allow the exchange of respiratory gases.
- They lack a nucleus so as to provide enough space for haemoglobin in order to carry a lot of oxygen in form of oxyhaemoglobin.
- They have a red pigment called haemoglobin in their cytoplasm which has a high affinity for oxygen and therefore rapidly transports oxygen.
- They have a thin and permeable membrane which enables faster diffusion of oxygen and carbon dioxide into them.
- They ack mitochondria which also makes more room for the packing of haemoglobin. Lack of mitochondria means red blood cells respire anaerobically and thus do not use up any of the oxygen they carry they carry.
- They are numerous about 5million per mm3 of blood. They thus make up about half the volume of blood giving blood enormous oxygen carrying capacity.
- They have an enzyme known as carbonic anhydrase within their cytoplasm which enables most of the carbon dioxide to be transported in form of bicarbonate ions (HCO_3^-), by catalyzing the reactions between carbon dioxide and water to from carbonic acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

Diagram showing the shapes of erythrocytes



NOTE; Erythrocytes have a life span of about 120 days.

LEUCOCYTES (white blood cells)

They are amoeboid cells having a nucleus and a colourless cytoplasm important for defense of the body against infections. They are fewer than erythrocytes (they are about 7000/m3 of blood). They are mainly manufactured by the bone marrow.

They are classified into two main types which include;

Granulocytes (polymorphonuclear leucocytes)

These are leucocytes with granules in their cytoplasm and a lobed nucleus. They originate in bone marrow. There are three types of granular leucocytes which include;

Basophils (0.5%)

Eosinophils (1.5%)

Neutrophils (70%)

Basophils: these represent 0.5% of the white blood cell population. They produce heparin and histamine.

Heparin is an anti-clotting protein which prevents blood clotting in blood vessels.

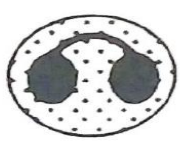
Histamine is a chemical found in damaged tissues which is involved in inflammation. Inflammation stimulates repair of damaged tissues. Over production of histamine occurs in some allergies such as hay fever.

Histamine brings about allergic reactions by causing dilation (widening) and increased permeability of small blood vessels which results in such symptoms as itching, localized swellings, sneezing, running nose, red eyes among others.

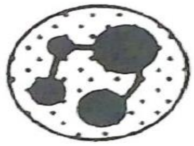
Structure

Eosinophils: they represent only 1.5% of the total number of white blood cells. They possess anti-histamine properties and their number increase in people with allergic reactions such as hay fever and asthma so as to combat the effects of histamine.

Structure



Neutrophils (phagocytes): these make up about 70% of the total number of white blood cells. They engulf pathogens phagocytotically and digest them actively inside to defend the body against diseases.



Agranulocytes (mononuclear leucocytes)

These are leucocytes with no granules in there cytoplasm usually with a spherical or bean shaped nucleus. They originate in bone marrow and lymph nodes. They are divided into two types;

1. Monocytes (4%)
2. Lymphocytes (24%)

Monocytes (4%): these are leucocytes which enter the tissues from which they develop into macrophages which carry out Phagocytosis to defend the body against pathogens. Together with neutrophils, they form a system of phagocytes throughout the body which acts as a first line of defense against infection.

They have a bean shaped nucleus.

Lymphocytes (24%): they are produced in the thymus gland and lymphoid tissues from cells which originate in the bone marrow. Lymphocytes are usually round and they possess a small quantity of the cytoplasm.

Lymphocytes produce antibodies, agglutinins, lysins, opsonins and antitoxins.

In adults they are produced and develop in the bone marrow and lymph glands while in embryos they are produced in the thymus gland, liver and spleen.

They have a life span of 21 days

Structure

BLOOD PLATELETS (THROMBOCYTES)

These are irregularly shaped, membrane bound cell fragments lacking the nuclei and are formed from the bone marrow cells. They are responsible for starting up the process of blood clotting. There are about 250,000 blood platelets per mm^3 of blood.

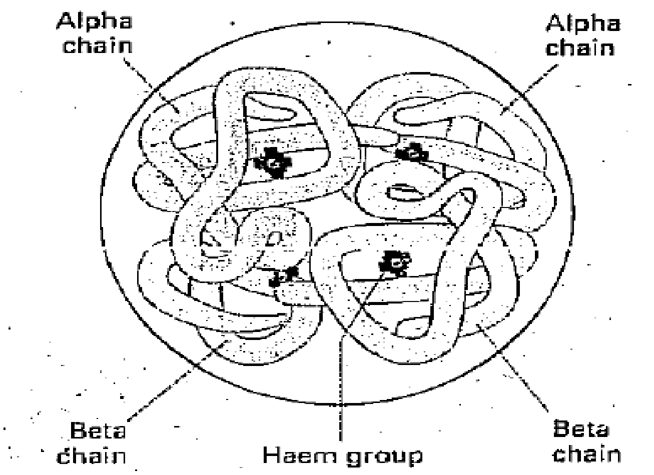
HAEMOGLOBIN STRUCTURE

Haemoglobin is a conjugated protein.

The protein part (called globin) consists of four polypeptide chains. These chains are of two types called alpha and beta. They are about the same length but have slightly different compositions.

Each chain is combined with a non-protein prosthetic group called haem. Haem consists of an atom of iron enclosed in a ring structure.

Each haem group can combine with one molecule of oxygen. This process is called oxygenation. Therefore, each molecule of haemoglobin can combine with a maximum of four molecules of oxygen.



Assignment;

a) How is haemoglobin adapted to its function?

TRANSPORT OF OXYGEN

Oxygen is carried from the lungs to the tissues in form of oxyhaemoglobin.

Oxygen diffuses into the red blood cell across its thin permeable membrane and combines with the haemoglobin to form oxyhaemoglobin.

Each of the four iron-containing haem groups in the haemoglobin molecule can combine with a molecule of oxygen.

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{oxygen}}{4\,O_2} \underset{\text{Tissues}}{\overset{\text{lungs}}{\rightleftharpoons}} \underset{\text{Oxyhaemoglobin}}{HbO_8}$$

The oxygen is loosely attached to the haemoglobin in the lungs and readily detached in the tissues.

Haemoglobin has a high affinity for oxygen. It readily combines with it to form oxyhaemoglobin when partial pressure of oxygen is high such as in the lung alveolar capillaries.

When partial pressure of oxygen is low as in capillaries supplying the respiring tissues, the bonds holding oxygen to haemoglobin become unstable and oxygen is released to the tissue. This diffuses in solution into the surrounding cells.

NB. The affinity of haemoglobin for oxygen is high in the lungs because of high oxygen partial pressures and low carbon dioxide partial pressures there.

The affinity of haemoglobin for oxygen is reduced in an environment where oxygen partial pressure is low. For example, in the capillaries of respiring tissues because of high carbon dioxide concentration there.

Oxygen tension and oxyhaemoglobin formation

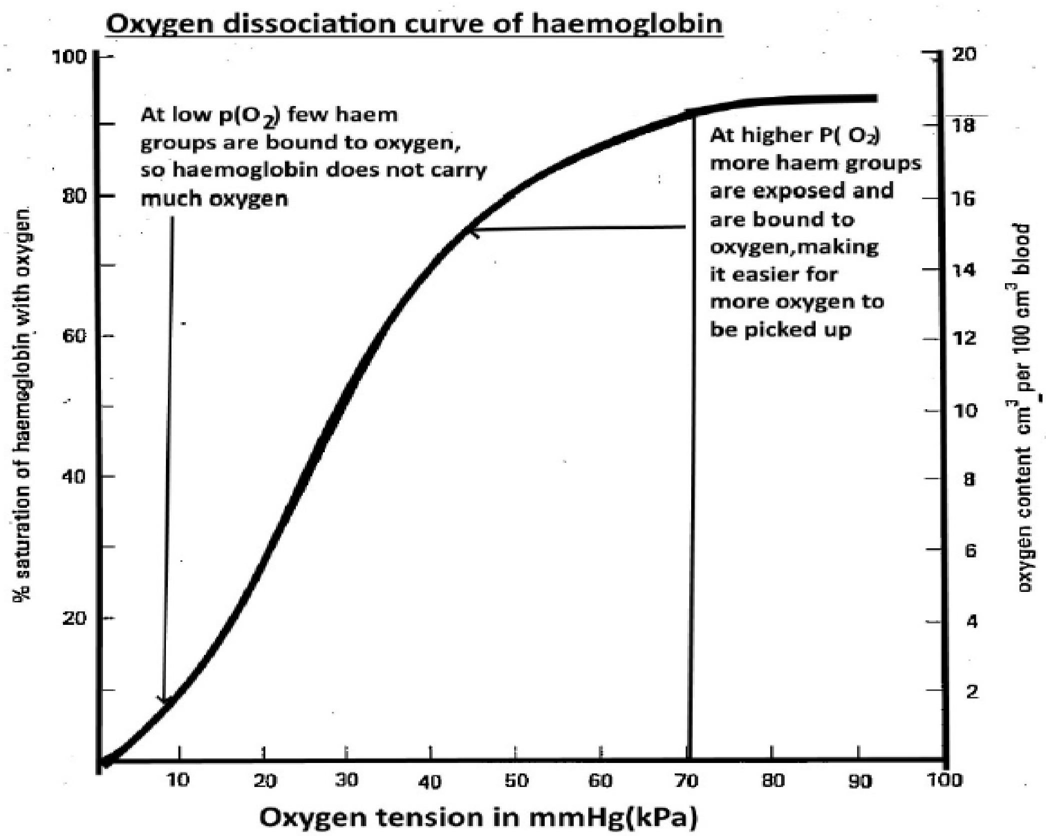
The ability of red blood cells (erythrocytes) to carry oxygen to the tissues is due to haemoglobin having a high affinity for oxygen. It can readily combine with oxygen and becomes fully saturated with it at relatively low partial pressures of the gas.

Partial pressure of a gas is the measure of the concentration of a gas expressed in Kilo Pascals (Kpa) or millimeters of mercury (mmHg).

The high affinity of haemoglobin for oxygen is measured experimentally by determining the percentage saturation of haemoglobin with oxygen.

When the percentage saturation of blood with oxygen is plotted against the partial pressure of oxygen an S-shaped curve or sigmoid curve is obtained and this curve is called the **oxygen dissociation curve.**

OXYGEN DISSOCIATION CURVE



Oxygen dissociation curve shows the degree of haemoglobin saturation with oxygen plotted against different values of oxygen partial pressures.

The sigmoid shape of the curve reflects the high affinity of haemoglobin for oxygen, whereby a slight increase in oxygen partial pressure leads to a large increase in the percentage saturation of haemoglobin with oxygen.

At the lowest partial pressure of oxygen of 0 kPa the percentage saturation of haemoglobin with oxygen is 0 %, because there is no oxygen bound to the haemoglobin.

As partial pressure of oxygen increases slightly, the percentage saturation of haemoglobin with oxygen increases gradually. This is because the first oxygen molecule to combine with the haem group does so with the greatest difficulty, since the polypeptide chains are tightly bound together. This makes it difficult for an oxygen molecule to gain access to the iron atoms of the haem groups.

Thereafter, as partial pressure of oxygen increases slightly further, the percentage saturation of haemoglobin with oxygen increases rapidly.

This is because the remaining haem groups combine with oxygen with increasing ease, due to distortion of the structure of the haemoglobin molecule when the first haem group combines with the first oxygen molecule.

As one molecule of oxygen becomes bound to one haem group the polypeptide chain opens up, exposing the other three haem groups of the haemoglobin molecule to oxygen. This makes it much easier for them to become oxygenated.

As partial pressure of oxygen increases further the percentage saturation of haemoglobin with oxygen increases gradually, because most binding sites of haemoglobin are already occupied by oxygen molecules

At very high partial pressures of oxygen the percentage saturation of haemoglobin with oxygen remains constant at a maximum, because all binding sites of haemoglobin are already occupied by oxygen molecules.

NB. When oxyhaemoglobin is exposed to regions where the partial pressure of oxygen is low, for example in the respiring tissues, the first oxygen molecule is released easily and faster but the last one is released less readily with a lot of difficulty and least readily.

In conclusion, the curve indicates that haemoglobin has a high affinity for oxygen where the oxygen tension is high for example, in the alveolar capillary of the lungs.

However, the affinity of haemoglobin for oxygen is lower where the oxygen tension is low and instead it dissociates to release oxygen for example in the blood capillaries supplying blood to respiring tissues.

Note; Animals which burrow into oxygen-deficient mud have haemoglobin which has a high affinity for oxygen. The oxygen dissociation curve for the lugworm is therefore situated to the left of human blood.

Effect of carbon dioxide on the oxygen dissociation curve (Bohr's effect)

Within tissues there is a high concentration of carbon dioxide produced during aerobic respiration

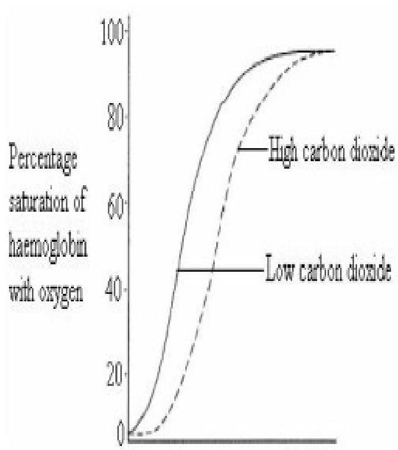
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

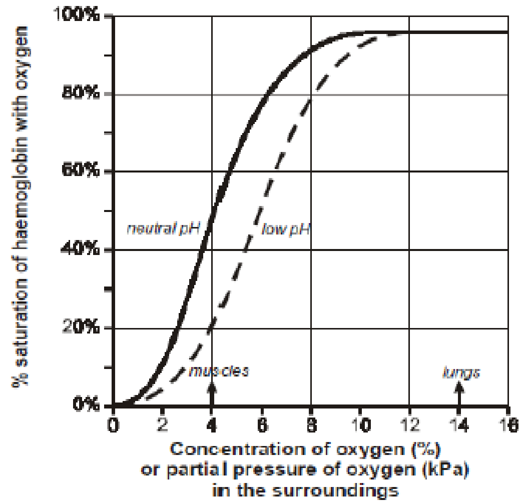
Increase in carbon dioxide concentration decreases the affinity of haemoglobin for oxygen, by making the pH of the surrounding medium more acidic (low). This shifts the oxygen dissociation curve to the right.

The shifting of the curve to the right is known as **Bohr's effect.**

Bohr's effect is the shifting of the oxygen dissociation curve to the right due to the increase in partial pressures of carbon dioxide which results into haemoglobin having a low affinity for oxygen and a high affinity for carbon dioxide.

Bohr's effect may also be defined as the lowering of the affinity of blood's haemoglobin for oxygen due to increased acidity caused by increase in carbon dioxide concentration.





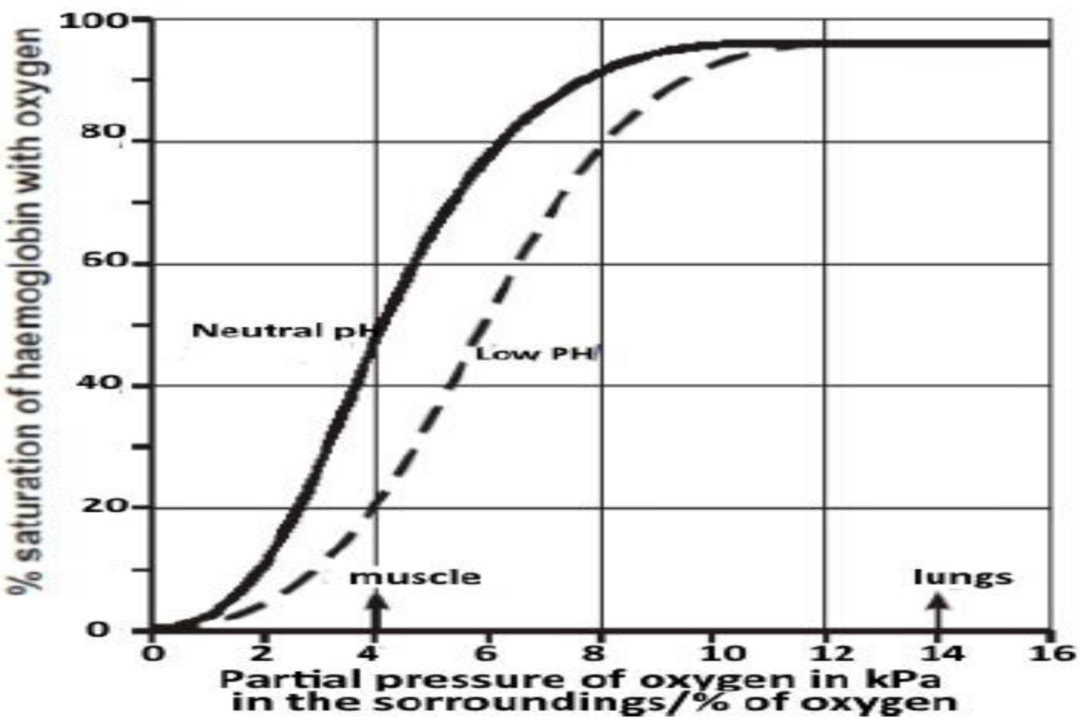
Shifting the oxygen dissociation curve to the **left** means that haemoglobin has a higher affinity for oxygen and therefore becomes fully saturated with oxygen at very low partial pressures of oxygen. It also means that haemoglobin has a low rate of dissociation to release oxygen to the tissues but a high rate of combining with oxygen.

Shifting of the oxygen dissociation curve to the right means that haemoglobin has a lower affinity for oxygen and a higher rate of dissociation to release oxygen to the tissues rapidly to support tissue respiration

As carbon dioxide partial pressure increases the oxygen dissociation curve of haemoglobin shifts to the right and downwards, because increased partial pressure of carbon dioxide reduces the affinity of haemoglobin for oxygen.

This is because carbon dioxide diffuses into red blood cells where it reacts with water forming carbonic acid under catalysis of carbonic anhydrase. The carbonic acid dissociates into protons and hydrogen carbonate ions, the hydrogen carbonate ions diffuse out of the red blood cell, and chloride ions diffuse into the red blood cell to maintain electrical neutrality.

The protons left inside displace the oxygen molecules from the haemoglobin binding sites and this reduces the affinity of haemoglobin for oxygen by increasing acidity, thereby inducing dissociation of oxyhaemoglobin into haemoglobin and oxygen, which can hardly recombine to regenerate oxyhaemoglobin, but instead leading to formation of haemoglobinic acid



Effect of carbon monoxide on the affinity of haemoglobin for oxygen

There's a loose and reversible reaction between oxygen molecules and iron (II) atoms of haem groups of haemoglobin to from oxyhaemoglobin. This means that iron (II) is not oxidized to iron (III) as haemoglobin combines with oxygen.

In the presence of carbon monoxide and oxygen, haemoglobin combines readily with carbon monoxide to form a permanent compound known as **carboxyhaemoglobin** rather than combining with oxygen.

A permanent carboxyhaemoglobin compound is formed because carbon monoxide oxidizes iron (II) to iron (III). This reduces the free haemoglobin molecules available to transport oxygen molecules to the tissues, which makes the tissues develop symptoms of **anoxia** (total lack of oxygen in the tissues).

Therefore, carbon monoxide is referred to as a respiratory poison because it can readily combine with haemoglobin much more than oxygen and the product formed does not easily dissociate.

Note; smokers have 10% of their total haemoglobin in form of carboxyhaemoglobin.

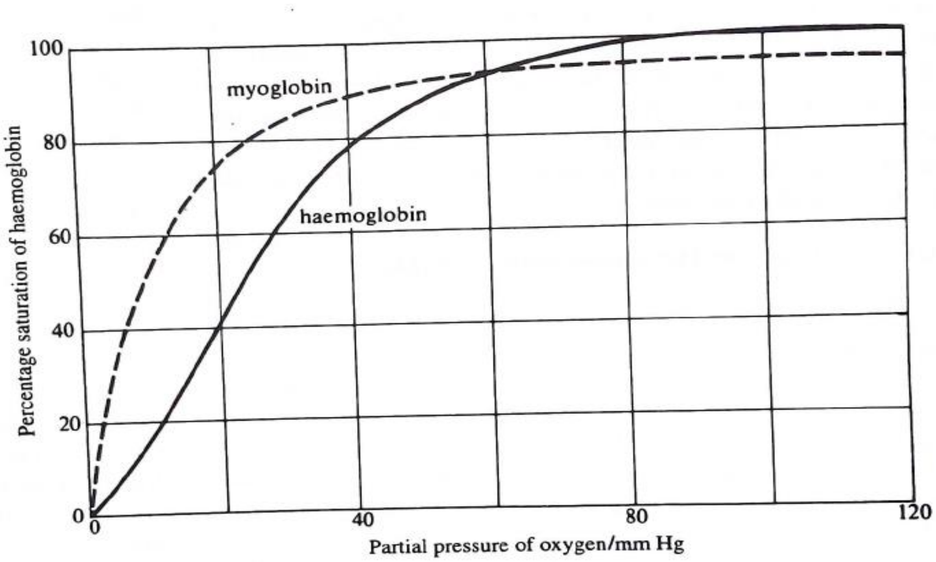
MYOGLOBIN AND OTHER PIGMENTS

Myoglobin is a respiratory pigment which also contains iron containing haem groups mostly found in the muscles. It remains fully saturated at partial pressures below that required for haemoglobin to give up its oxygen.

Myoglobin has a higher affinity for oxygen than haemoglobin. It readily combines with oxygen and it becomes fully saturated with it at a lower partial pressure of oxygen.

Myoglobin acts as a store of oxygen in resting muscles in form of **oxymyoglobin** and only releases the oxygen it stores when oxyhaemoglobin has been exhausted mainly during vigorous muscular activity.

Because myoglobin has a higher affinity for oxygen than haemoglobin, the oxygen dissociation curve for myoglobin lies to the left of that of haemoglobin as shown in the graph.

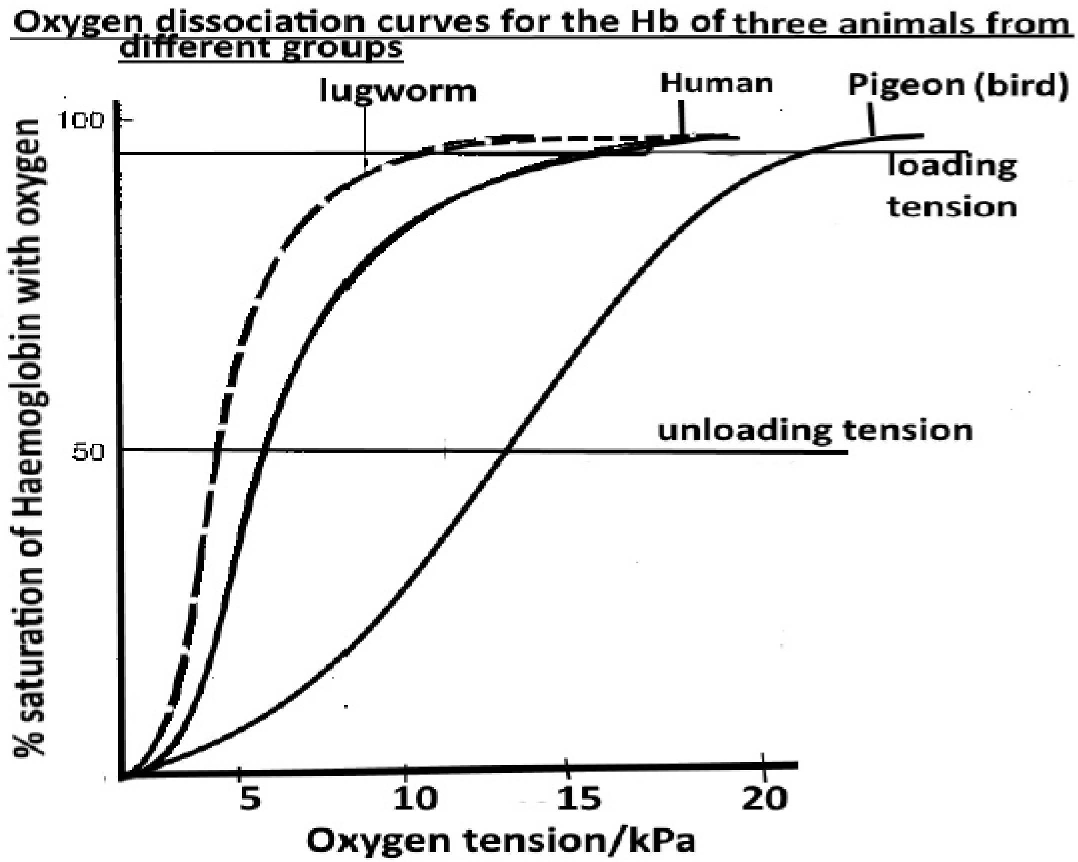


Note;

High affinity implies a higher rate of association of haemoglobin with oxygen and a low rate of dissociation to release oxygen.

Low affinity implies a lower rate of association of haemoglobin with oxygen and higher rate of dissociation to release oxygen and

Comparison between the oxygen dissociation curve for Lugworms' haemoglobin, pigeon's Hb and that of Man



Lugworm: The oxygen dissociation curve of the lugworm's haemoglobin lies on the left of that of man's haemoglobin.

This indicates that the haemoglobin of the lugworm has a higher affinity for oxygen than that of man. This is because the lugworm lives in oxygen deficient mud and so in order to extract enough oxygen from that environment of low oxygen tension, the haemoglobin of the lugworm must have a higher affinity for oxygen than that of man thriving in a well-supplied environment with oxygen.

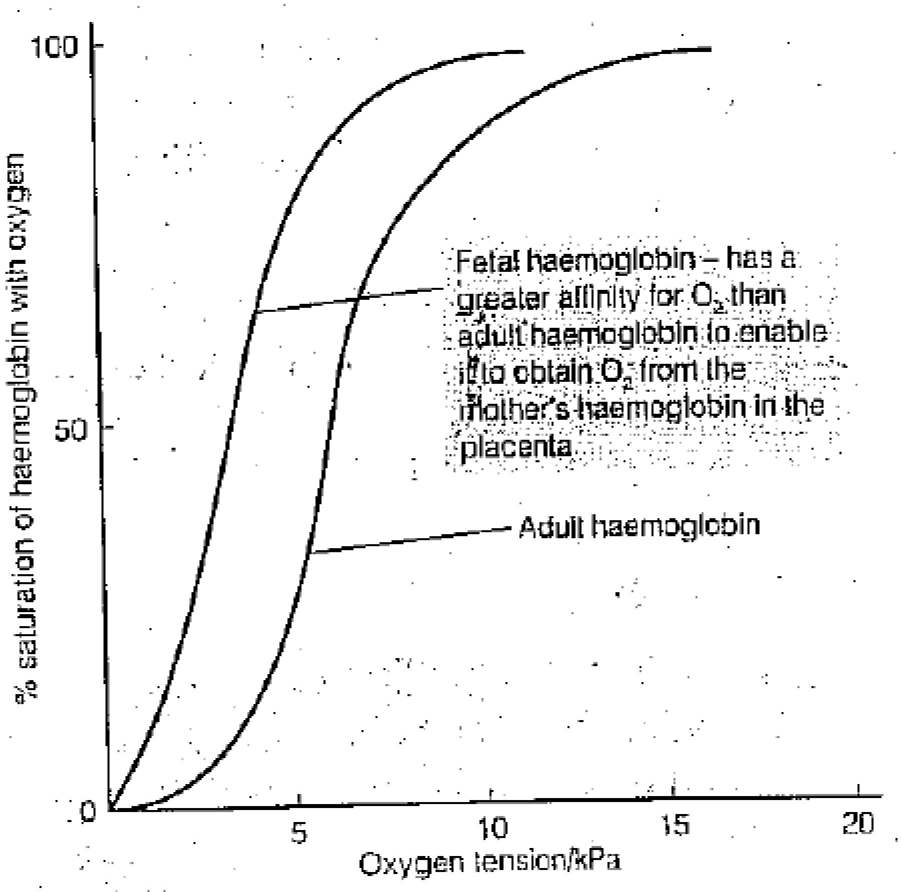
This implies that the lugworm's haemoglobin dissociates less rapidly to release oxygen to its tissues compared to that of man which makes the lugworm less active than man, who releases much oxygen rapidly to the tissues.

Pigeon: The oxygen dissociation curve of the pigeon's haemoglobin lies on the right of that of man's haemoglobin.

This indicates that the haemoglobin of the pigeon has a lower affinity for oxygen than that of man. This is because as flight muscles demands much energy, birds have higher metabolic-rates.

To supply oxygen to the active tissues rapidly, their haemoglobin must release it more readily.

Comparison between the oxygen dissociation curve of maternal haemoglobin and that of the foetal haemoglobin

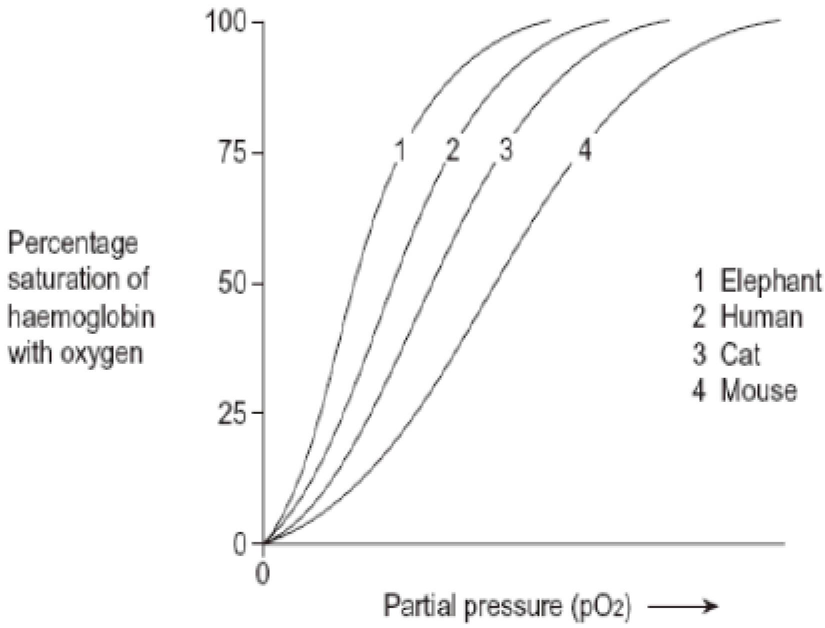


The oxygen dissociation curve of foetal haemoglobin lies to the left of maternal haemoglobin.

This indicates that the foetal hemoglobin has a higher affinity for oxygen than that of the mother. This enables the foetal haemoglobin to pick sufficient oxygen from the mother via the placenta and also increases on the oxygen carrying capacity to the tissues, especially when the foetus needs a lot of energy.

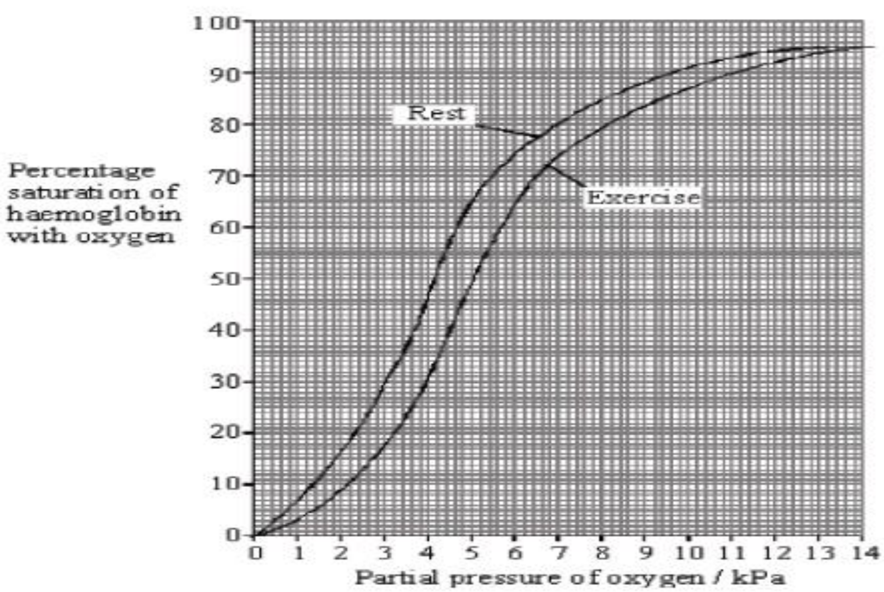
It also increases on the oxygen carrying capacity to the tissues of the foetus in the situation whereby deoxygenated and oxygenated blood are mixed due to the bypasses of ductus arteriosus and foramen ovale in the foetus.

Comparison between the oxygen dissociation curves of different sized mammals



Small animals have higher metabolic rates and so need more oxygen per gram of tissue than larger animals. Therefore, they have blood that gives up oxygen more readily. Their dissociation curves are on the right of the larger animals

Comparison between the oxygen dissociation curves at rest and during exercise



During exercise, the oxyhaemoglobin releases oxygen more readily hence the oxygen dissociation curve during exercise is to the right of the curve when at rest.

Effect of changing altitude on oxygen carriage

There is a decrease in the partial pressure of oxygen in the atmosphere with increase in altitude from sea level. Therefore, the volume of oxygen is less at high altitudes than at sea level.

When an organism moves from the sea level to high altitudes, very fast, such an organism tends to develop symptoms of anoxia (lack of oxygen) which include headache, fatigue, nausea, and becoming unconscious.

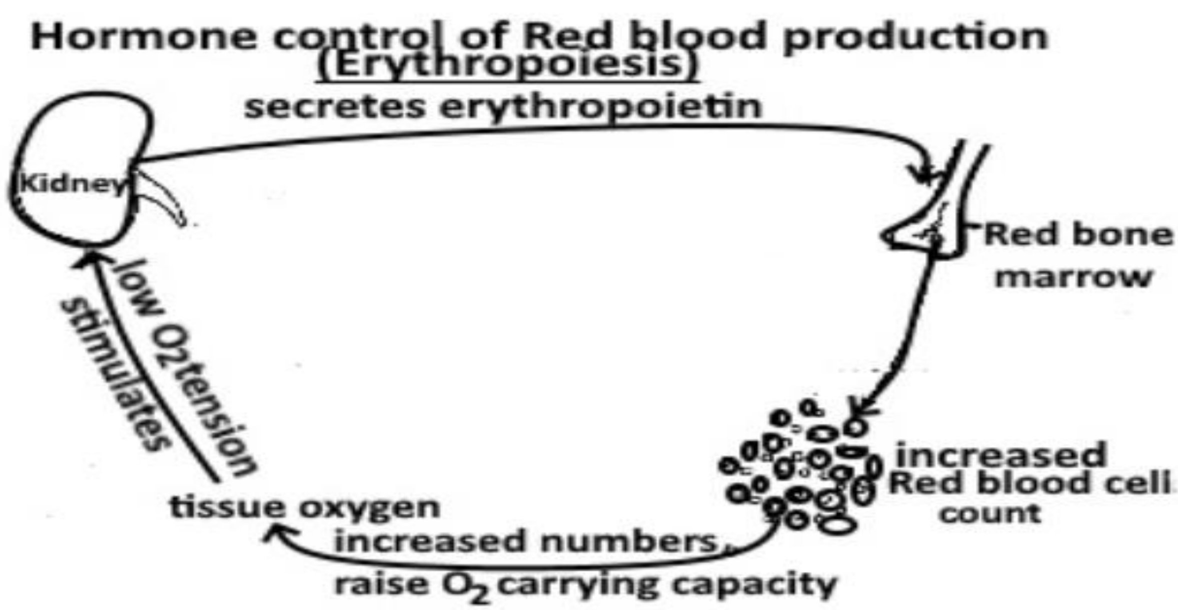
However, when an organism moves slowly from sea level to high altitudes like the mountain climbers, such an organism can at first develop symptoms of anoxia but later on such symptoms disappear due to adjustments in the respiratory and circulatory systems in response to insufficient oxygen reaching the tissues from the surrounding.

The amount of haemoglobin and the red blood cell count increases together with the rate of breathing and the heartbeat.

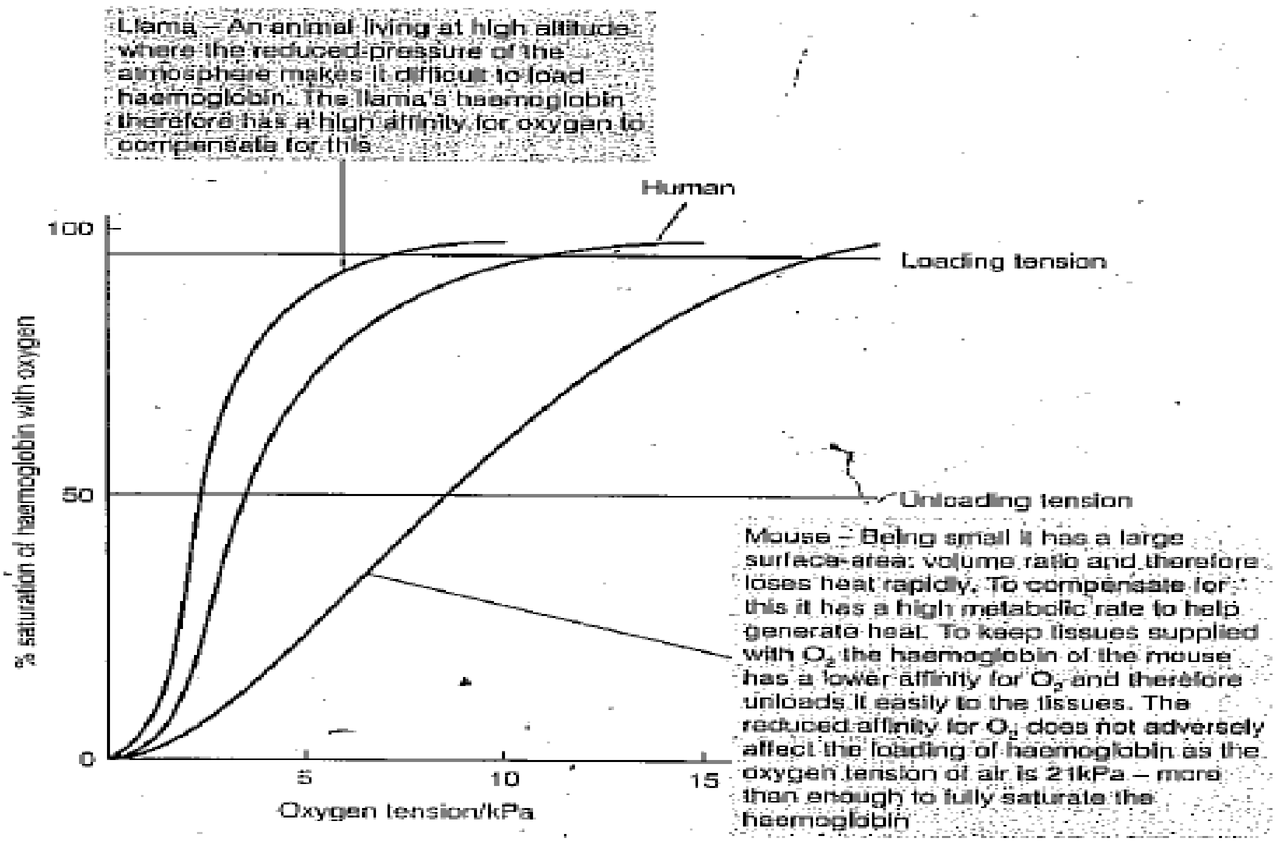
More red blood cell formation occurs in the bone marrow under the control of the hormone called ***erythropoietin*** secreted by the kidney. Secretion of erythropoietin is stimulated by lower oxygen tension in the tissues.

Increase in the amount of haemoglobin and red blood cells together with increase in the breathing rate and heart beat increases the oxygen carrying capacity of the blood to the tissues which leads to the disappearance of the symptoms of anoxia and which also makes the individual organism to be acclimatized.

Acclimatization is therefore a condition whereby an organism carries out a series of physiological adjustments in moving from a low altitude area to a high one to avoid symptoms of anoxia so that such an organism can survive in an environment of low oxygen content.



Comparison of an oxygen dissociation curve of a highland mammal and that of a human being

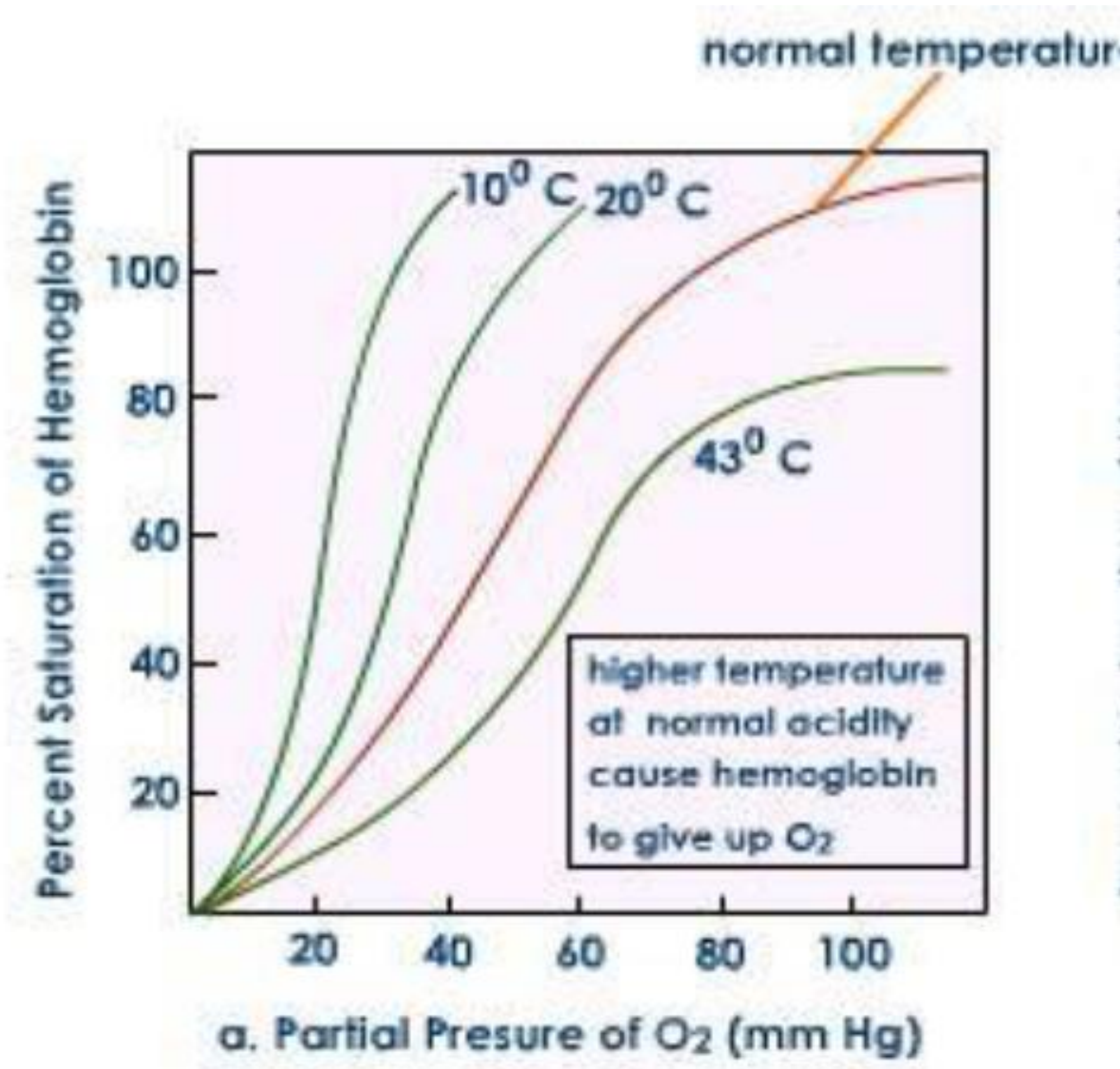


Effect of temperature on haemoglobin oxygen dissociation curve

A rise in temperature lowers the affinity of haemoglobin for oxygen thus causing unloading from the pigment.

A rise in temperature increases the rate of dissociation of oxyhaemoglobin to release oxygen to the tissues.

Increased tissue respiration which occurs in the skeletal muscles during exercise generates heat. The subsequent rise in temperature causes the release of extra oxygen from the blood to the tissues. This is so because increase in temperature makes the bonds which combine haemoglobin with oxygen to break, resulting into the dissociation of oxyhaemoglobin.



TRANSPORT OF CARBON DIOXIDE

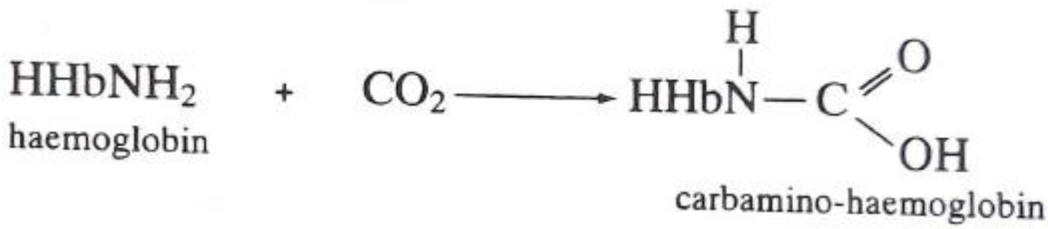
Carbon dioxide is transported from the body tissues mainly inform of bi-carbonate (Hydrogen carbonate) ions in blood plasma to the lungs for removal.

Although carbon dioxide is mainly transported inform of bi-carbonate ions (85%), carbon dioxide can also be transported in the following ways;

a). About 5% of carbon dioxide is transported in solution form. Most of the carbon dioxide carried in this way is transported in physical solution.

b). In combination with haemoglobin. About 10% of carbon dioxide combines with the amino group ($-NH_2$) of haemoglobin to form a neutral compound known as carbaminohemoglobin.

If less oxygen is being carried by haemoglobin molecules, then more carbon dioxide is carried in this way.



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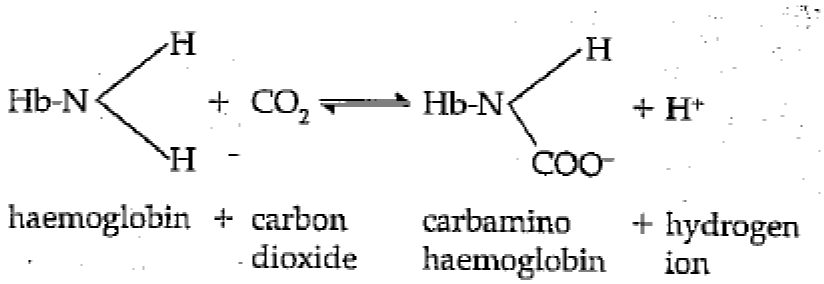
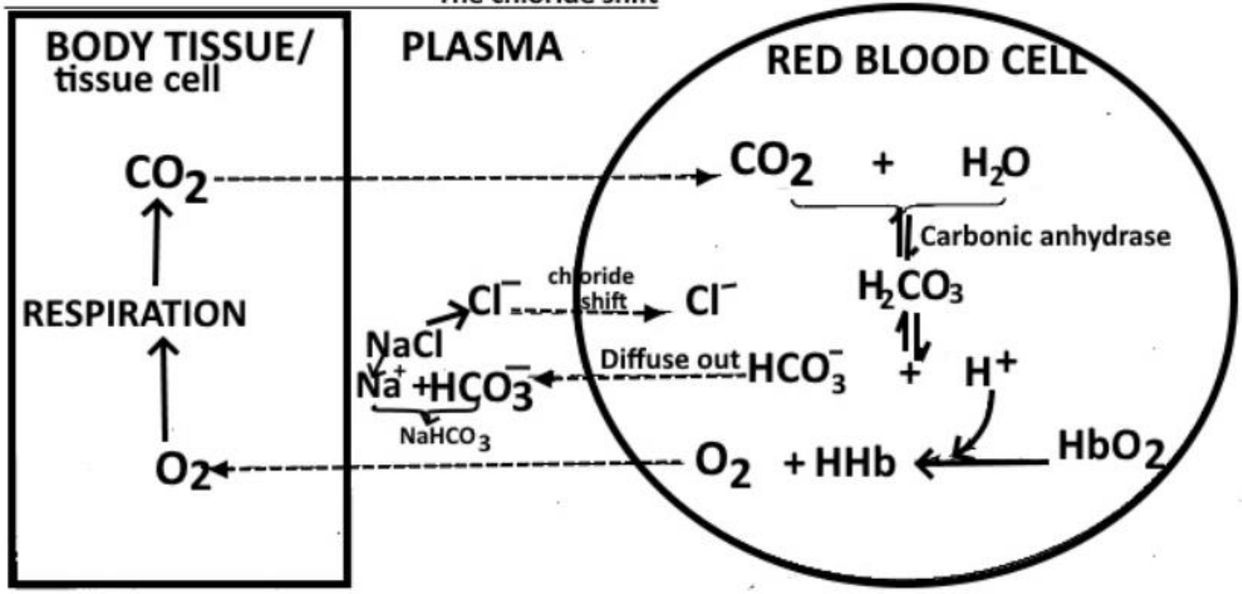


Transportation of carbon dioxide inform of hydrogen carbonate ions

The chloride shift



When carbon dioxide is formed during respiration, it diffuses from the tissues into the erythrocytes (red blood cells), via their thin and permeable membrane.

Inside the erythrocytes, carbon dioxide reacts with water in the presence of carbonic anhydrase enzyme to form carbonic acid.

The formed carbonic acid then dissociates into hydrogen ions and hydrogen carbonate ions.

The formed hydrogen ions decrease the pH in erythrocytes which results into the dissociation of oxyhaemoglobin being carried from the lungs to the tissues into the free haemoglobin molecules and free oxygen molecules.

$$HbO_8 \longrightarrow Hb + 4O_{2\,(g)}$$

The free oxygen molecules diffuse into the tissues to be used in respiration. The free haemoglobin molecules buffer the hydrogen ions (H+) inside the red blood cells into a weak acid known as **haemoglobinic acid**

$$H^+ + Hb \longrightarrow HHb$$

In case of excess H+ plasma proteins are used to buffer them into another weak acid called proteinic acid.

The formed hydrogen carbonate ions within the erythrocytes diffuse out into the plasma along the concentration gradient and combine with sodium to form sodium hydrogen carbonate which is then taken to the lungs.

The outward movement of bicarbonate ions from the erythrocytes into the plasma results into an imbalance of positively charged and negatively charged ions within the cytoplasm.

In order to maintain electrochemical neutrality, to remove this imbalance in the red blood cells, chloride ions diffuse from the plasma into the red blood cells, a phenomenon known as the **chloride shift**

When the bicarbonate ions reach the lungs, they react with H+ to form carbonic acid which eventually dissociates into carbon dioxide and water.

$$H^{+} + HCO_3^{-} \longrightarrow H_2CO_3$$

$$H_2CO_3^{-} \longrightarrow H_2O + CO_2$$

The carbon dioxide and water formed from the dissociation of carbonic acid in the lung capillaries are then expelled out by the lungs during exhalation so as to maintain the blood pH constant

CIRCULATORY SYSTEM IN ANIMALS

Every circulatory system possesses three distinct characteristics

1. A circulatory fluid, generally called blood
2. A contractile pumping device to propel the fluid around the body. This may either be a modified blood vessel or a heart
3. Tubes through which the fluid can circulate, called blood vessels.

Types of circulatory systems in the vertebrates and non-vertebrates

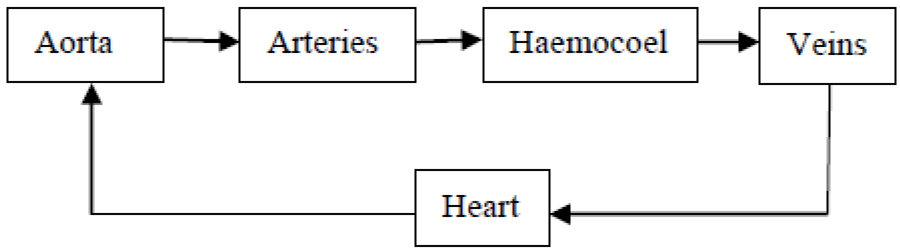
There are two types of vascular systems, the closed vascular system and the open vascular system.

1. The open vascular system

Blood flow occurs within the body spaces called haemocoel instead of blood vessels. This exists in most arthropods, molluscs and tunicates.

In this system, blood is pumped by the heart into an aorta which branches into a number of arteries which open into the haemocoel. From the haemocoel, blood under low pressure moves slowly to the tissues where there's exchange of materials for example, gases, nutrients among others.

From the haemocoel blood percolates back into the heart via the open-ended veins.



2. Closed vascular system

In a closed vascular system, blood flows in blood vessels or sinuses. It occurs in all vertebrates, annelids such as earthworms, cephalopods and echinoderms.

The distribution of blood in this system is therefore adjustable for example; blood from the heart is at high pressure and that to the heart is at low pressure.

Closed vascular systems are further divided into **single** and **double circulation**.

A. Single circulation

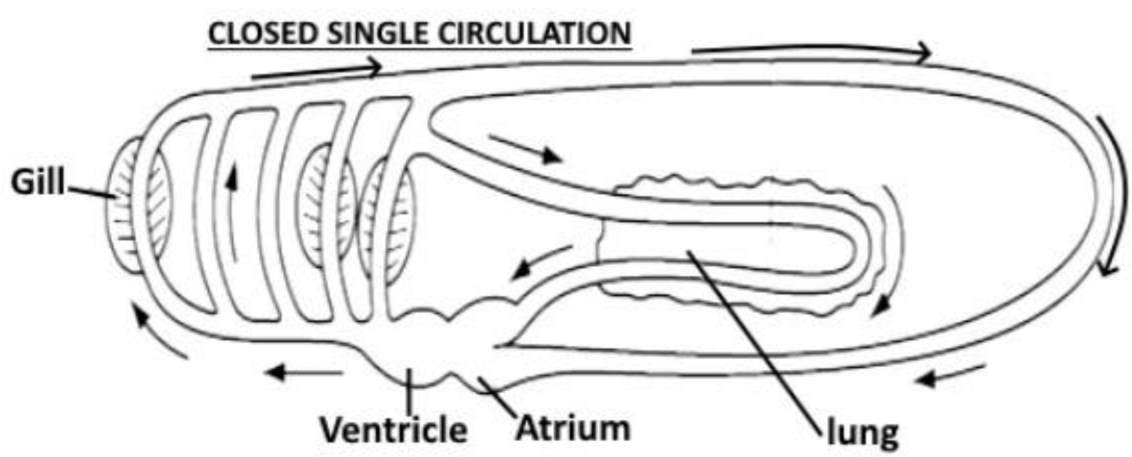
Single circulation is the flow of blood through the heart once for every complete circulation around the body.

Closed single circulation in fish

Fish consists of a two chambered heart.

The ventricle of the two chambered heart pumps deoxygenated blood to the gills where it becomes oxygenated. The oxygenated blood flows to the body tissues where it loses its oxygen.

Deoxygenated blood then flows from the body tissues back to the heart.



The problem of single circulation is that blood tends to move very slowly at the venous side due to the significant drop in pressure before completing the circulation. The drop in pressure is as a result of capillaries having a considerable resistance to blood flow (capillaries in the gills and body tissues).

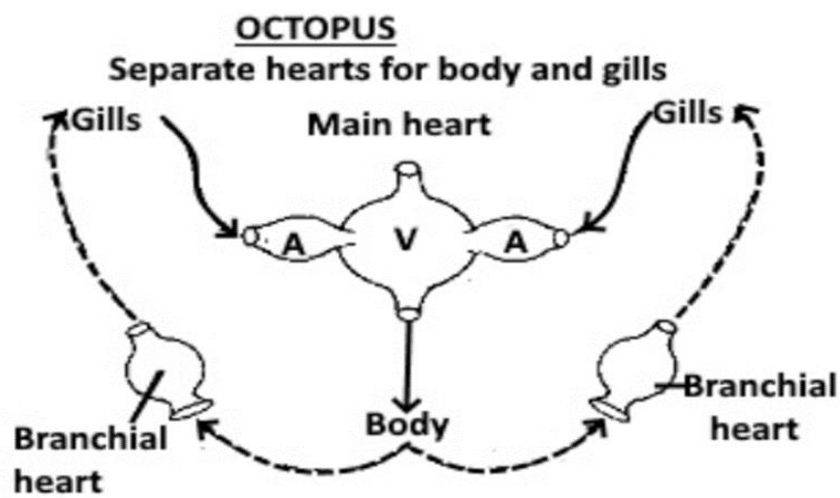
It also results into sluggish flow of blood in the veins which affects the distribution of oxygen and other metabolites to the tissues due to high resistance towards blood flow by the capillaries of the lungs and the body tissues.

Solution: The sluggishness of blood flow at the venous side is solved by replacing the veins with large sinuses

The closed single circulation in octopus and squids

Some organisms for example; the octopus and squids solve the problem of sluggish flow of blood of the venous side by possessing brachial hearts which pump deoxygenated blood from the body tissues of the gills and eventually back to the main heart.

The main heart pumps, oxygenated blood to body tissues from the gills.



B. Double circulation

Double circulation is the flow of blood through the heart twice for every complete circulation around the body.

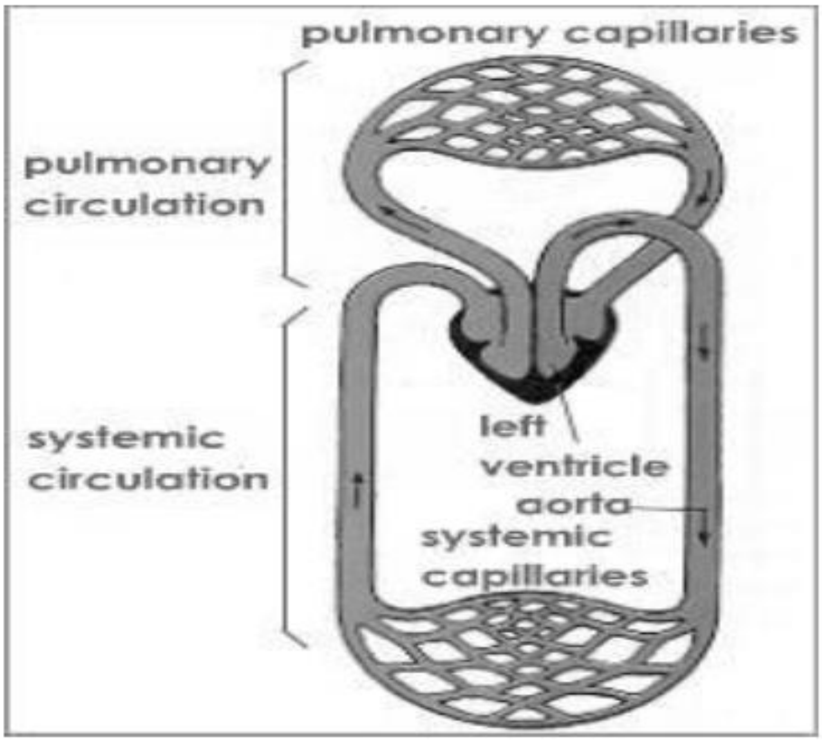
In double circulation deoxygenated blood from body tissues is pumped from the heart to the lungs from where it returns to the heart after being oxygenated and it is then re-pumped to the body tissues so as to supply oxygen to the body tissues.

A double circulation serves as one of the solutions towards the sluggish flow of blood at the venous side in single circulation

In double circulation, the heart must be divided into the left and right chambers to prevent oxygenated blood from mixing with deoxygenated blood.

Reptiles, birds and mammals have a four chambered heart made up of the right atrium and ventricle and the left and atrium and ventricle.

ILLUSTRATION

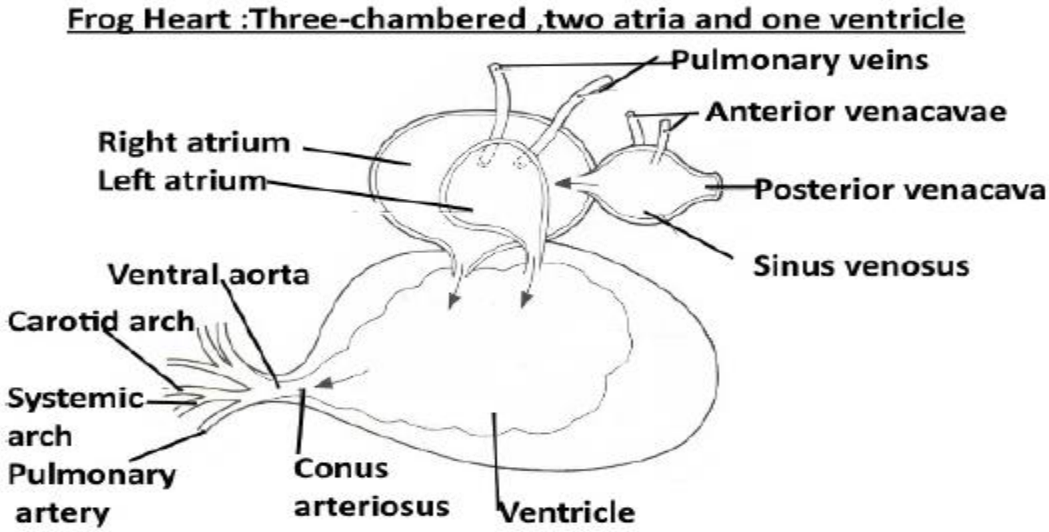


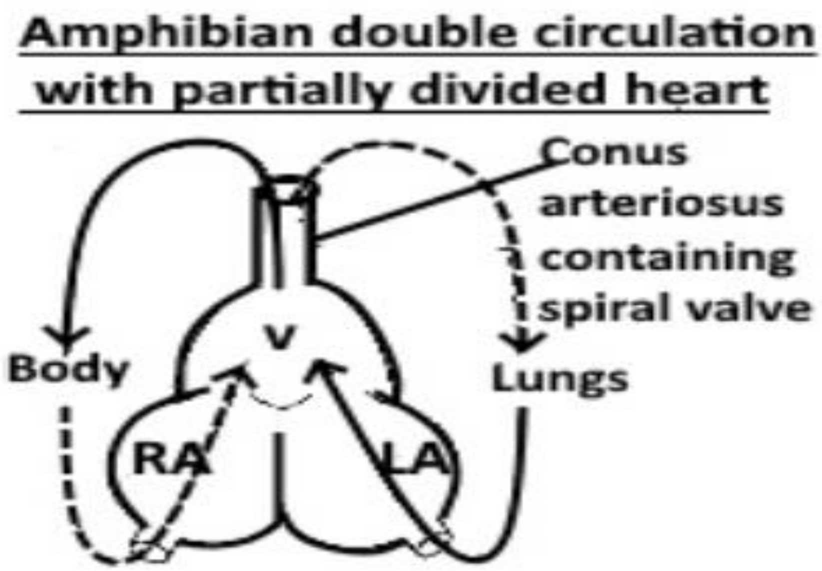
Amphibia (frog) (Incomplete double circulation)

The frog experiences double circulation although its heart has three chambers namely; one ventricle and the two atria (the left and right atria). Both deoxygenated and oxygenated blood in the frog flow through the same ventricle and conus arteriosus at the same time without mixing.

There is minimized mixing of oxygenated and deoxygenated blood.

This is achieved due to the folding in the walls of the ventricle which enhances the separation of deoxygenated blood from oxygenated blood and this separation is also facilitated by the spiral valves in the conus arteriosus.





Blood which has been oxygenated at the lungs is returned to the left atrium via the pulmonary vein while deoxygenated blood from the body is passed to the right atrium via the sinus venosus by the anterior and posterior venacava. However, both atria contract at the same time and deliver their blood to the single ventricle.

Both deoxygenated and oxygenated blood in the frog flow through the same ventricle and conus arteriosus at the same time without mixing.

This is achieved due to the inner surface of the dorsal and ventral walls of the **ventricle being built up into ridges which prevent mixing** of the blood to some extent and enhances the separation of deoxygenated blood from oxygenated blood.

When the blood passes from the ventricle to the conus arteriosus mixing is further **prevented by a spiral valve** which incompletely divides the conus into two distinct corridors.

The complete double closed circulation in mammals

Blood flows through a four chambered heart twice for each complete circuit of the body.

One circulation is between the heart and body organs except the lungs; called the systemic circulation, and the other circulation is between the heart and lungs called the pulmonary circulation

Pulmonary circulation

Involves flow of deoxygenated blood from the right ventricle pumped to the lungs through pulmonary artery via the open semi- lunar valves at a high pressure due to contraction of the walls of the right ventricle.

The blood is transported to the lungs to the where it picks oxygen and loses carbon dioxide.

The oxygenated blood flows from the lungs into the bicuspid valve of the left atrium and then into the left ventricle of the heart.

Oxygenated blood enters the left atrium due to decrease in its pressure due to relaxation of its cardiac muscles

Systemic circulation

Involves flow of oxygenated blood from the left atrium of the heart into the left ventricle and then pumped to the rest the body tissues via aorta and the return of deoxygenated blood from the body tissues back to the heart.

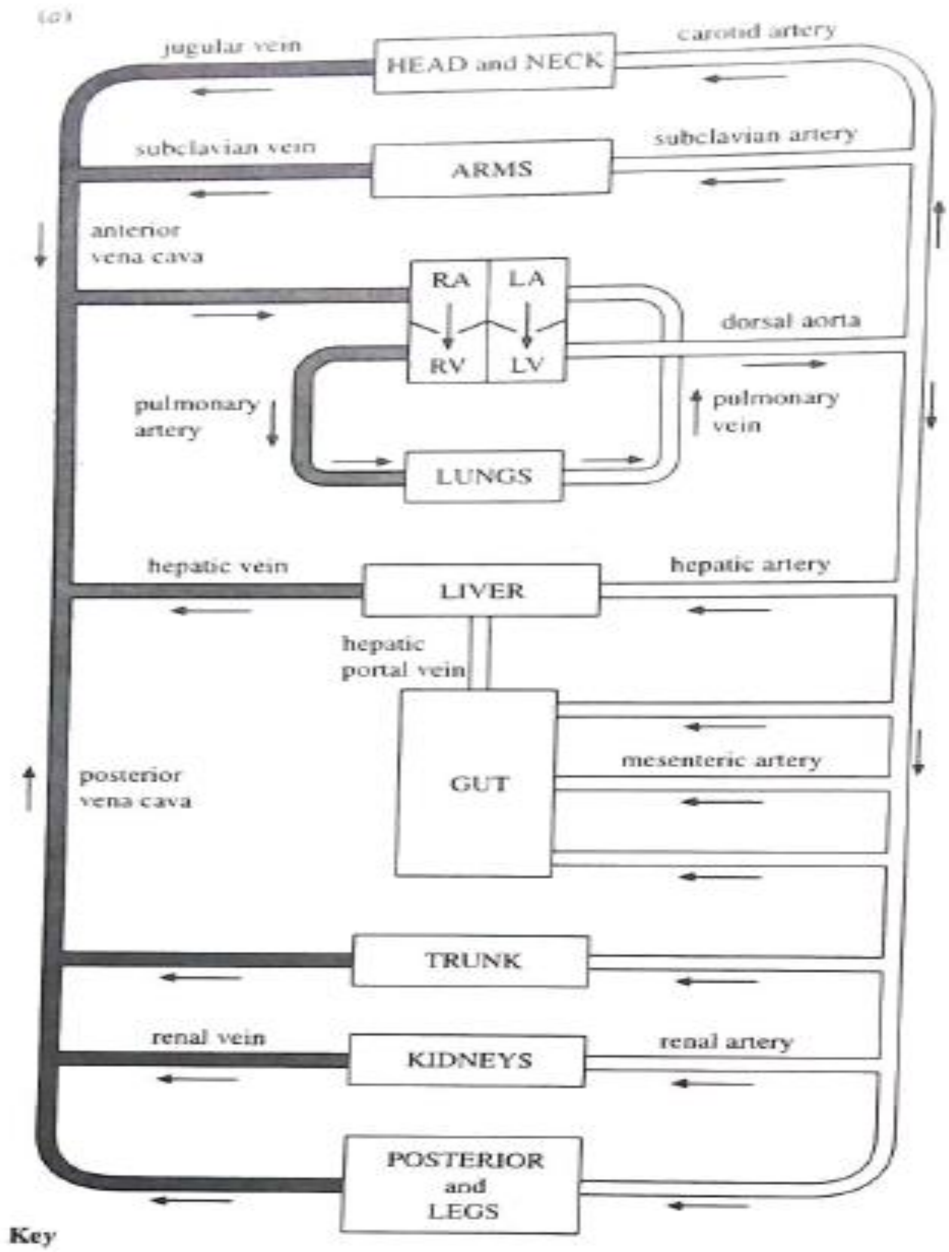
The walls of the left ventricle contract powerfully, thereby reducing the ventricular volume and increasing the ventricular pressure which forces the oxygenated blood to flow from the ventricle through the open aortic valves into aorta at a high pressure.

The aorta branches into arteries, the arteries into arterioles and the arterioles into a network of blood capillaries in the tissues where exchange of gases and materials occurs.

Finally, the deoxygenated blood from the tissues flows through venules and then to veins

The blood returns to the right atrium through the venacava

Illustration



MAMMALIAN BLOOD CIRCULATION

The mammalian blood circulation is a double blood circulation which is mainly based on the heart and blood vessels,

BLOOD VESSELS

There are three main types of blood vessels; arteries, veins and capillaries. The walls of these blood vessels occur in three layers, namely;

1. Tunica externa (outer most layer)

2. Tunica media (middle layer)

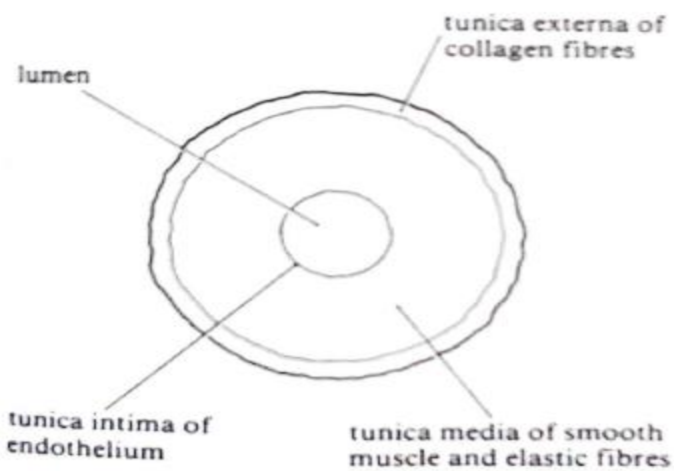
3. Tunica interna (inner most layer)

Tunica externa, this is the outermost layer which is tough and made up of thick collagen fibres which provide strength and prevents extensive stretching.

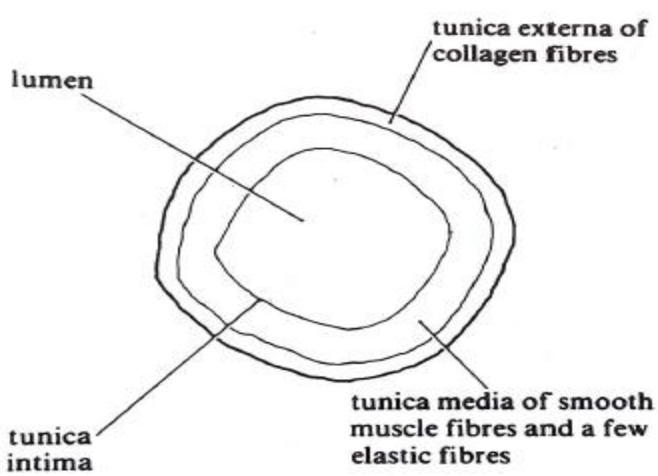
Tunica media is the middle layer which consists of smooth muscles, collagen and elastic fibres. The structural proteins allow for the stretching of the walls of blood vessels during Vaso-dilation. The smooth muscles allow for the distension and constriction of the walls of the blood vessels.

Tunica interna is the innermost layer composed of a single layer of squamous endothelium. It is found in all walls of blood vessels. Capillaries have only the tunica interna.

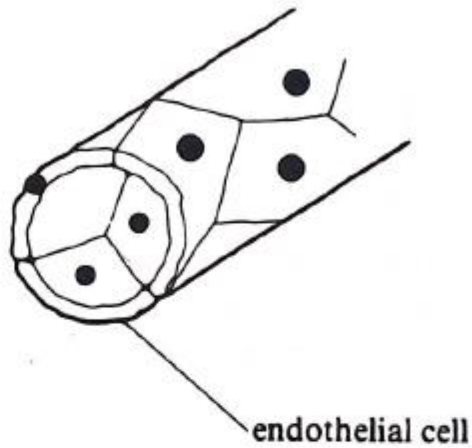
Artery



Vein



Capillary



Comparison between arteries and veins

Both tunica media and tunica externa are more developed in arteries than veins and therefore arteries have thicker walls than those of veins. Arteries have thicker walls than veins because blood flows through them at a higher pressure than in the veins, due to the pumping action of blood by the heart. Arteries therefore have thicker walls to counteract the pressure by which blood moves through them. The capillaries lack both the tunica externa and the tunica interna.

In addition, the walls of the arteries are more elastic than those of veins, in order to overcome the pressure by which blood flows through them by rapidly stretching without bursting.

Also, arteries have a narrower lumen than veins, which increases the pressure of the blood flowing through them.

Arteries also lack valves while veins have valves which prevent the backflow of blood in veins. However, arteries do not need valves since they transport blood under high pressure, which pressure ensures that blood flows forward.

Blood in arteries moves inform of pulses while in veins is flows smoothly without any pulse.

A pulse is a series of waves of dilation that pass along the arteries caused by the pressure of the blood pumped from the heart through contractions of the left ventricle.

Arteries transport oxygenated blood from the heart to the tissues except the pulmonary artery which transports deoxygenated blood from the heart to the lungs.

Veins transport deoxygenated blood from tissues to the heart except the pulmonary vein which transports oxygenated blood from the lungs to the heart.

Therefore, ***arteries*** can be defined as blood vessels which transport blood away from the heart and ***veins*** are defined as blood vessels which transport blood from the tissues to the heart.

Adaptations of arteries to their function

- Large arteries near the heart (aorta, subclavian and carotids) have thick muscular walls with much elastic tissue, enabling them to stretch (dilate) and not rapture when the heart contracts and forces blood into them at high pressure.
- Between heart beats the arteries undergo elastic recoil and contract smoothing out the flow of blood along their length.
- Smaller arteries further away from the heart are supplied with neurons from the sympathetic nervous system, where nervous stimulation regulates the diameter of these arteries and thus controls the flow of blood to different parts of the body.
- Arterioles possess circular muscle fibres called sphincters at the point where they enter the blood capillaries, and contraction of the sphincters prevents blood flowing into the blood capillary bed networks, enabling regulation of the quantity of blood flowing into blood capillary beds according to the needs of the body
  Note: Following contraction of sphincters the blood shortcuts from arterioles to venules through cross connections called shunt vessels
- The bases of the aorta and pulmonary artery contain semilunar valves which prevent back flow of blood into the heart.

VEINS

Veins transport blood towards the heart

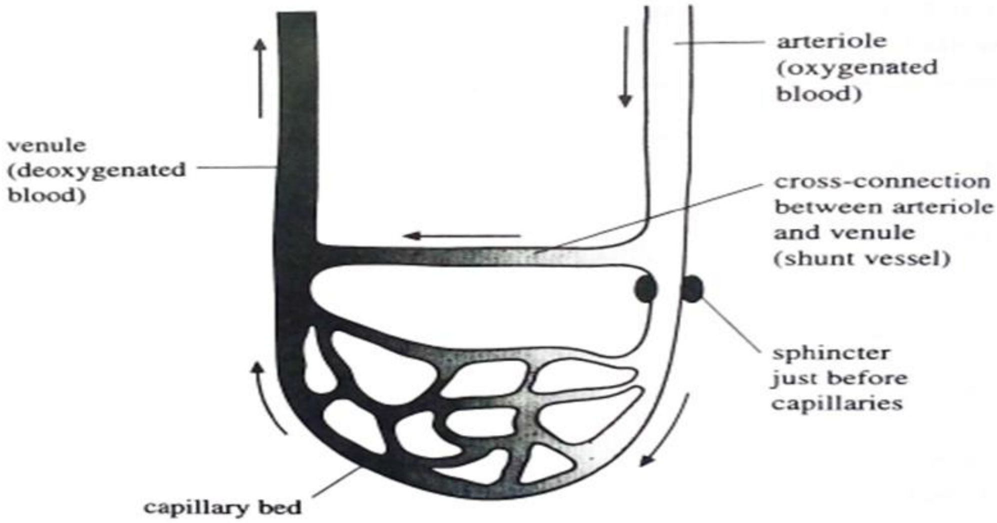
Adaptations of veins for their function

- Veins have a large lumen which provides enough space for the mass flow of large volumes of blood back to the heart.
- They have wide lumen to encourage flow of blood at low pressure.
- They have thinner walls than arteries which are adequate to withstand low pressure.
- They have valves at intervals along their length which prevent blood from flowing backwards / maintain flow of blood in one direction.
- Veins possess semilunar valves formed from folds of the inner walls of the veins, which prevent the back flow of blood, ensuring one-way flow of blood

Blood capillaries

Blood capillaries link arteries to veins and function as the site for the exchange of materials between blood and tissues.

Diagram showing the capillary network



Adaptations of blood capillaries

1. Blood capillaries are the smallest blood vessels found in close contact with tissues in form of a dense network which allows a high rate of diffusion of materials during their exchange between the blood circulatory system and the tissues.

2. They are numerous in number to provide a large surface area which increases the rate of diffusion and allows rapid exchange of materials between blood and the tissue fluid.

3. They have a thin and permeable membrane which is made up of thin flattened pavement cells which allow rapid diffusion and exchange of materials between blood and tissues with minimum resistance.

4. They possess the capillary sphincter muscles which contract and relax so as to regulate the amount of blood entering into the capillary network.

5. Some capillaries have a bypass arterio-venous shunt vessel which links the arterioles and venules directly so as to regulate the amount of blood which flows through the capillary network for example, in the capillaries of the feet, hands, stomach among others.

6. The capillary network offers maximum resistance to blood flowing through them hence decreasing the speed of blood flow which allows the maximum diffusion and exchange of materials between blood and the tissues.

REMAINING CONCEPTS (To be handled at school)

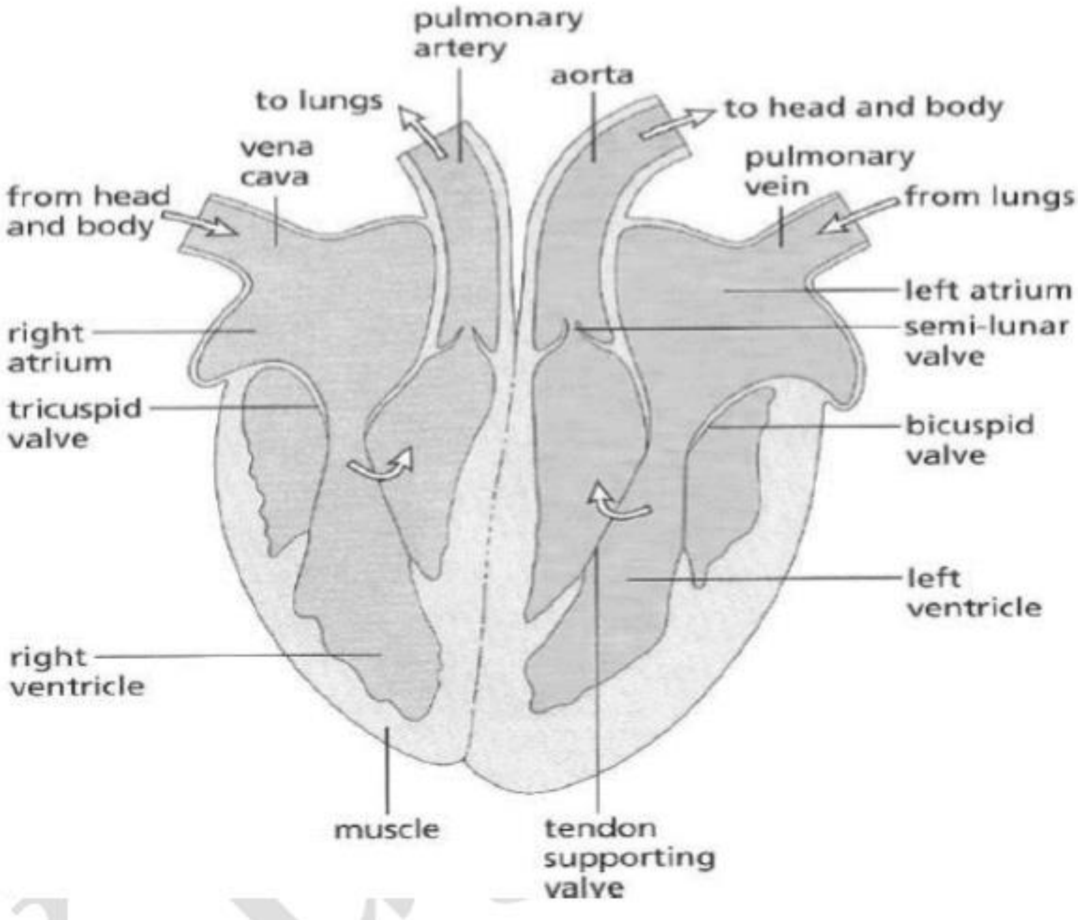
1. THE MAMMALIAN HEART
2. IMMUNITY (DEFENSE AGAINST DISEASES)

A BLESSED HOLIDAY TO YOU ALL

END

THE MAMMALIAN HEART

Structure of the mammalian heart



The heart is a muscular organ that pumps blood to all body organs using its chambers. It is made up of four chambers which include the right and left atria (auricles) and the right and left ventricles.

The four chambers enhance the blood flow through the heart at the same time without mixing it (deoxygenated blood is separated from oxygenated blood).

The oxygenated blood flows through the left atrium and ventricle while the deoxygenated blood flows through the right atrium and ventricle.

The heart is composed of the **cardiac muscles** within its walls which are **myogenic** in nature, in a way that, the initiation of their contraction is not under the control of the central nervous system but is within the muscles themselves. This enables them to contract continuously and rhythmically without fatigue and therefore enables the heart to beat and pump without stopping.

The heart consists of **atrioventricular** valves/ pocket valves and **semi lunar valves**. The atrioventricular valves include the following;

1. The three (3) flapped **tricuspid valves** found between the right atrium and the right ventricle
2. The two (2) flapped **bicuspid valves** which prevent back flow of blood from the left ventricle to the left ventricle.

The semi lunar valves are prevented from turning inside out by connective tissues called **tendinous chords**

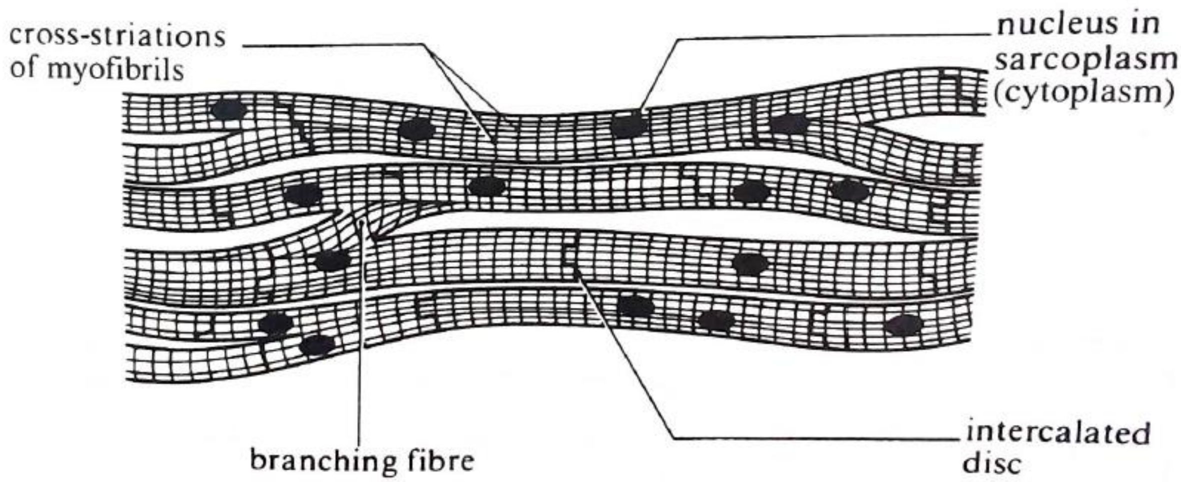
The heart linked with four blood vessels which include the following;

1. **The venacava** which transports deoxygenated blood from body tissues to the right atrium of the heart.
2. **The pulmonary artery** which transports deoxygenated blood from the right ventricle of the heart to the lungs.
3. **The pulmonary vein** which transports oxygenated blood from the lungs into the left atrium of the heart.
4. **The aorta** which is the biggest vessel and it transports oxygenated blood from the left ventricle of the heart to the body tissues.

The left ventricle is more muscular (thicker) than the right ventricle because the left ventricle has to contract more powerfully than the right ventricle in order to pump oxygenated blood with high pressure to move for a long distance to the body tissues.

The right ventricle pumps deoxygenated blood with low pressure for a short distance to the lungs.

Structure of the heart muscle (myocardium)



It consists of numerous muscle fibres called **myofibrils** with cross striated muscle cells called cardiomyocytes. The myofibrils contain actin and myosin filaments which bring about contraction.

Each muscle fibre possesses one or two large nuclei, surrounded by a sarcoplasmic reticulum.

It has dark bands known as **intercalated discs** which are cell surface membranes separating individual muscle cells.

The muscle cells have a cytoplasm containing numerous large mitochondria and glycogen granules.

The fibres branch and cross-connect with each other to form a complex net-like arrangement.

NB. Cardiac muscle is **myogenic** meaning its contractions develop within the muscle. The rate of contraction can be influenced by the autonomic nervous system

Adaptations of the cardiac muscle to its function

- Cardiac muscle cells are highly branched terminally and connected to each other by intercalated discs to form a network that allows rapid spread of waves of electrical excitation from cell to cell, so that linked cells contract rhythmically and simultaneously for fast heartbeat.

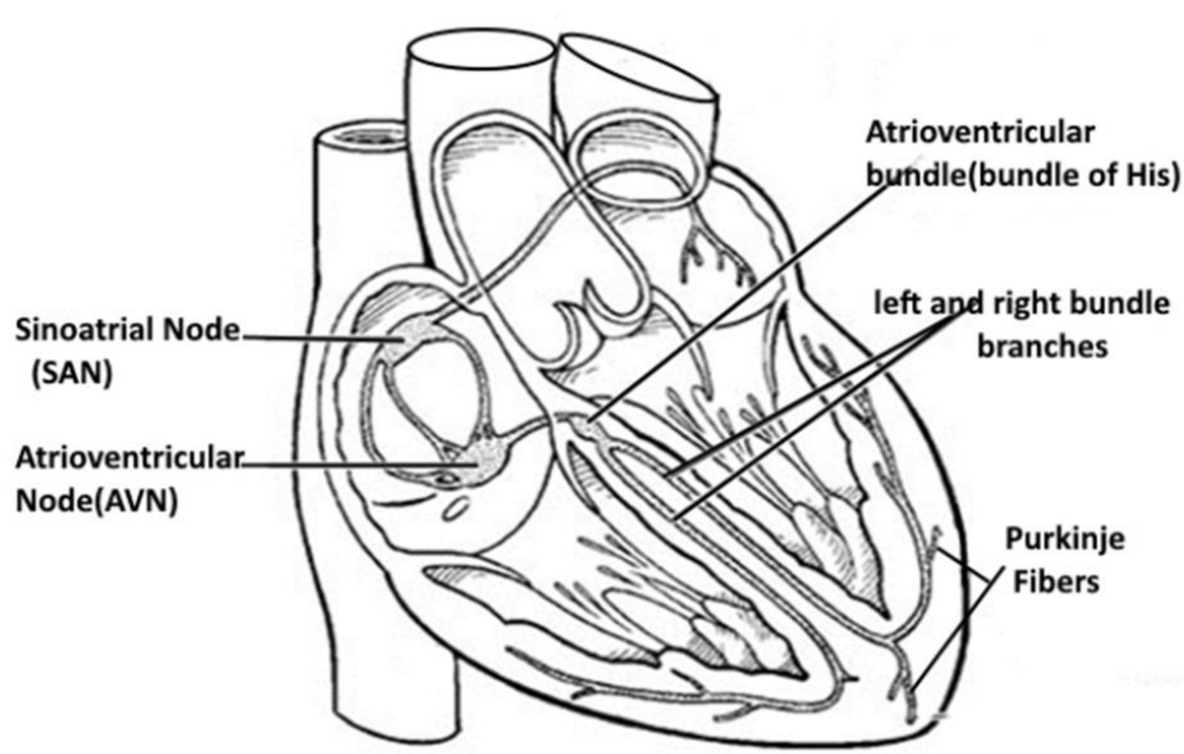
- It has a dense supply of blood capillaries which ensures adequate supply of oxygen and nutrients for fast production of adequate ATP, for continuous rapid muscle contraction, and rapid excretion of carbon dioxide and other metabolic wastes

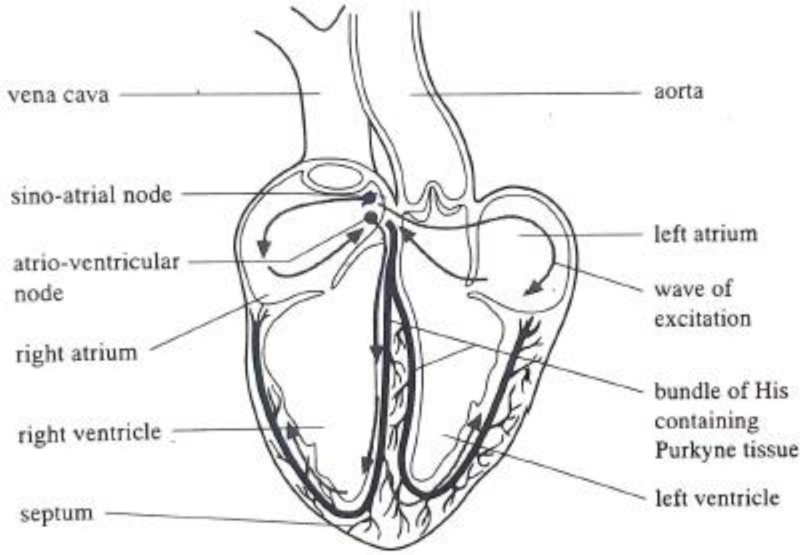
- It has numerous large mitochondria and glycogen granules to rapidly provide adequate energy in form of ATP by aerobic respiration, for continuous rapid contraction without fatigue

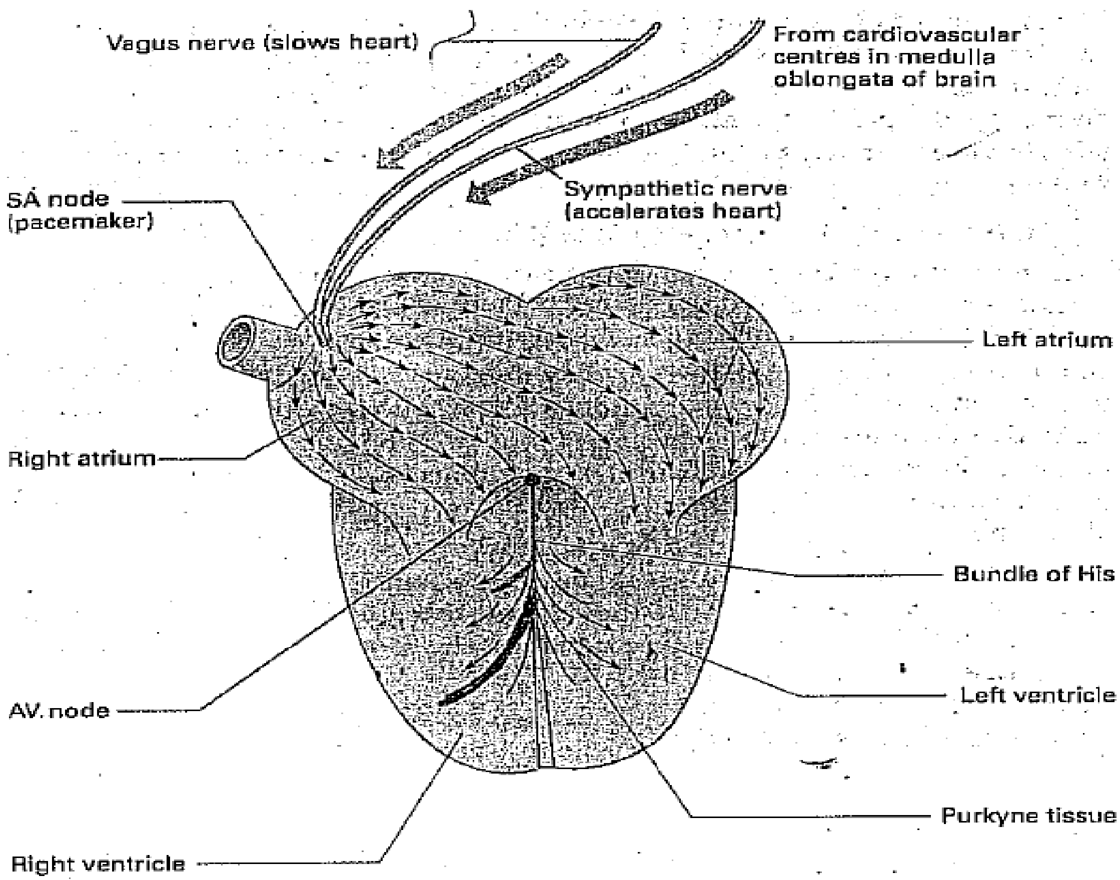
- It has the Sino-atrio node (SAN) which emits waves of electrical excitation that initiate continuous and rhythmic contraction without fatigue for continuous heartbeat

- It has cross striations for mechanical strength to support its fast and continuous contractions
- It undergoes rapid rhythmic contractions and relaxations with long refractory period, and thus does not fatigue as contraction is not sustained.
- It has well-developed T-system for rapid transmission of impulses; thus, rapid contraction and relaxation
- It has branched muscle fibres to offer a large surface area for fast spread of waves of electrical excitation, for continuous contraction hence continuous heartbeat

Initiation of the heart beat (Myogenic stimulation of the heart beat)







The cardiac muscle is **myogenic** in nature in a way that the initiation of its contraction is within the muscle itself, but not under the control of the central nervous system (brain and spinal cord).

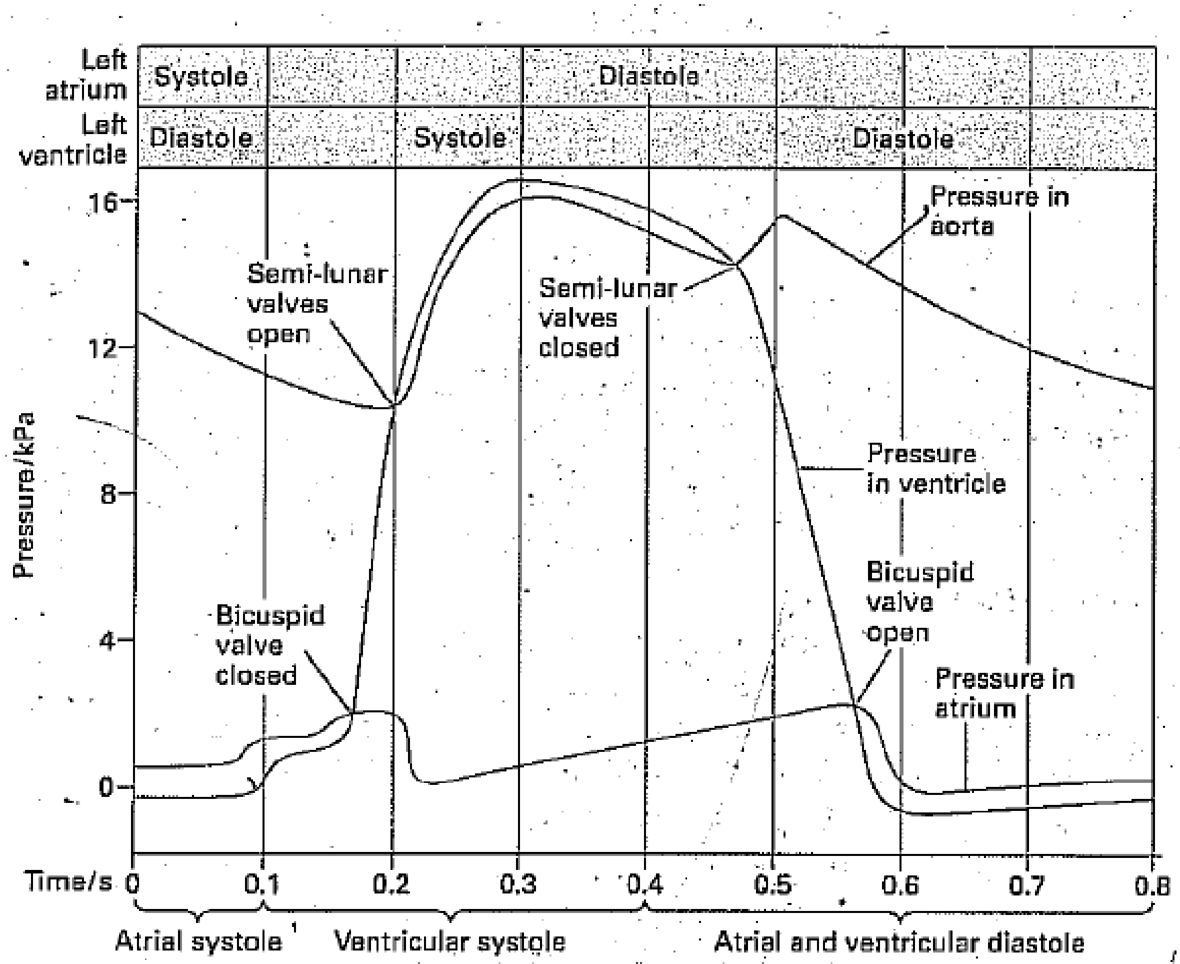
This enables the muscle to contract continuously and rhythmically without fatigue to enable the heart to beat continuously and rhythmically without stopping.

The intrinsic initiation of the heart beat enables the heart to remain beating even when it is surgically removed from the body, provided it is under ideal conditions.

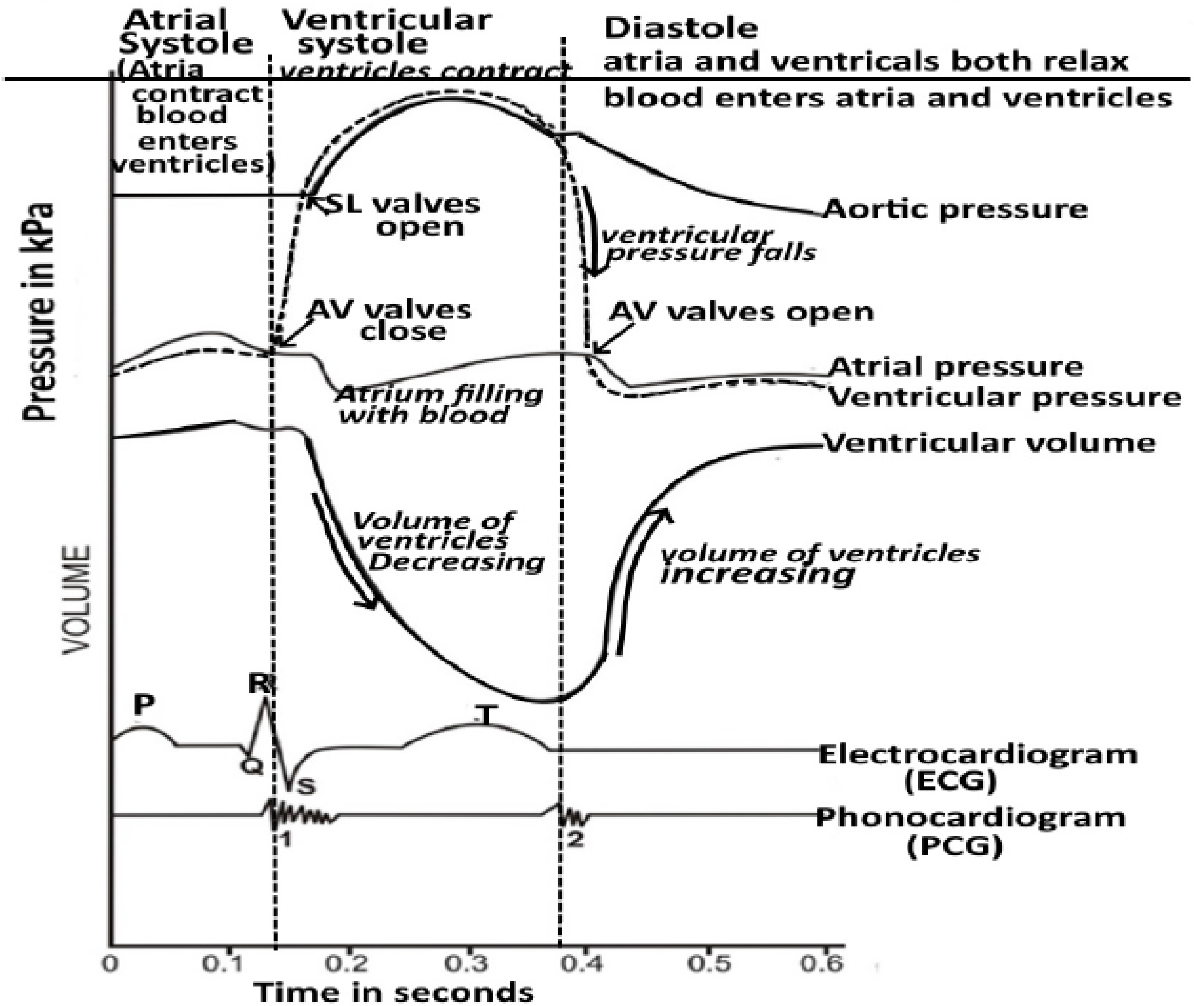
The rhythmic contraction of the cardiac muscles is initiated by a specialized network of fine cardiac muscles found inside the wall of the right atrium close to the entrance of blood from venacava into the right atrium. This network of fine cardiac muscle fibre is known as **Sino Atrial Node (SAN)** and it serves as **a pace maker**
The SAN is called a pace maker because it determines the rate of contraction of the rest of the cardiac muscle.
The **SAN** generates waves of electrical impulses called cardiac impulses over the atria. The impulses spread out very rapidly over both atria causing them to contract and force blood into the ventricles via the open atrial ventricular valves.

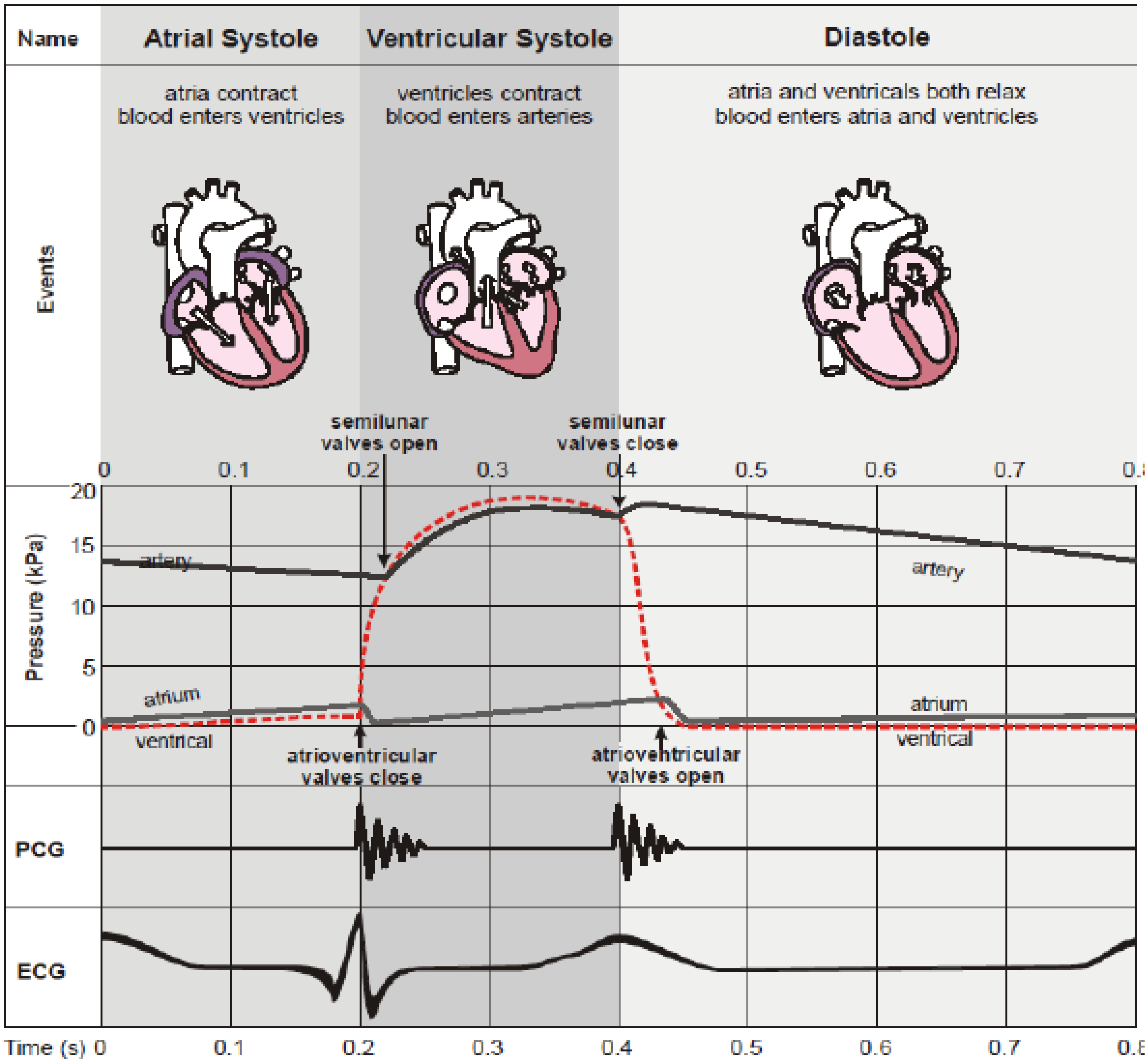
When the electrical excitations reach the junction at the boundary of the atria, they excite another specialised plexus of other cardiac muscle chambers known as **Atrio Ventricular Node (AVN)**.
When excited, the AVN sends waves of electrical excitations down to another bundle of cardiac muscle fibres formed along the inter-ventricular septum called the Purkinje tissue (Purkyne tissue) or Bundle of His to the apex of the heart.
This conducts and spreads the excitement to both ventricles which eventually pump blood into the arteries.

The cardiac cycle (Sequence of the heart beat)


Left atrium
Systole
Diastole
Left ventricle
Diastole
Systole
Diastole
Pressure/kPa
16
12
8
4
0
Semi-lunar valves open
Semi-lunar valves closed
Pressure in aorta
Pressure in ventricle
Bicuspid valve closed
Bicuspid valve open
Pressure in atrium
Time/s 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
Atrial systole
Ventricular systole
Atrial and ventricular diastole

Graphs illustrating the pressure and volume changes that occur during the mammalian cardiac cycle (dog)





The cardiac cycle:
This is the sequence of events of heart beat by which blood is pumped around the body.

The pumping action of the heart consists of alternate contractions of heart muscles (cardiac muscles) called **systoles** and relaxations called **diastoles**.

Cardiac output refers to the volume of blood pumped from each ventricle.

The cardiac cycle begins with the contractions of the atria (**atrial systole),** which is initiated by SA node that causes the atria volume to decrease and the atria pressure increase. As the atria contract, the ventricles relax **(undergo ventricular diastole)**.
The contraction of the atria forces the bicuspid and tricuspid valves to open so that blood moves from atria into the ventricles.

Contraction of atria walls has an effect of sealing off the venacava and pulmonary veins, thereby preventing the back flow of blood into the vessels as the blood pressure rises within the atria. It takes 0.1 seconds.

When the ventricles are filled with blood from atria, their walls contract simultaneously (**ventricular systole)**, and the atria relax (**atrial diastole).** Ventricular systole is initiated by impulses from **AV node** to the **bundle of His**/**Purkinje fibres** and rapidly through the ventricle muscles.

The volume of the ventricles reduces while the pressure increases, forcing the bicuspid and tricuspid valves to close and prevent the back flow of blood into the atria.

The increased pressure in the ventricles also forces blood to be pumped into the pulmonary artery and aorta via the open semi lunar valves from the ventricles. This enables the blood to be pumped into the lungs via the pulmonary artery and into the body tissue via the aorta.

The ventricular systole is more powerful than the atrial systole because the ventricles are more muscular than the atria and therefore generate more pressure. The powerful ventricular systole forces blood into the aorta and pulmonary artery.

After ventricular systole, there's a short period of simultaneous atrial and ventricular relaxations. In the **ventricular diastole**, the high pressure developed in the ventricles causing a slight back flow of blood which closes the semi lunar valves, thereby reducing blood back flow.

Relaxation of the atrial wall and contraction of the ventricle, initiates the refilling of the atria by blood under relatively low pressure. Deoxygenated blood in the venacava flows into the right atrium and oxygenated blood from the lungs flows into the left atrium via the pulmonary vein.

NOTE;

- The closing of the atrioventricular valves during ventricular systole produces the first heart sound, described as ***lub.***
- The closing of the semi lunar valves causes the second heart sound, described as ***dub.***
- The pulse in the arteries is due to ventricular systole and elastic recoil of the arteries due to high pressure of blood.
- The pulse is more pronounced in the arteries

The **PCG** (phonocardiogram) is a recording of the sound the heart makes.
The cardiac muscle itself is silent and the sounds are made by the valves when closing.

- The closing of the atrioventricular valves during ventricular systole produces the first heart sound, described as ***lub.***

- The closing of the semi lunar valves causes the second heart sound, described as ***dub.***

The **ECG** (electrocardiogram) is a recording of the electrical activity of the heart. Atypical **ECG** consists of characteristic waves of electrical activity which correspond to particular events in the cardiac cycle.
If a disease disrupts the heart's conduction system, the ECG is changed. Changes in these ECG waves are therefore used to diagnose cardiovascular diseases.

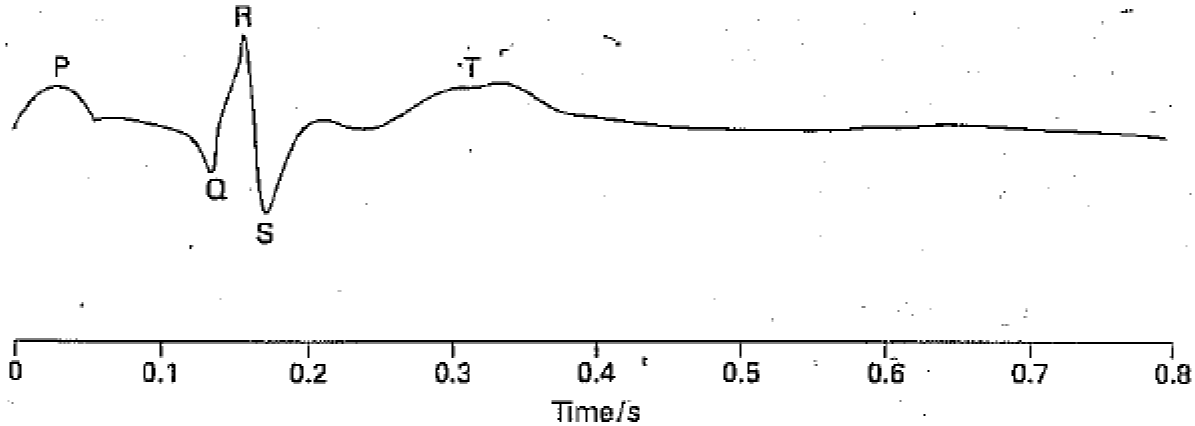


***Figure 3** An electrocardiogram (ECG) shows the electrical activity in the heart. This trace shows a single cardiac cycle in a healthy heart.*

The P wave is caused by atrial systole
The QRS wave is caused by ventricular systole
The T wave coincides with ventricular diastole
The heart rate can be calculated from the interval between one P wave and the next.

Characteristics of the cardiac muscle in relation to excitation and contraction

- The absolute relative refractory period is longer than that of other muscles (the heart cannot be fatigued easily)
- The generation of the wave from the SAN has a refractory period between contraction of the heart and relaxation of the heart (the waves are not generated continuously).

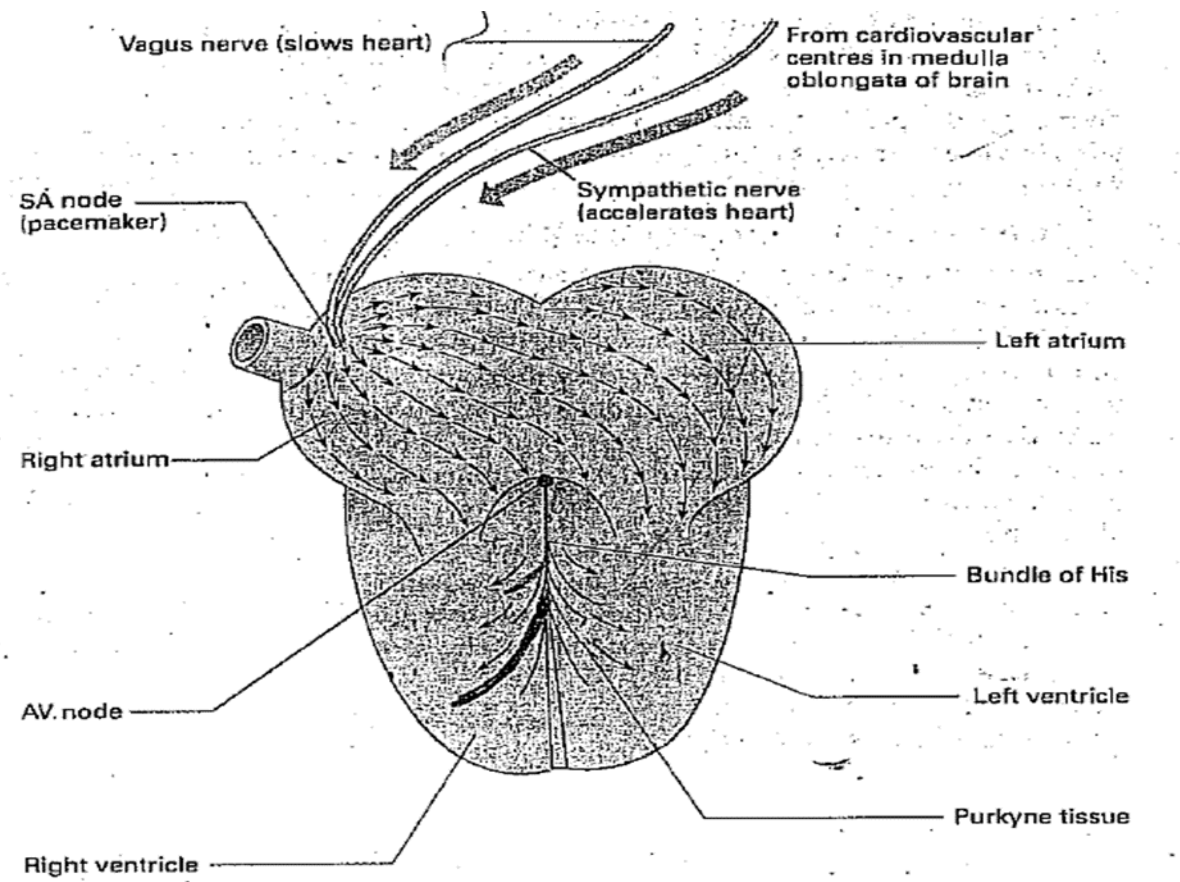
Control of the rate of the heart beat

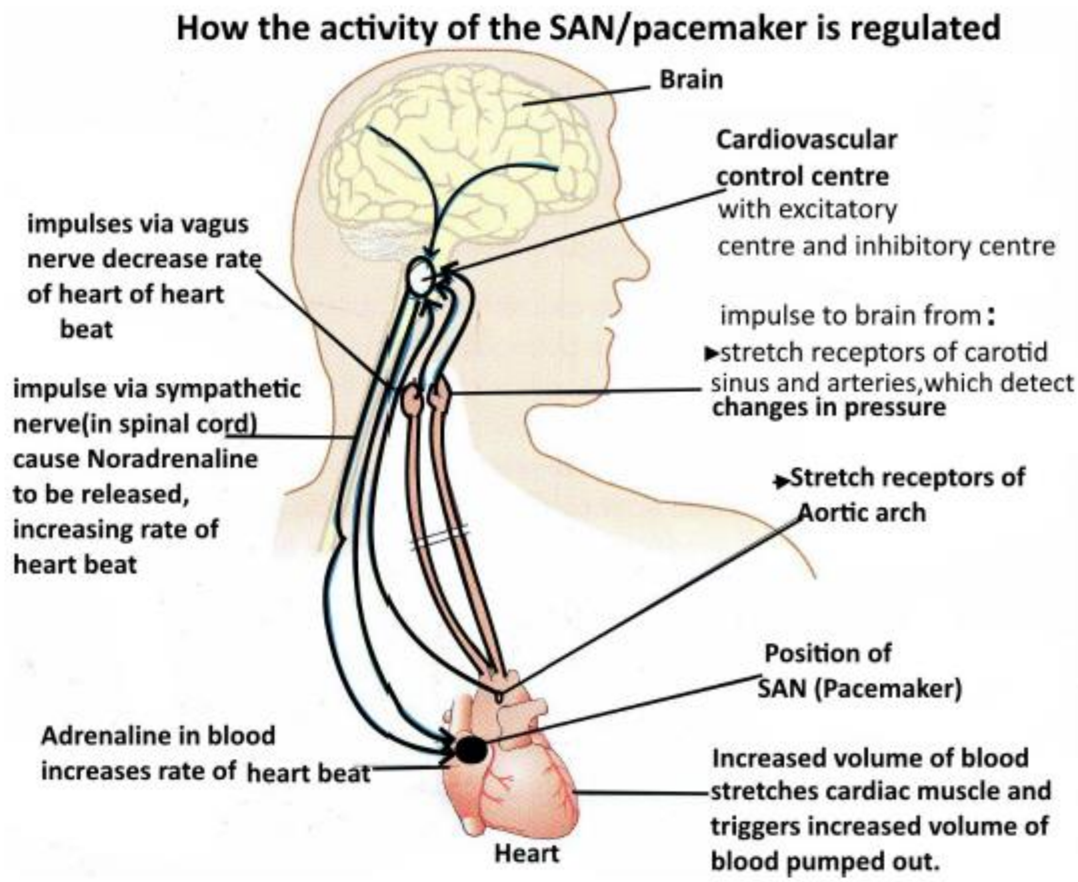
Though the initiation of the contraction of cardiac muscle (initiation of heart beat) is not under the control of the central nervous system, the rate at which the heart beats to pump blood is under the control of the autonomic (Involuntary) nervous system.

The heart is innervated (supplied with nerves) by the sympathetic nerve from the sympathetic autonomic nervous system and by the vagus nerve, a branch of a parasympathetic autonomic nervous system.

The nerves modify the rate at which the pace maker gives waves of electrical excitations hence controlling the speeding up or slowing down of the rate of the rate of heart beat.

When the rate of heart beat increases beyond the normal rate, the vagus nerve (parasympathetic nerve) is stimulated such that it lowers back to normal the rate of heart beat.
When the rate of the heart beat lowers below the normal rate or if there’s need for higher rate of heart beat the sympathetic nerve is stimulated to bring back or increase to the cardiac frequency usually to the normal rate. Therefore, the sympathetic and vagus nerves are antagonistic, functionally.





NOTE;

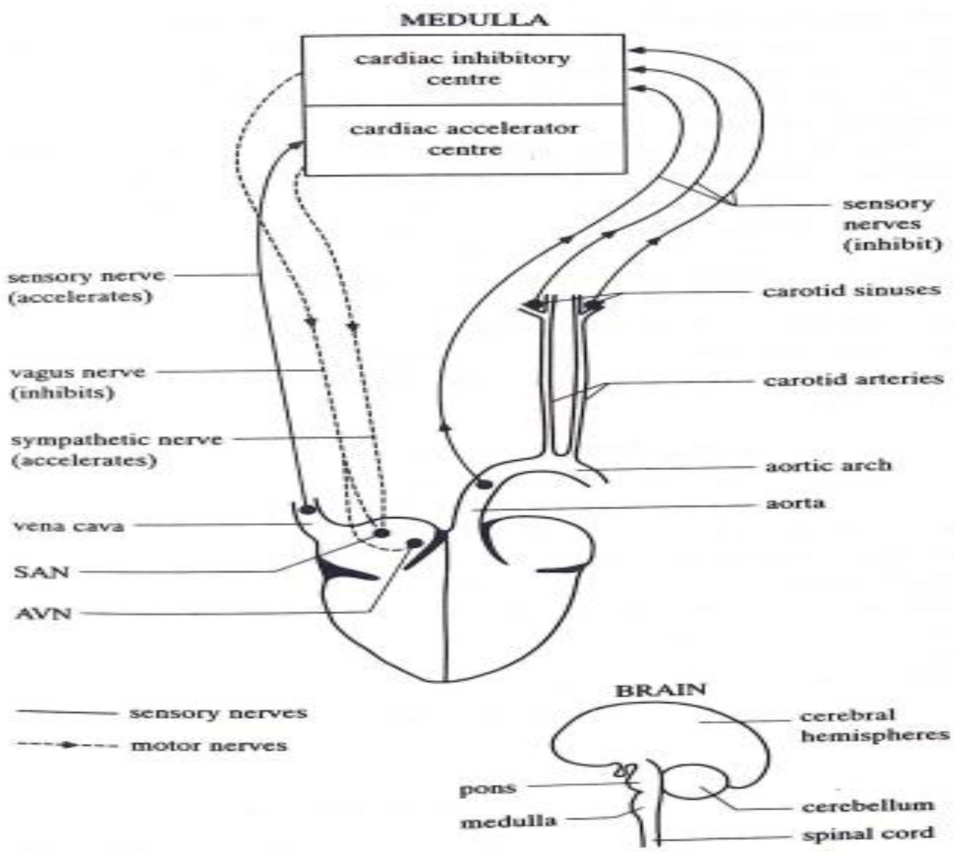
Cardiac output (volume of blood going out of the heart) = **Rate of heart beat X Cardiac frequency**

Internal factors affecting the heart beat

1. Body temperature
2. Blood pH
3. Carbon dioxide concentration
4. Partial pressure of oxygen
5. Hormonal balance
6. Salt balance
7. Blood pressure
8. Emotional situations

9. Impulses from the venacava and aorta

Effect of carbon dioxide concentration on the heart beat



Increased muscular activity increases carbon dioxide concentration, lowering pH below the norm.

This stimulates the chemoreceptors in the carotid artery and aorta, sending sensory impulses to the cardiac accelerator Centre in the medulla.

The cardiac accelerator centre sends motor impulses via the sympathetic nerve of the sympathetic nervous system which releases noradrenaline at the neuromuscular junction with the SAN, increasing the rate at which it emits waves of electrical excitations, increasing the rate of the contraction of the cardiac muscles of heart.

This increases cardiac output, blood pressure and speed of blood flow to the muscle with excess carbon dioxide to remove it away from the muscles to the lungs.

Decreased carbon dioxide tension, raises PH above the norm, stimulating chemoreceptors in the carotid body and aortic body, sending sensory impulses to the cardiac inhibitory center in the medulla.

The cardiac inhibitory center sends motor impulses via the vagus nerves of the parasympathetic nervous system which releases acetylcholine at the neuromuscular junctions with the SAN, AVN, and bundle of His.
This reduces the rate of electrical excitation emission by SAN, thereby reducing the rate of cardiac muscle contraction hence reducing the rate of heart beat.

Hormonal control of the heart rate
A number of hormones affect the heart rate directly or indirectly

Adrenaline
The cerebral cortex fires impulses to the cardiac acceleratory Centre of medulla oblongata which fires impulses along the sympathetic nerves to the adrenal medulla.

Adrenal medulla secretes adrenaline and noradrenaline into the blood stream which stimulate the SAN to increase the rate at which waves of electrical excitation are emitted to the cardiac muscle hence increase in the heart rate.

Both hormones stimulate the heart, although adrenaline is more effective. Cardiac output and blood pressure are increased by increasing the rate.

The two hormones also have effects on the body which prepare the body for action (‘flight and fight” response)

Thyroxine

Thyroxine is produced by the thyroid gland and it raises basal metabolic rate.

Thyroxine can directly increase the heart rate by stimulating the SAN to increase on the rate at which it emits waves of electrical excitations to the cardiac muscle hence increasing the rate of heart beat.

Indirectly, it increasing the basal metabolic rate, which increases the breakdown of glucose to form energy. Thereby increasing the oxygen demand by the muscles which stimulates an increase in the rate of heart beat.

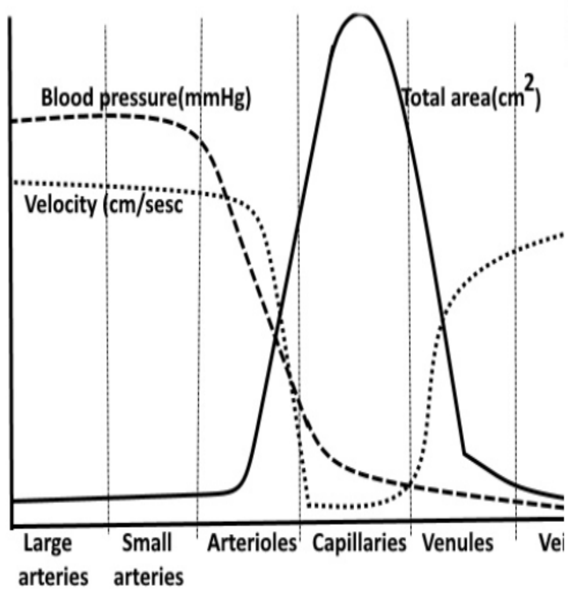
BLOOD PRESSURE

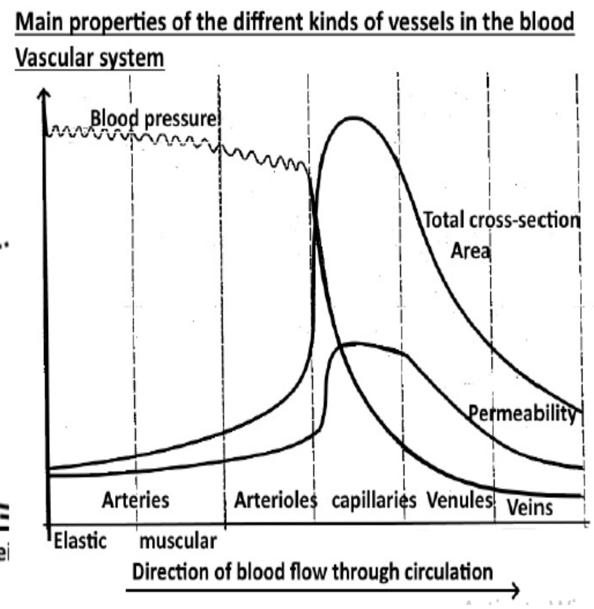
This is the force developed by blood against the walls of blood vessels mainly due to pumping action of blood by the heart.
OR.

Blood pressure is the force developed by blood against the Walls of blood vessels during contraction and relaxation of the ventricles.

The force exerted against the elastic wall of an artery stretches the wall, and the recoil of the arterial wall plays a critical role in maintaining blood pressure, and hence blood flow, throughout the cardiac cycle.
The numerous arterioles and capillaries resist blood flow hence reducing the blood pressure.

Ventricular systole causes a blood pressure of 120 mmHg
Ventricular diastole causes a blood pressure of 80 mmHg





Control of blood pressure

Blood pressure is controlled via control of heart rate and cardiac output together with the control of peripheral resistance towards blood flow by the blood vessels, mainly the arteries.
When the arterioles constrict, there is increased resistance towards blood flow which results into increase in blood pressure.

When the arterioles undergo vasodilation, the resistance towards blood flow reduces which in turn reduces blood pressure.

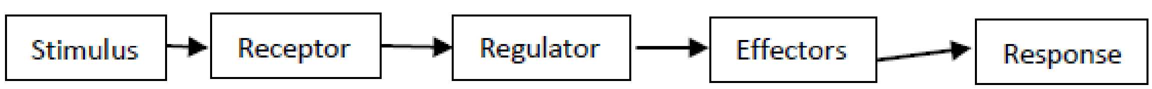
Small receptors which are sensitive to stretching, called **baro receptors** found in the walls of aortic arc, carotid sinuses, vena cava and the right atrium become stimulated when blood pressure increases above the norm.

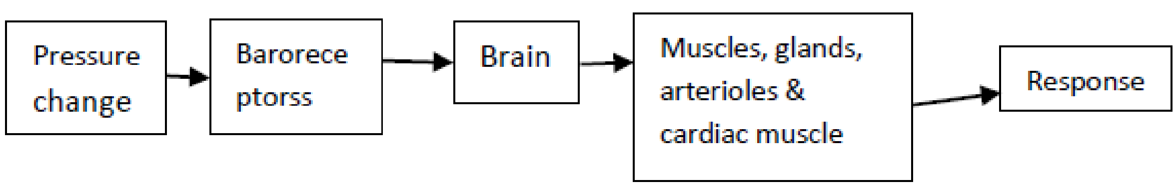
They fire impulses to the vasomotor centre and cardio vascular centre found in the medulla oblongata of the brain via the sympathetic nerves.
The cardio vascular centre sends impulses to the heart via the vagus nerves, which results into reduction of the cardiac output.

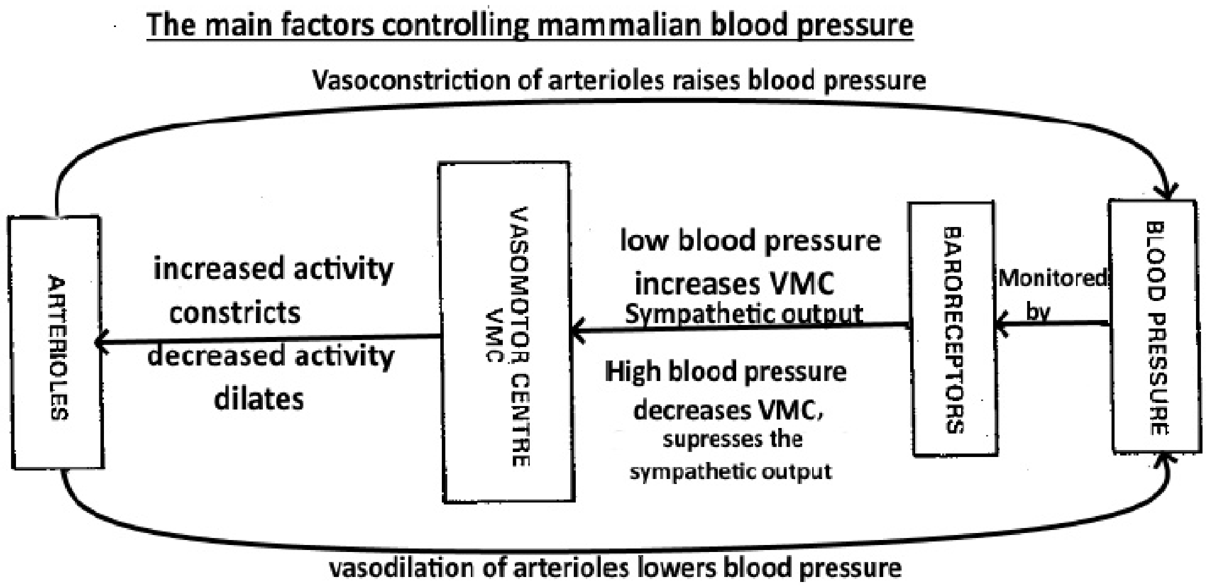
The vasomotor centre on receiving impulses, its sympathetic output is suppressed and this lowers the blood pressure by causing vasodilation of the arterioles

When the blood pressure lowers below the norm, the baro receptors stop being stimulated and this leads to impulses being fired from the cardio vascular centre to heart. The cardiac output is then increased.
Decrease in blood pressure also increases the vasomotor centre sympathetic output which results into vasoconstriction of the arterioles hence increasing the blood pressure back to normal.

NOTE: When the arterioles constrict (vasoconstriction) blood pressure is raised and when they dilate (expand) the blood pressure decreases.







The brain includes the vasomotor, cardiovascular centre and the medulla oblongata

Note: - Blood pressure depends on the following factors;

- Blood volume
- Force of the heart
- Blood vessel radius/ diameter of the lumen

Blood volume is adjusted to some extent through contraction of the spleen and liver which bring stored blood into circulation. The stored blood is due to the regulation of the fluid intake and fluid loss by organs such as the kidney and the skin during homeostasis.

Blood vessels offer resistance (**R**) to blood flow. The resistance is inversely proportional to the fourth power of the radius (r) of the vessel ($R \propto \frac{1}{r^4}$).

Therefore, the resistance increases as the vessel becomes narrower and since we are dealing with the fourth power of the radius, small changes in the arterioles radius will make a large difference to the resistance.

NOTE:

Blood is expelled from the heart only when it contracts. Blood flow through the arteries is therefore *intermittent,* the blood flowing rapidly during systole and slowly during diastole. However, by the time the blood reaches the capillaries it is flowing evenly. The gradual change from intermittent to even flow is made possible by the elasticity of the of the arterial walls which contain elastic tissue and smooth muscles

DEFENCE AGAINST DISEASES

Instruction: ***Copy all the notes in your own handwriting and read/discuss them. We will only discuss the major concepts when we report back to school.***

Every mammal is equipped with a complex system of defensive mechanisms which are designed to enable it prevent the entry of microbes into it, to withstand attacks by pathogens and to remove foreign materials from the system.

Immunity is the ability of an organism to resist infection or to counter the harmful effects of toxins produced by infecting organisms.

The defensive mechanisms of blood include the following;

1. Clotting of blood
2. Phagocytosis
3. Immune response to infection

BLOOD CLOTTING PROCESS

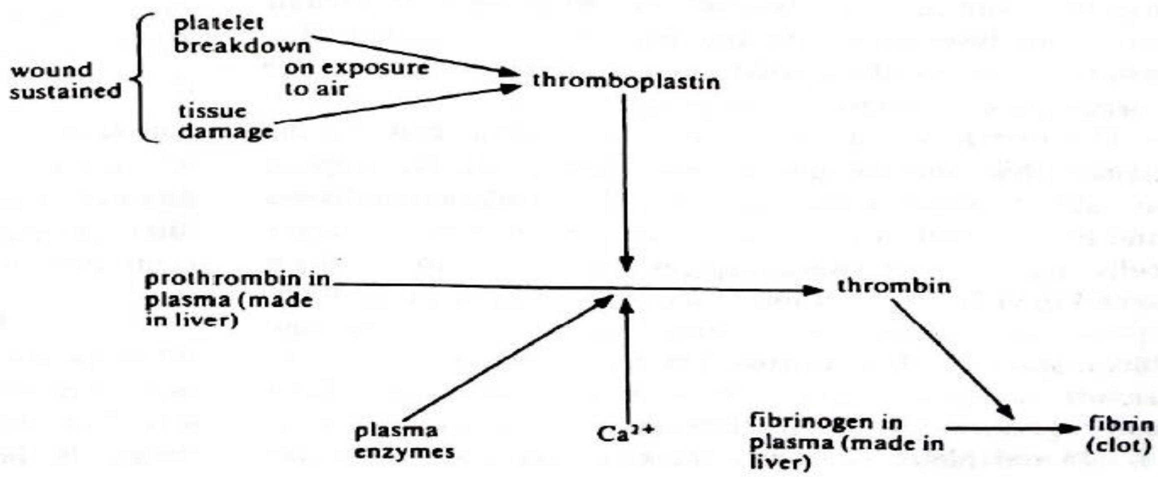
When blood platelets and damaged tissues are exposed to air, the **platelets** rupture and release an enzyme called t**hromboplastin,** which in presence of calcium ions and vitamin K Cause the inactive plasma protein, **prothrombin** to become converted to its active form **thrombin.**

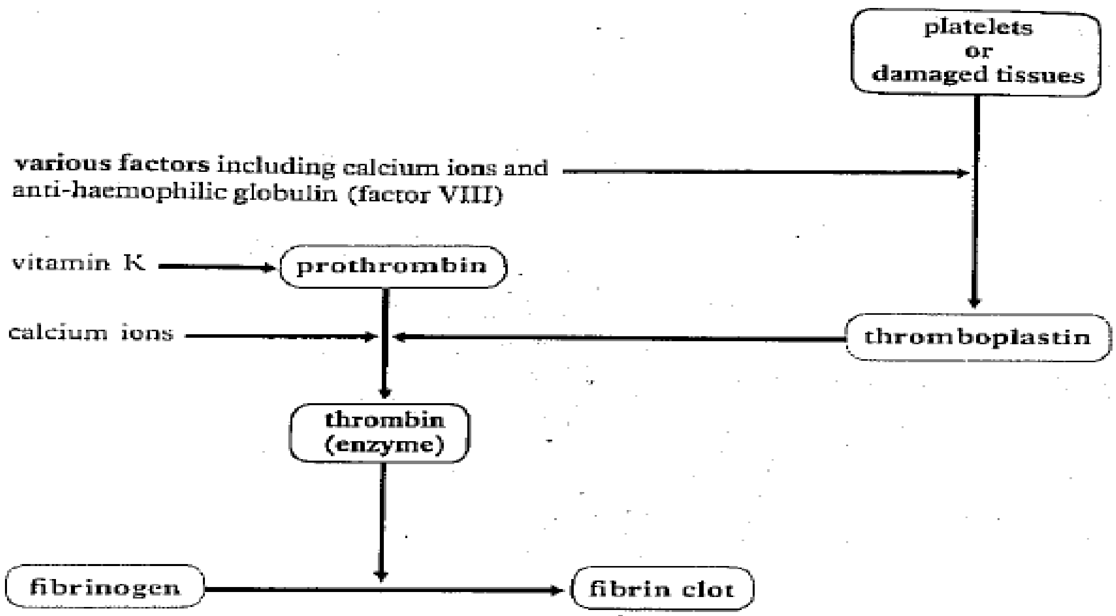
Thrombin is a proteolytic enzyme that hydrolyses another soluble plasma protein called **fibrinogen** into an insoluble protein called **Fibrin** which forms a meshwork of threads/fibers at the wounded area.

Within the fibrous network of fibrin blood cells become trapped, thereby forming a fibrin clot or a blood clot. These dry o form a clot beneath which repair of the wound takes place.

The clot not only prevents further blood loss, but also prevents the entry of bacteria and other microbes which might otherwise cause infection.

NB. The platelets when raptured attract clotting factors which create a cascade effect whereby each activates the next in the chain. Amongst these factors is factor VIII the absence of which, due to a sex linked genetic defect, is the cause of **haemophilia.** At the end of these chain reactions, factor X is produced which in presence of calcium ions and vitamin K cause the inactive plasma protein, **prothrombin** to become converted to its active form **thrombin.**





Note:

a) **Heparin** is an anticoagulant which inhibits the conversion of prothrombin to thrombin thereby preventing blood clotting.

b) Apart from blood clotting, the entry of microbes into the body can be prevented by the following;

- Using impermeable skin and its protective fluid called sebum (oily secretion in the skin)
- Using mucus and cilia to trap the microbes and then remove them
- By using hydrochloric acid in the stomach
- By using lysozyme enzyme in the tears and nasal fluids
- By vomiting and sneezing

NB Blood does not clot in the vessels because;

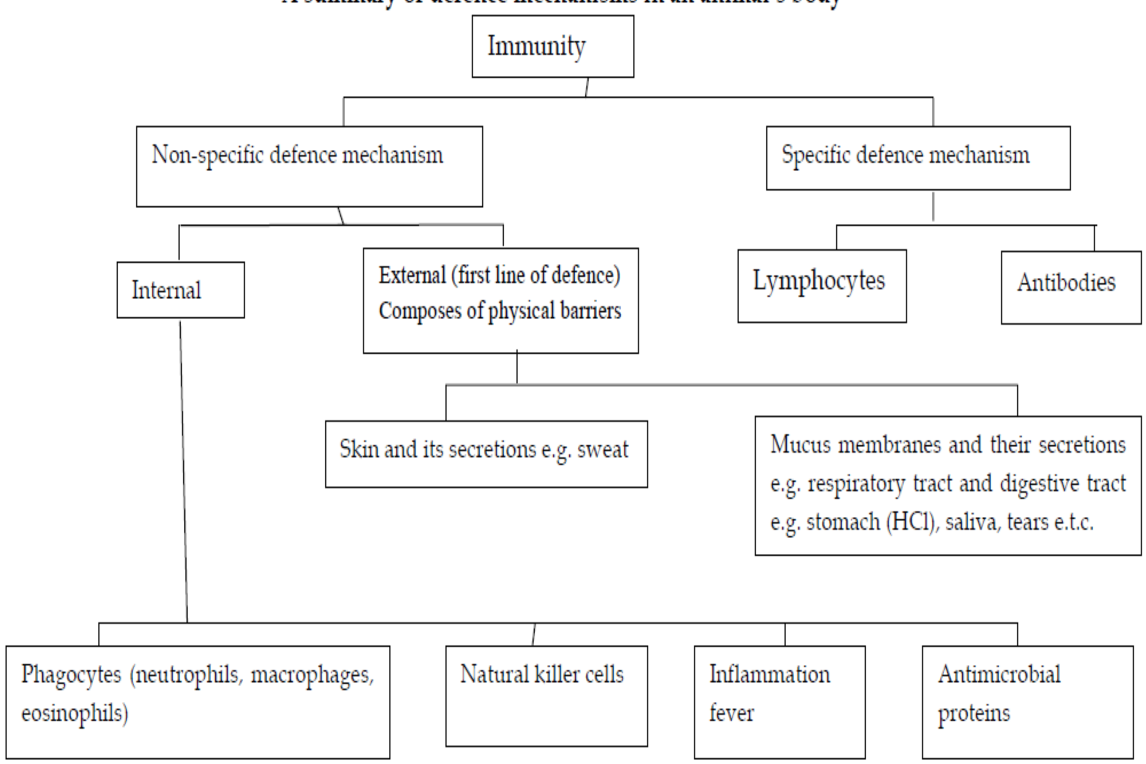
1. Connective tissue plus the liver produce a chemical, heparin, which prevents the conversion of prothrombin to thrombin, and fibrinogen to fibrin.
2. Blood vessels are smooth to the flow of blood. Damage to the vessel's endothelium can lead to platelets breakdown which leads to clotting of blood.

BODY DEFENCE SYSTEM AND MECHANISM IN MAMMALS (HUMANS)

An animal must defend itself against unwelcome intruders for example; dangerous viruses and other pathogens it encounters. The body also deals with abnormal cells (cancer cells) that develop periodically in the animal's body.

Two comparative defensive systems are used to fight pathogenic and abnormal cells in the body.
One of the systems is **non-specific** in nature (it does not distinguish one infection agent from another).
The other defense system is **specific** in nature and constitutes the **immune system**.

A summary of defence mechanisms in an animal's body



SPECIFIC SYSTEM

This line of defense system is specific in nature and constitutes the **immune system**

The immune system constitutes a third line of defense. However, the immune system responds specifically to a particular type of invader. This immune response includes the production of specific defense proteins called **antibodies**.

It also involves participation of several different types of cells that are derived from the white blood cells called **lymphocytes**.
The immune response offers a specific defense against infection. It is also described as **acquired immunity**.

NON SPECIFIC SYSTEM

The non-specific system includes two lines of defense which an invader encounters in sequence.
The first line of defense is external comprising of epithelial tissues that cover and line our bodies (skin and mucus membranes) and other secretions these tissues produce.

The second line of non-specific defense is internal. It is triggered by chemical signals and uses antimicrobial proteins and phagocytic cells that indiscriminately attack any invader that penetrates the body's outer barrier. Inflammation is a sign that shows that the second line of defense has been deployed.

NOTE:
The non-specific defense system which involves use of phagocytes, natural killer cells and antimicrobial proteins is said to offer innate immunity (in born) which is abroad defense mechanism against infection.

The non-specific defense mechanism acts in 6 ways which include;

1. Through physical barriers for example the skin.
2. Phagocytosis.
3. Natural killer cell.
4. Anti-microbial proteins.
5. Inflammation.
6. Fever

THE SKIN AND MEMBRANES

The intact skin is **a barrier that cannot be penetrated by bacteria or viruses,** although minute abrasions allow their passage.
In the same way, the mucus membranes which line the digestive, respiratory and urinal-genital tracts prevent the entry of potentially harmful microbes.

Apart from their role as physical barriers, the skin and mucus membranes **produce secretions that counter pathogens.** For example; in humans, secretions from the sebaceous and sweat gland give the skin a pH ranging from 3-5 which is acidic enough to discourage micro-organism from colonizing it.

Saliva, tears and mucus secretions that bathe the surface of the exposed epithelia wash away many potential invaders and in addition, these secretions contain various antimicrobial proteins.

For example.

- The enzyme lysozyme which digests the cell walls of many bacteria, destroys many microbes entering the upper respiratory system and openings around the eyes.
- Mucus, which is viscous secreted by cells of the mucus membranes also traps particles that contact it. Microbes entering the upper respiratory system are caught in the mucus and are the swallowed or expelled.
- The lining of the trachea has specialized epithelial cells equipped with cilia which sweep out microbes and other particles trapped by mucus, preventing them from entering the lungs.
- Microbes present in food or trapped in swallowed mucus from the upper respiratory system pass through the highly acidic gastric juice produced by the stomach lining which destroys most of the microbes before they enter the intestinal tract.

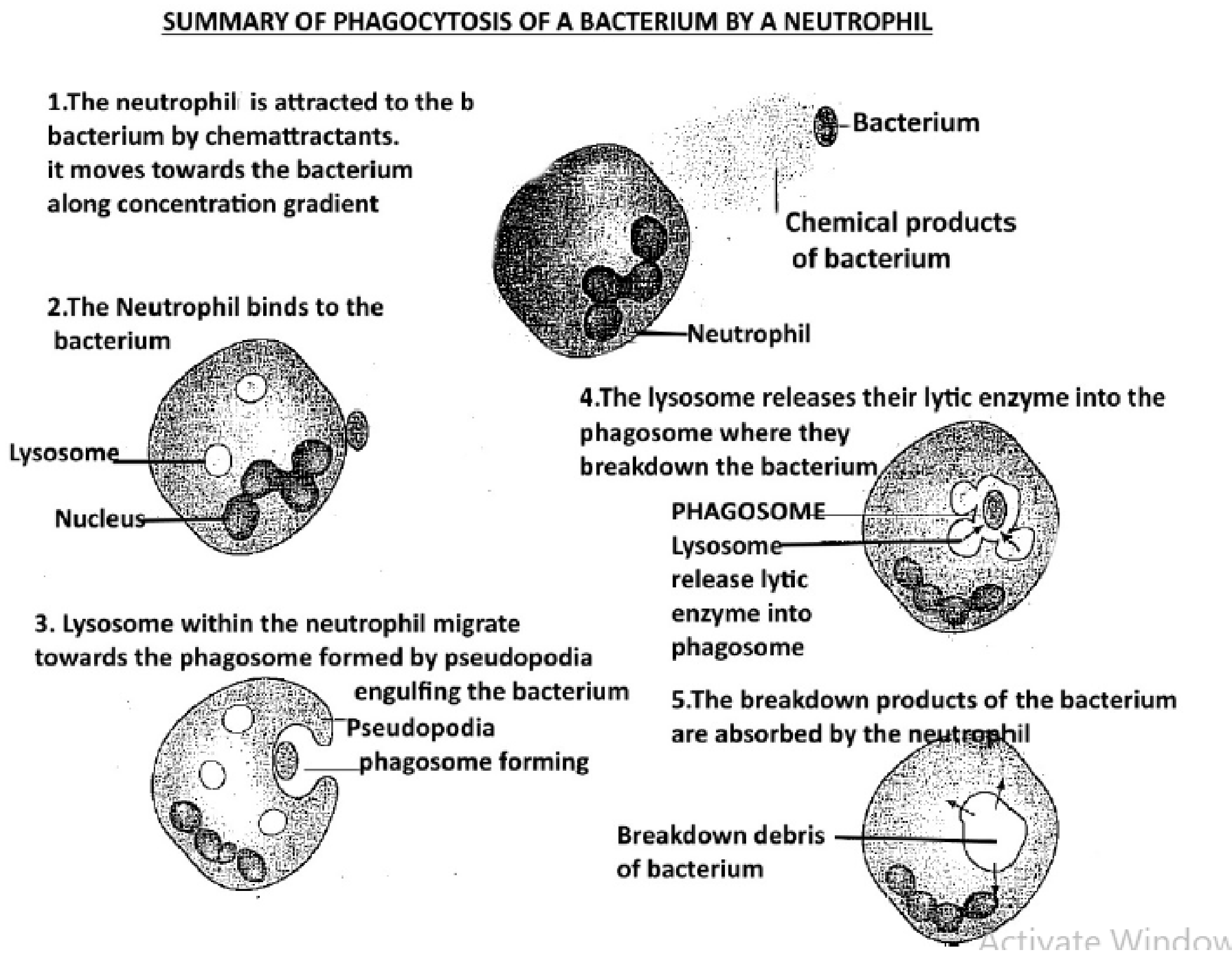
PHAGOCYTIC DEFENCE MECHANISM

Certain white blood cells particularly **neutrophils** and **monocytes** are attracted by chemicals released by body cells which have been damaged by invading pathogens. These white blood cells show **amoeboid** movements which engulf, ingest and destroy pathogens.

Neutrophils can squeeze through blood capillary walls a process called **diapedesis** and move about in tissue spaces.
The monocytes migrate out of blood stream then become larger white blood cells called macrophages.
Some macrophages are permanently located in tissues and organs such as the liver, spleen, kidney and lymph nodes while other circulate throughout the body.
The term macrophage means "big eater" and these cells are long lived phagocytes which even engulf much larger particles like old red blood cells and protozoan parasites.

The **eosinophils** have low phagocytic activity but are critical in defense against multicellular parasitic invaders such as the blood fluke (*Schistosoma mansoni*).

They rarely engulf such a large parasite but position themselves against the parasites body and discharge destructive enzymes which damage the invader.



NATURAL KILLER (NK) CELLS

This is a class of white blood cells which attack virus-infected body cells and abnormal cells that could form tumours.

The virus infected cells have viral proteins displayed on their surfaces and these are recognized by the natural killer cells that contain contains perforin – filled vesicles.

When an N.K cell encounters a virus infected cell, perforin molecules are released by exocytosis.

Perforin molecules make large holes or pores in the cell's plasma membrane, causing leakage of the cytoplasmic contents. This results into cell death. The membrane of NK cell is not affected by these membrane dissolving molecules.

INFLAMMATION

This is a localized non-specific response initiated by the defense system of the body, in which the part of the body infected by a micro –organism has **its blood vessels dilated**, **more permeable to blood components** and having **increased blood flow.**

The part swells up, becomes warm and red as the phagocytes destroy the invading pathogens.

An inflammation is usually a result of physical damage to the skin or mucus membranes by bacteria.

This physical damage causes release of chemical signals such as **histamine** and **prostaglandins.** The chemical signals induce **increased permeability of the blood capillaries** and the **flow of blood to the affected area** respectively.

They also attract phagocytic cells and lymphocytes which on arrival at the site of injury, consume pathogens and the cell debris and consequently the tissue heals.

N.B. It is the damaged cells and certain leucocytes that produce histamine and Prostaglandins. The histamine cause vasodilatation, the capillaries dilate and the walls become leaky.

As more fluid collects around the wound, the site becomes red, swollen and warm.

The localized swelling is called **oedema**. The prostaglandins are the ones that promote blood flow to the site of injury and increase the sensation of pain.

FEVER

Fever refers to increase in body temperature.

It is triggered **when microbes infect larger areas of the body**. In response to infection, certain leucocytes release pyrogens which are also anti-microbial proteins of the complement system.

The pyrogens stimulate the hypothalamus to rise the body temperature set-point from its normal value to about 39°C hence casing a fever. The fever has several beneficial effects which include;

1. It increases the activity of phagocytes which then attack the invading microbes more efficiently.
2. It increases the production of interferons in virus infected cells.
   Interferons are proteins which inhibit viral replication, activate natural killer and stimulate macrophages to destroy tumour cells and virus infected cells.

ANTIMICROBIAL PROTEINS

These are proteins that function in the mechanisms by attacking microbes directly or by impeding their production for example **lysozyme.**

Other antimicrobial proteins include about 30 serum proteins that make up the complement system proteins through a sequence of stops, leading to lysis (bursting) of invading cells.

Some complement proteins initiate inflammation and also play a role in acquired defense (specific defense system).

Interferon is one of the proteins of the complement system which provides innate defense against viral infection. The interferon protein is secreted by virus infected body cells and induce neighbouring uninfected to produce other substances that inhibit viral reproduction.

In this way, interferons limit the spread of viruses in the body helping to control viral infections such as colds and influenza.

SPECIFIC DEFENSE SYSTEM /IMMUNE SYSTEM (ACQUIRED IMMUNITY)

The specific immune response confers immunity against specific microbes.

The specific defense system involves the immune system whose response results from the interaction among;

- **Several types of lymphocytes**,
- **The molecules they produce (antibodies),** and
- The **foreign material introduced by microbes (antigens).**

MECHANISM OF IMMUNE RESPONSES/MAJOR CELLS IN THE IMMUNE SYSTEM.

The immune system mounts two different types of responses to antigens namely;

1. Cell-mediated response.
2. Humoral response.

1. B-CELLS (B-LYMPHOCYTES) AND THE HUMORAL RESPONSE

These are **lymphocytes that produce antibodies when stimulated.**

Each B-cell has a function of recognizing a particular antigen and producing antibodies that will bind to it. The cell surface membrane of B-cells contains antigen receptors whose specific shape is identical to the antibodies that that cell can make.

All the receptors in the membrane of one cell are identical, so a given cell can only recognize only one type of antigen. When it binds to an antigen, the cell is activated to clone its self, meaning it multiplies to form many copies of its self.

B-cells are produced and mature in the bone marrows from the stem cells.

There are two types of B-cells namely;

1. Memory cells
2. Effector cells (carry out response). Effector cells are also known as plasma cells.

The effector cells live for only a short period of time.

MEMORY CELLS

The memory cells survive for long periods of time and enable a rapid response to be made to any future infection.

These are derived from B cells and T-cells. They are long lived and confer future immunity against subsequent infections by the same antigen i.e. they are the ones responsible for causing the secondary immune response.

HUMORAL RESPONSE

The humoral immunity results in the production of antibodies which are secreted by B-cells, the antibodies circulate as soluble proteins in blood plasma and lymph, the fluids that were once called humors.

2. T-CELLS (T-LYMPOCYTES) AND THE CELL MEDIATED RESPONSE.

The T cells are produced in the **bone marrow but mature in the thymus gland** where they develop specific receptors which recognize specific antigens.

The thymus gland is located in the thorax just above the heart. It begins to function in the embryo and it’s most active at the time of, and just after birth. After the period of weaning, it decreases in size and soon ceases to function.

Evidence to show that the thymus gland is important in the development of the immune system.

- Removal of the gland from the new born mouse results in death from deficiency of lymphocytes in its tissue fluid and blood.
- Tissue from an older mouse grafted onto an experimental new born mouse with the gland removed is unable to recognize and react to antigens.
- If the thymus gland is removed from a much older mouse, this mouse suffers no adverse effects.

  Mature T-cells possess either;
  - A T_4 molecule (**T_4-Cells**) or
  - A T_8 molecule (**T_8- cells**) and this gives them different functions.

T_4 CELLS (Helper T-cells)

T_4 cells are known as T-helper cells. The HIV Virus which causes AIDS infects mainly T-helper cells.

These produce chemicals which activate other cells such as phagocytes to engulf harmful material. The chemicals attach themselves to the foreign material and so label them as requiring phagocytosis. These labelled chemicals are called opsonins.

The T-helper cells also activate B-lymphocytes to divide to produce plasma cells as well as assisting the T-killer cells to destroy pathogens.

The T_4 cell then produces large amounts of lymphokines; these have various functions which include;

- Stimulate T cells to multiply
- Promote inflammation
- Stimulate B-cells to produce antibodies

T_8 CELLS

There are **two types of T_8 cells** and these include

1. Suppressor cells
2. Killer cells (or cytotoxic cells)

Each type of T cell produces a different type of **lymphokine**.

T-killer-cells (Cytotoxic cells)

Killer cells (one type of T_8 cells) produce smaller amount of cellular toxic substances called ***lymphokines*** which kill the invading cells called microbes and body cells which have become infected by viruses, and cancer cells.

This is done by a chemical attack or by punching holes in the cells.

Since viruses require host cells to reproduce, this sacrifice effectively prevents multiplication of viruses.

T-suppressor-cells

Once an infection has been eliminated, these cells suppress the activities of the lymphocytes and so maintain control of the immune system.

Suppressor T-cells therefore regulate the immune response and prevents antibodies from being produced by the B-cells.

CELL MEDIATED RESPONSE

In the cell mediated response, the immunity depends on the direct action of the T-lymphocytes rather than antibodies.

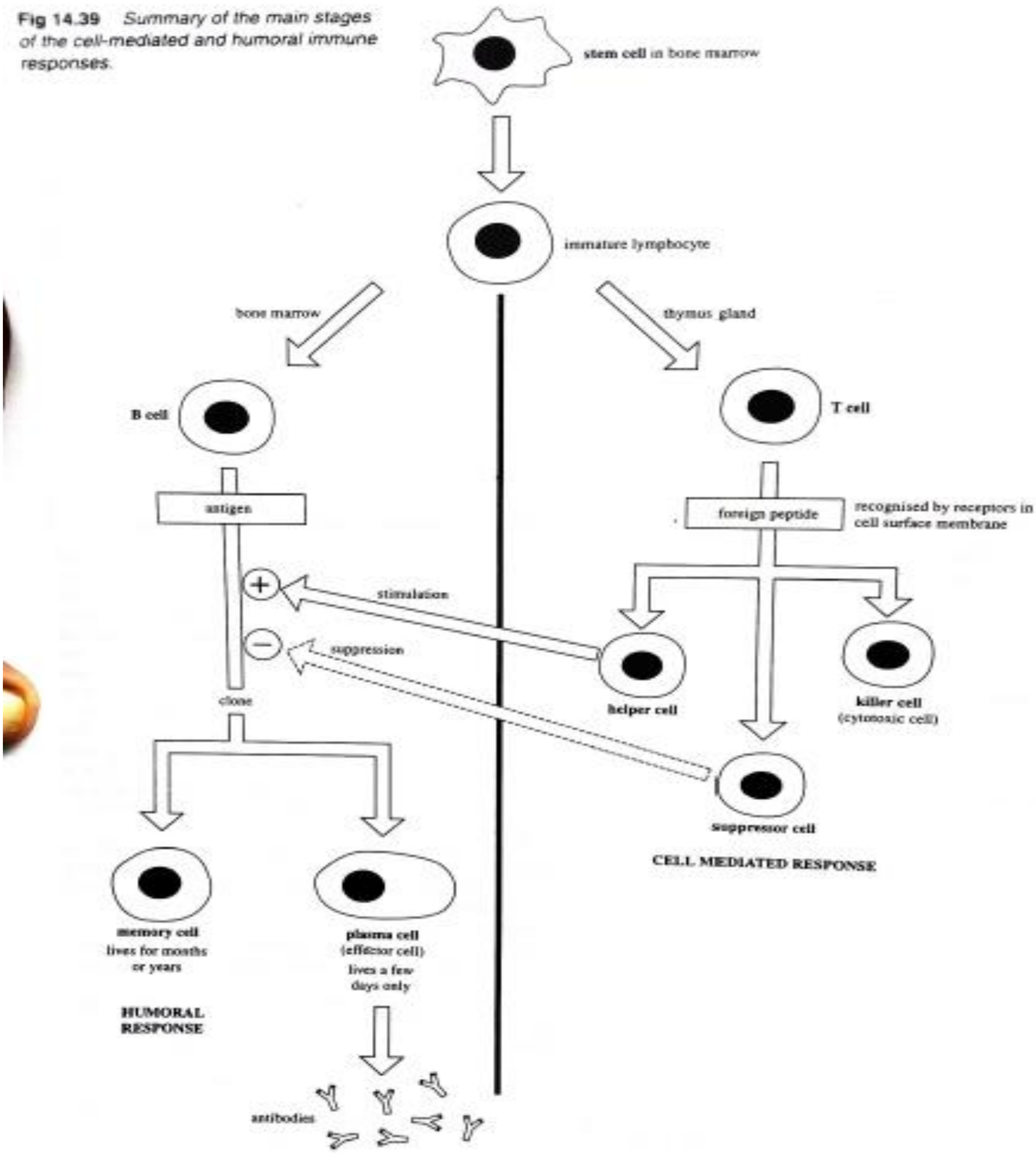


Fig 14.39 *Summary of the main stages of the cell-mediated and humoral immune responses.*

MOLECULES OF THE IMMUNE SYSTEM

1. Antibody

This is a specific protein (immunoglobin) which recognizes and binds to specific antigens. Antibodies either neutralize antigens or tag cells that are antigens for easy attack by macrophages.

2. Epitopes

These are antigen determinants with specific sequences of amino acids that confer a specific shape to the antigen molecules which is then recognized by an antibody or T-cell receptor.

An antigen can have several different epitopes on its surface and different antibodies can therefore bind a single antigen.

3. Cytokines (lymphokines)

These are peptides and proteins that regulate many cell activities (growth and repair) and act as signal in both the specific and non-specific immune responses

Examples of cytokines include

- Interferons

- Interleukin

4. Complement system.

This is a group of about 20 proteins found in plasma and other body fluid. These are inactive until the body is exposed to antigens e.g. histamines.

CHARACTERISTICS OF THE IMMUNE SYSTEM

The immune system develops a specific response against each type of foreign microbe, toxin or transplanted tissues.

The immune system has 4 features which include;

1. Specificity.
2. Diversity
3. Memory
4. Self/non self-recognition.

1. **Specificity**

The immune system has the ability to recognize and eliminate particular microorganisms, and foreign molecules. The immune system responds to an antigen by activating specialized lymphocytes and producing specific proteins called antibodies.

Antigens that trigger an immune response include molecules belonging to viruses, bacteria, fungi, protozoa and parasitic worms.

Anti-bodes recognize antigens using epitopes which are antigenic determinants on the surfaces of the antigens.

If an antigen has several epitopes, it stimulates several different B cells which secrete specific distinct antibodies against it.

2. **Diversity**

The immune system has the ability to respond to very many kids of invaders each recognized by its antigenic markers.

This diversity of response is possible because the immune system is equipped with an enormous variety of lymphocyte population among the antibody producing lymphocytes (B-lymphocytes).

Each population is stimulated by a specific antigen and responds by synthesizing and secreting the appropriate type of antibody.

3. **Memory**

The immune system has the ability to "**remember**" an antigen encountered and react more promptly and effectively on the subsequent exposures. This characteristic is also known as acquired immunity.

4. **Self/non self-recognition**

The immune system distinguishes the body's own molecules from foreign molecules (antigens). Failure of self/non self-recognition leads to anti immune disorders in which the immune system destroys the body's own tissues

TYPES OF IMMUNITY

Immunity maybe described as active or passive. Both types may be acquired naturally or artificially.

Providing immunity artificially is called **immunization.**

ACTIVE IMMUNITY

Active immunity occurs when an organism manufactures its own antibodies.

Natural active immunity

This is the kind of immunity which is obtained as a result of an infection. The body manufactures its own antibodies when exposed to an infectious antigen.

Because memory cells, produced on exposure to the first infection, are able to stimulate production of massive quantities of antibody when exposed to the same antigen again, this type of immunity is most effective and generally persists for a long time, sometimes even for life.

Artificial active immunity (immunization)

This is achieved by injecting small amounts of antigen called the vaccine into the body of an individual. The process is called vaccination.

If the whole organism is used as the vaccine, it is first made safe by being killed or attenuated.

The antigen stimulates the body to manufacture antibodies against the antigen.

Types of vaccines currently in use

1. **Toxoids.** Toxins (poisons) produced by tetanus and diphtheria bacteria are detoxified by formaldehyde, yet their antigen properties remain. Therefore vaccination with the toxoid will stimulate antibody production without producing symptoms of the disease.

2. **Killed organisms.** Some dead viruses and bacteria are able to provoke a normal antibody response and are used and are used for immunization purposes. An example is the flu vaccine which contains dead flu viruses.

3. **Live vaccines (attenuated organisms).** An attenuated organism is one which has been crippled in some way so that it cannot cause disease. They are living pathogens which have been treated for example by heating so that they multiply but are unable to cause symptoms of the disease. They are therefore harmless but non-the less they induce the body to produce appropriate antibodies

4. **Extracted antigens.** Chemicals with antigenic properties may be extracted from the pathogenic organisms and injected. Influenza vaccine is manufactured this way.

5. **Artificial antigens.** Through genetic engineering, it is now possible to transfer the genes producing antigens from a pathogenic organism to a harmless one which can easily be grown in a laboratory. Mass production of antigens is then possible. Vaccines used in the treatment of hepatitis B are produced in this way.

PASSIVE IMMUNITY

Passive immunity id the result of antibodies being passed into the individual rather than being produced by the individual its self.

The antibodies give immediate protection unlike active immunity which takes a few days or weeks to build up. However, it only provides protection against infection for only a few weeks. The antibodies are broken down by the body's natural process so their numbers fall and protection is lost.

NATURAL PASSIVE IMMUNITY

Passive immunity maybe gained naturally for example, antibodies from the mother can cross the placenta and enter her fetus. In this way, they provide protection to the baby until its own immunity is fully developed. Passive immunity can also be provided by colostrum, the first secretion of the mammary glands. The baby absorbs the antibodies via its gut.

ARTIFICIAL PASSIVE IMMUNITY

Here, antibodies which have been formed in one individual are extracted and then injected into the blood of another individual which may or may not be of the same species.

They can be used for immediate protection if a person has or is likely to be exposed to a particular disease. For example, specific antibodies used to combat tetanus and diphtheria used to be cultured in horses and injected in humans. Only antibodies of human origin are now only used for humans.

HOW ANTIBODIES WORK

An antibody does not directly destroy an antigenic invader.

However antibodies bind to antigens to form an antigen-antibody complex which is the basis for several effector mechanisms which make macrophages recognize the antigens and destroy them.

The binding of antibodies to antigens takes various forms, some of which include the following.

1. **Neutralization.**

Here the antibody blocks certain sites on an antigen or toxins making it ineffective. Antibodies neutralize a virus by attaching to the sites the virus uses to bind to its host cell.

The antibodies bind to toxic molecules produced by a pathogen and in doing so neutralize their harmful effects. Eventually, phagocytic cells (macrophages) destroy these antigen-antibody complexes.

2. **Agglutination (clumping)**

Some antibodies have many binding sites and can join to antigens on many different pathogens. In this way, the pathogens can be joined together in clumps making them more vulnerable to attack from other types of antibodies.

The clumping of antigens for example bacteria makes it possible to be recognized by macrophages and other phagocytes which destroy the antibody-antigen complex.

3. **Precipitation**

Some antibodies bind together soluble antigens into large units which are thus precipitated out of solution. As such they are more easily ingested by phagocytes.

4. **Opsonisation**

Here, the antibody molecule coat the surface of a microbe making it easier for phagocyte leucocytes to engulf it.

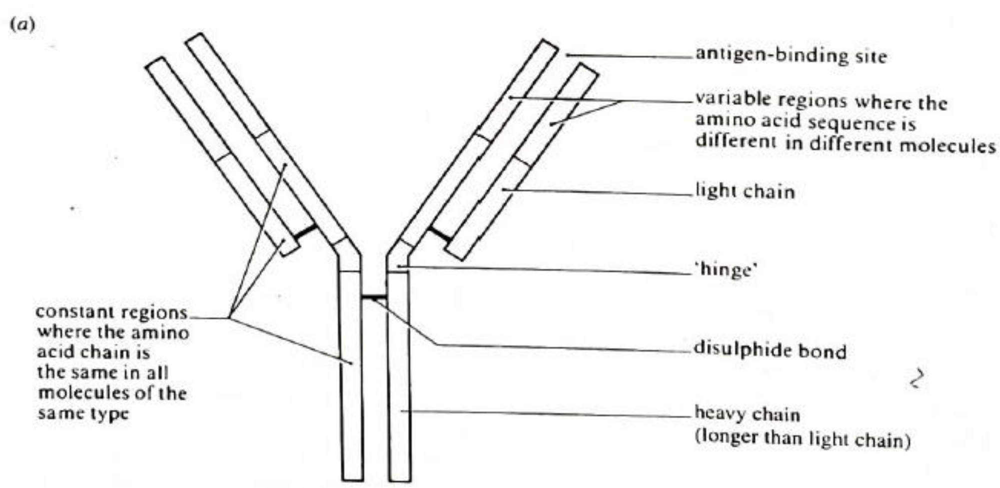
5. **Lysis**

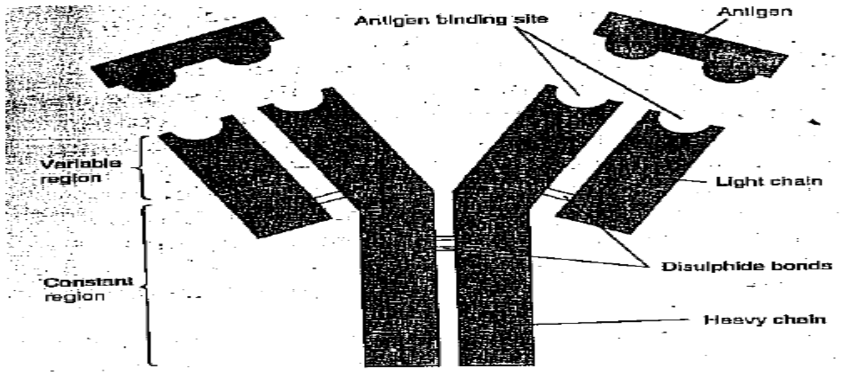
Antibodies which are attached to pathogens act as binding sites for a number of blood proteins which are collectively known as the complement system. Some of these proteins are enzymes which cause break down of the pathogen.

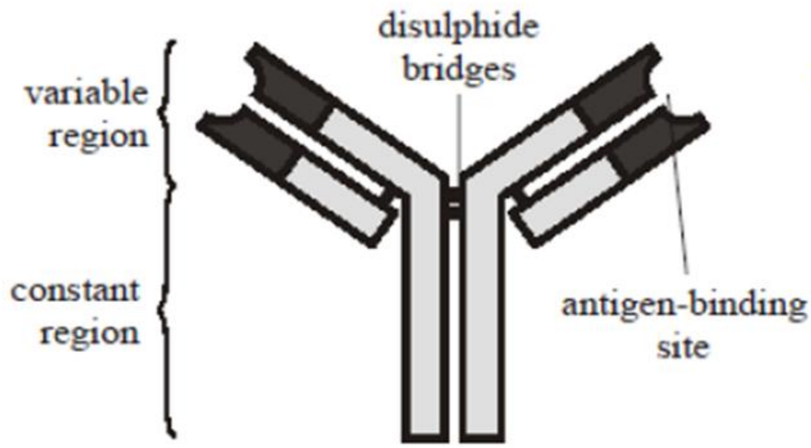
STRUCTURE OF AN ANTIBODY

The typical structure of an antibody molecule is composed of four polypeptide chains; two light and two heavy chains linked together by di-sulphide bridge bonds.

It is a Y shaped molecule. Most of the molecule is the same for all antibodies of the same immunoglobulin class.







stylised diagram

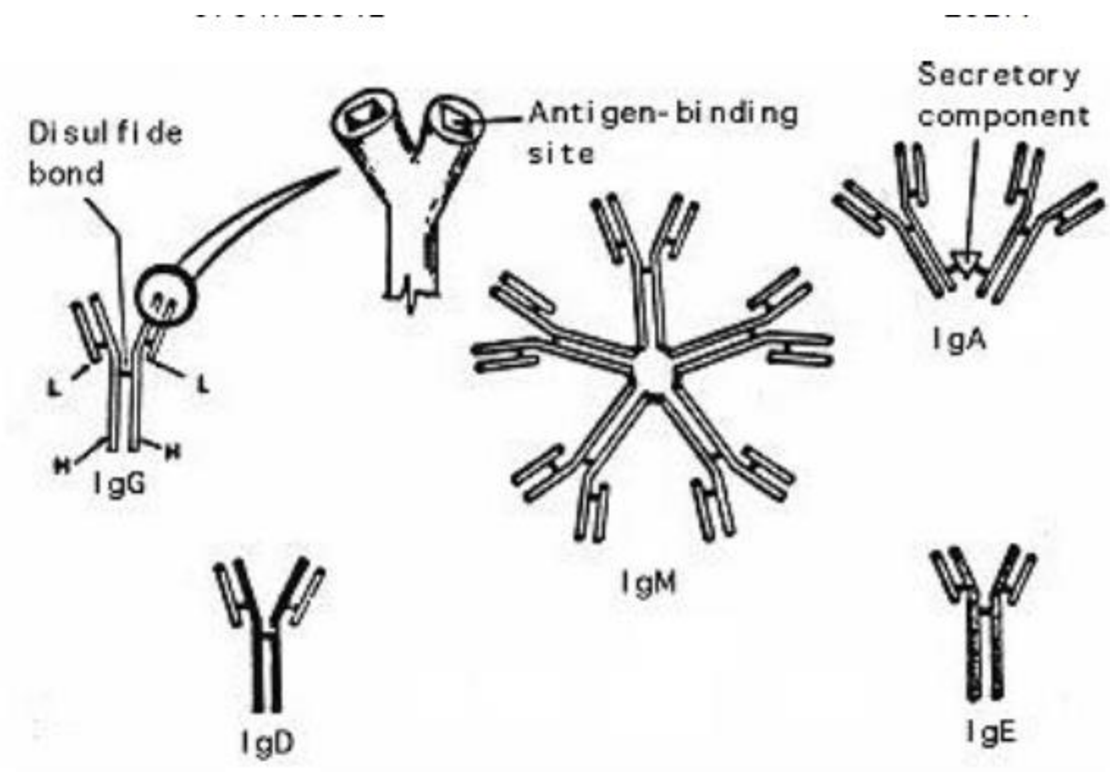
TYPES OF ANTIBODIES

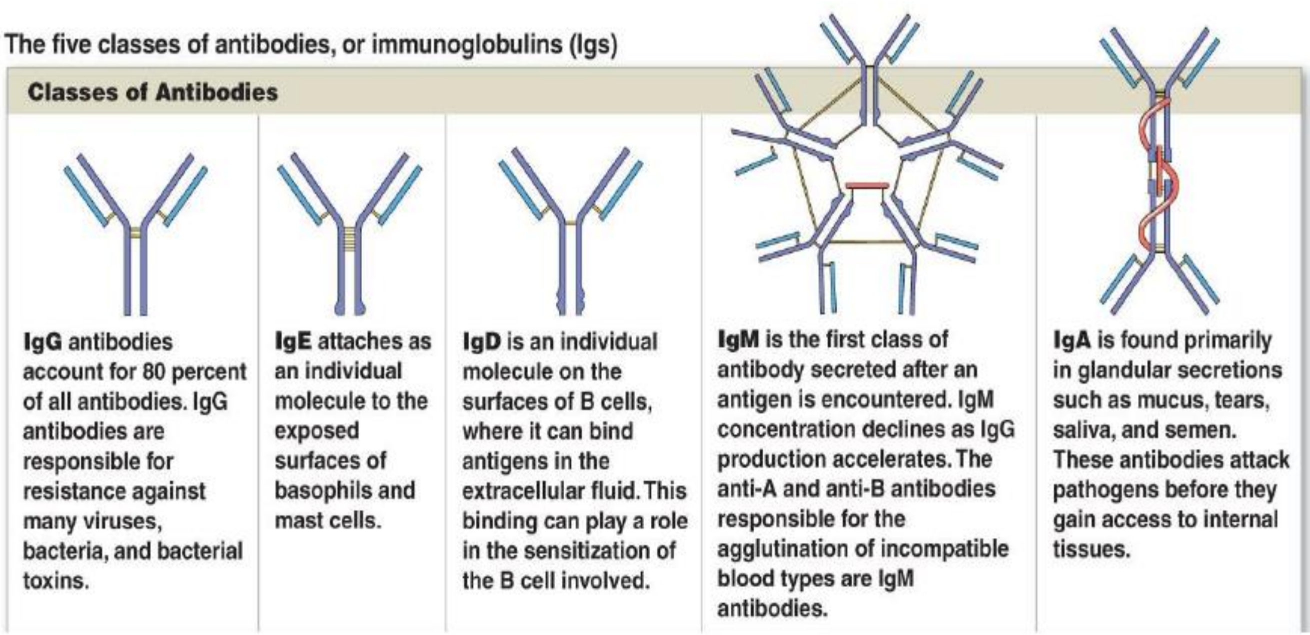
Antibodies constitute a class of proteins called immunoglobulins (igs).

Every antibody molecule has at least two identical sites that bind to the epitope that provide its production.

There are 5 classes of immunoglobulins namely

1. IgM (pentamer)
2. IgG (monomers)
3. IgA (dimers)
4. IgD(monomers)
5. IgE (monomers)





IgM

These are the 1st circulating antibodies to appear in response to an initial exposure to an antigen. Their concentration in blood declines rapidly and this is useful diagnostically because their presence indicates a current infection by the pathogen, causing its formation.

The IgM consists of 5 Y shaped monomers arranged in a pentamer structure.

Note. The numerous antigen-binding sites of an IgM makes it very effective in agglutinating antigens and in reactions involving complements.

However the IgM is too large to cross the placenta and does not confer material immunity

IgG

IgG is the **most abundant** of the circulating antibodies. It readily crosses the wall of blood vessels and enters tissue fluids. IgG crosses the placenta and confers passive immunity from the mother to the fetus. IgG protects against bacteria, viruses and toxin circulating in blood and lymph and triggers action to the complement system.

IgA

This is produced inform of 2 Y shaped monomers (it is a dimer) by cells abundant in mucus membranes.

The main function of IgA is to prevent the attachment of viruses and bacteria to epithelial surfaces. IgA is also found in many body secretion such as saliva perspiration (sweat) and tears. It is also present in colostrum (1st milk of nursing mammal) it protects the infant from gastro-intestinal infections.

IgD

IgD antibodies do not activate the complement system and cannot cross the placenta. They are mostly on the surfaces of the B cells where they function as antigen receptors required for initiating the differentiation of B-cells into plasma and memory cells

IgE

These are slightly larger than IgG molecules and represent only a very small fraction of the total antibodies in blood. The tail region attach to receptors of mast cells and basophils and when triggered by an antigen, cause the cells to release histamine and other chemicals that cause an allergic reaction.

Memory and secondary immune response

Memory cells function in secondary immune response.

In primary immune response there is selective proliferation (multiplication) of lymphocytes to form clones of effector cells upon the first exposure to an antigen. Here there is a lag period between initial exposure to an antigen and maximum production of effector cells.

During the lag period, the lymphocytes secreted by the antigen differentiates into effector T-cells

(TH and TC) and antibody producing plasma cells

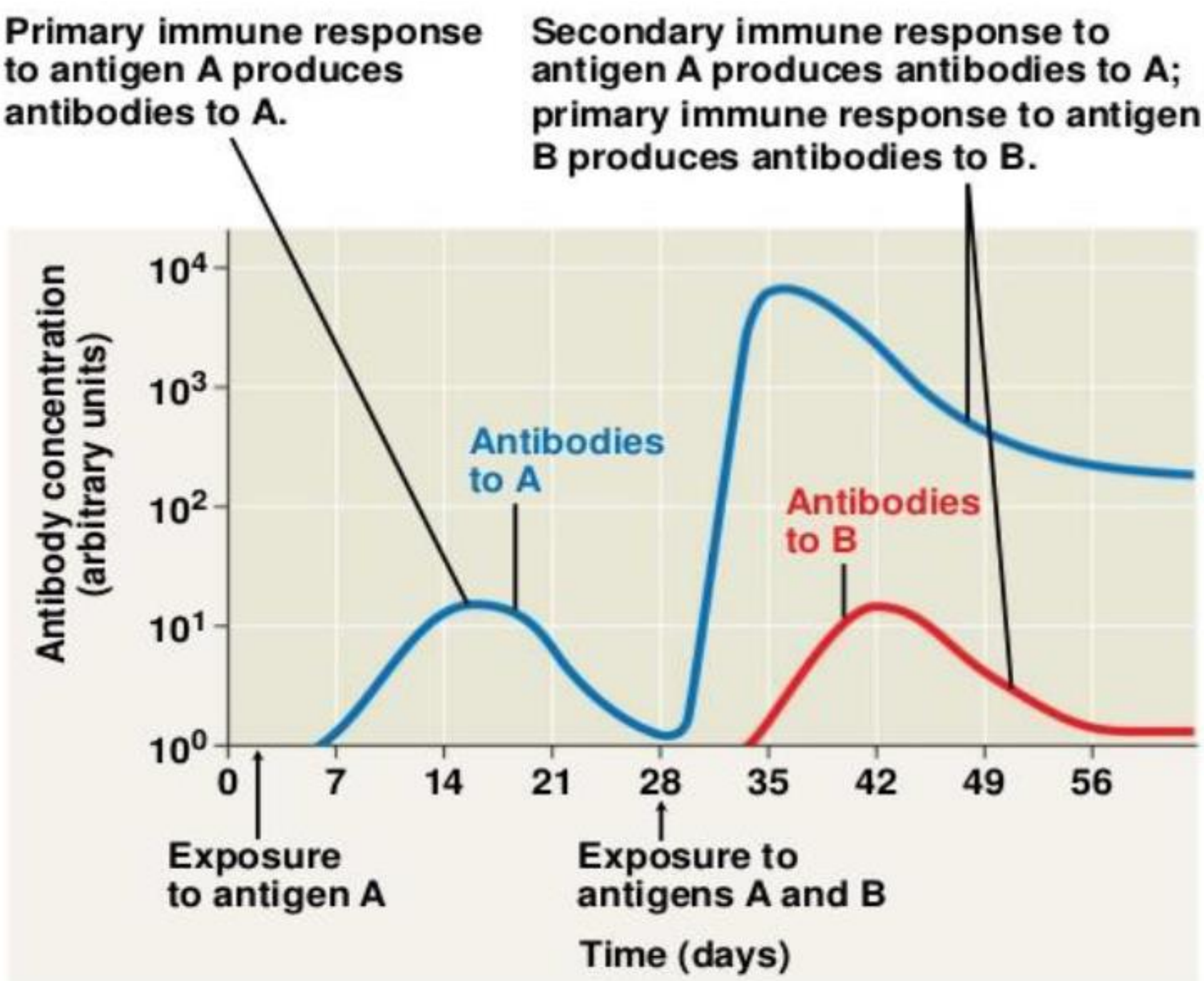
If the body is exposed to the same antigen at a later time, the response is faster and more prolonged than the primary immune response. This is the secondary immune response.

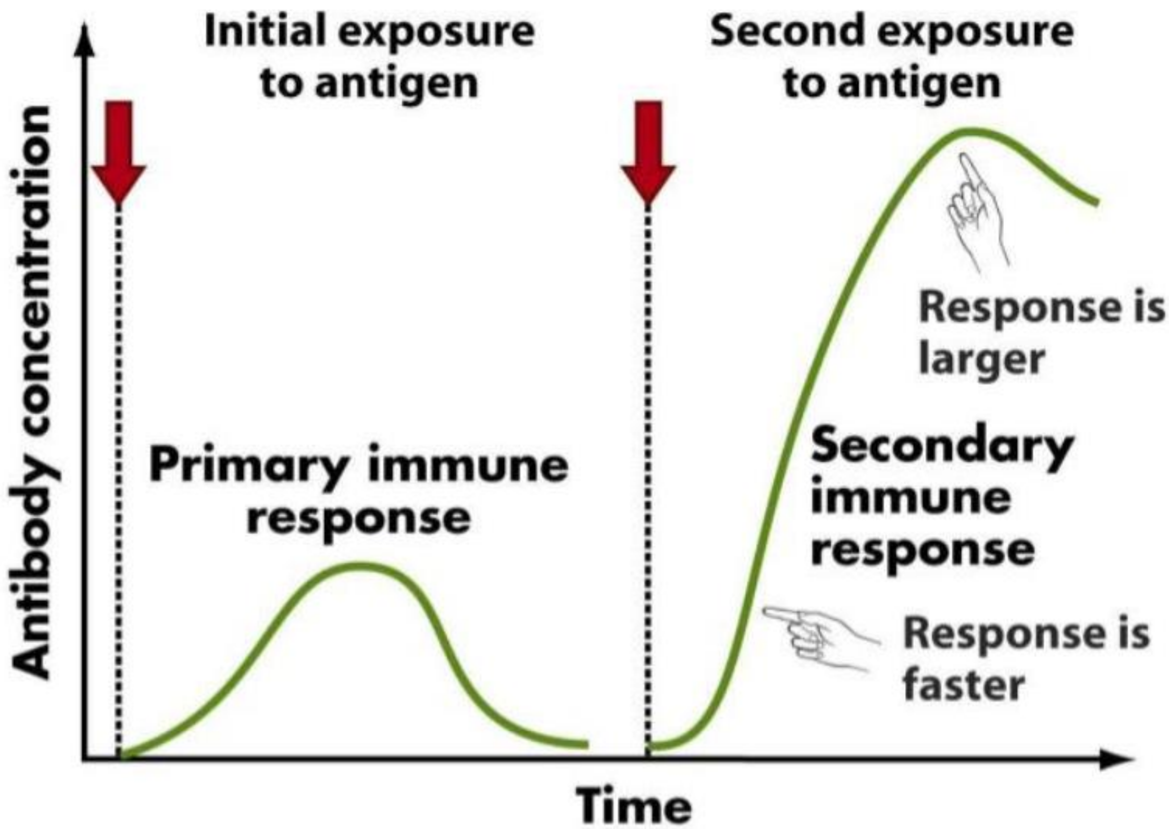
Secondary immune response is the rapid response that results in faster production of effector T-cells and antibody molecules when the body is exposed to subsequent infection of the same antigen that has ever invaded the body.

Antibodies produced during the secondary immune response are more effective in binding to the antigen than those produced during the primary immune response.

The immune systems' ability to recognize an antigen as previously encountered is called **immunological memory.** The ability is based on long lived effector cells of the immune response, memory cells are not active- memory cells survive for long periods and proliferate rapidly when expose to the same antigen that caused their formation secondary immune gives rise to new clone to memory cells as well as effector cells.

Graph to illustrate changes in antibody concentration during primary and secondary immune responses to antigens




Initial exposure
to antigen
Second exposure
to antigen
Antibody concentration
Response is
larger
Primary immune
response
Secondary
immune
response
Response is
faster
Time

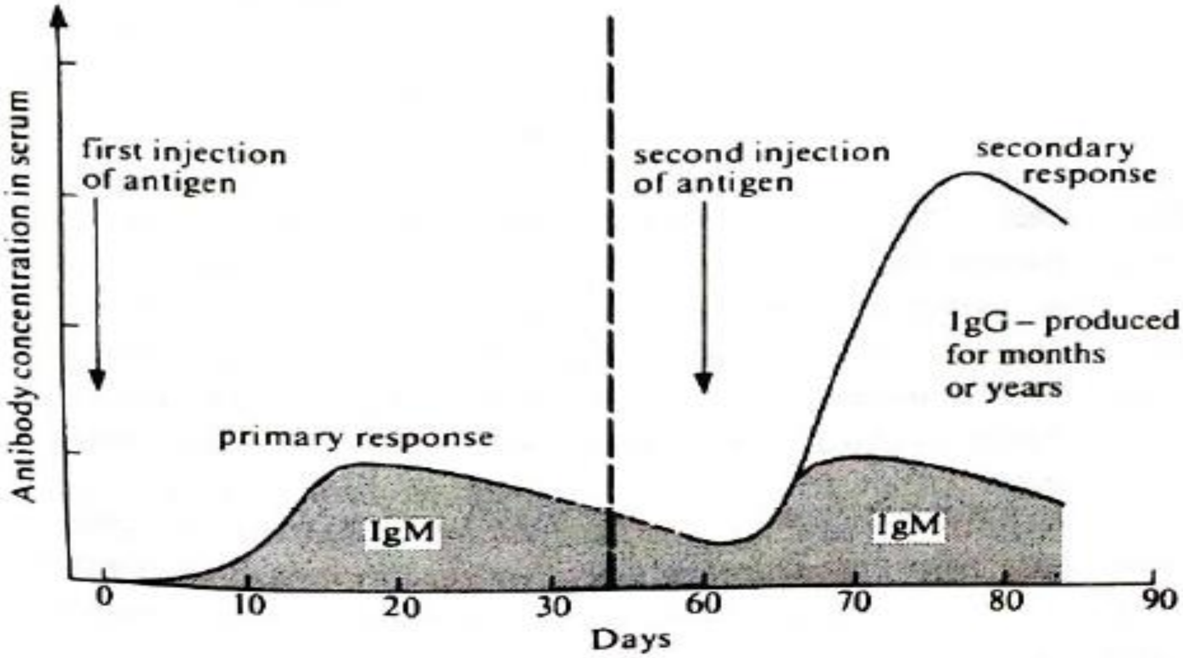


Fig 14.41 *Primary and secondary response to an initial and later dose of antigen. The secondary response is more rapid and intense than the first. IgM and IgG are two different types of antibody (immunoglobulins). IgM is responsible for the primary response. IgG starts the secondary response. (The heavy chain of the antibodies is different.)*

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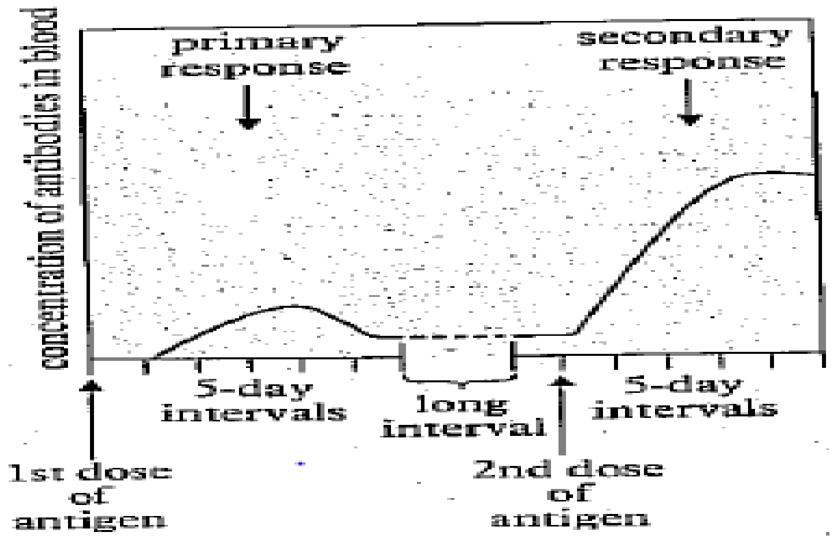


Figure 17.8 The effect of immunization on antibody production. The first dose of antigen triggers the production of a relatively small number of antibodies (primary response). The second dose results in a larger, more rapid and sustained production of antibodies (secondary response). Immunity against some diseases (e.g. measles and poliomyelitis) can last a lifetime; but for other diseases (e.g. typhoid, cholera and tetanus) further doses of antigen ('boosters') need to be given from time to time.

Primary response

One B-cell is activated by a specific antigen with complementary shape;✓ to the immunoglobulins on its cell surface;✓which then divides to produce a clone of cells;✓capable also of producing identical antibodies against the antigen;✓however some of the B-cells form memory cells;✓

Secondary response

On exposure to the same antigen, the memory cells formed in the primary response;✓ divide to produce large numbers of B-cells;✓ which in turn, each, produces a clone of B-cells that make antibodies to destroy antigens;✓

It results in the production of large numbers of antibodies;✓hence the antigens are combated quickly before they cause a secondary infection;✓and this brings about efficiency in the immune system;✓

ASSIGNMENT: Research about-**Self and non-self-recognition**

ABNORMAL IMMUNE FUNCTION

Sometimes, the immune system fails to defend the animal against intruders instead turns against the components of the body which leads to certain diseases.

Conditions of immune system abnormalities include;

- Auto immune disease.
- Allergy.
- Immune deficiency.

AUTO IMMUNE DISEASES

The immune system turns against components of the body leading to auto immune diseases.

In insulin dependent diabetes, an auto immune reaction causes the destruction of insulin producing cells of the pancreas.

Rheumatial arthritis is a crippling auto immune disease in which inflammation damages the cartilage and bone of joints.

Rheumatic fever is an auto immune condition in young adults where antibodies produced in response to streptococcal infection (such as strep throat) react with heart muscles tissue damaging the heart valves. Repeated episodes of infecting results in more antibodies and more heart damage.

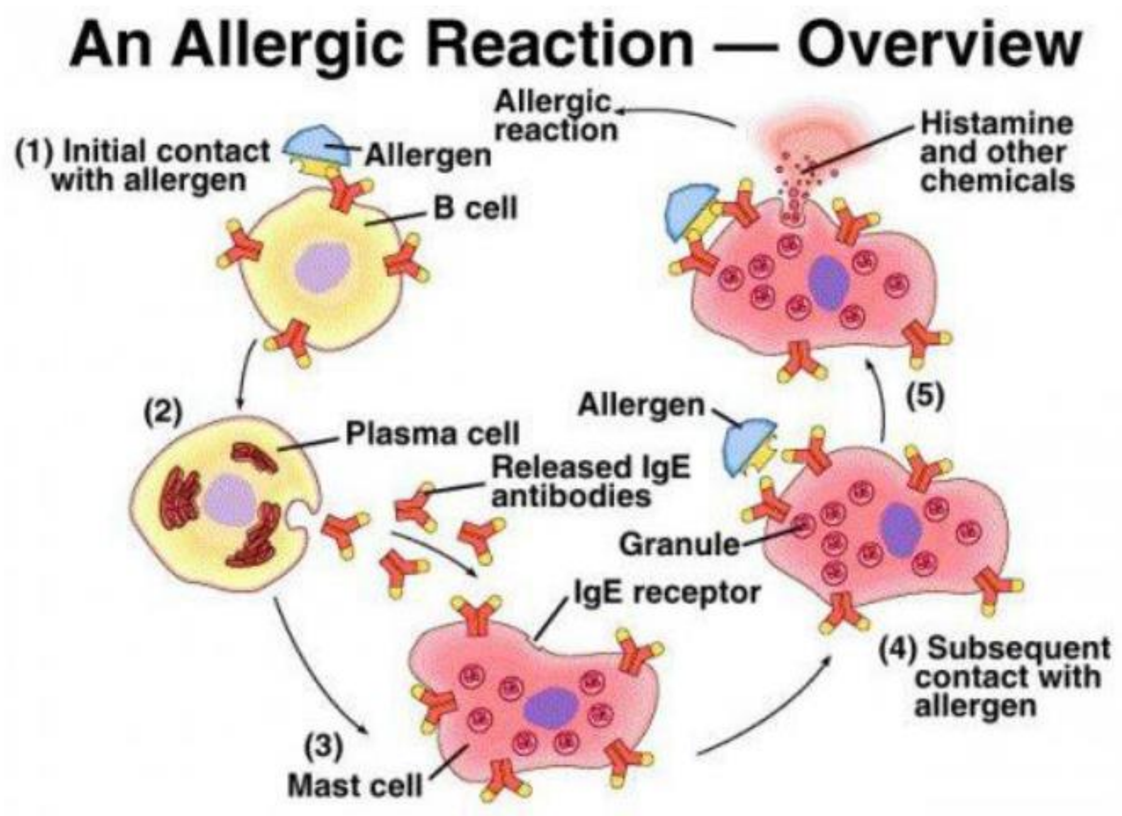
Allergy

Allergies are hypersensitivities of the body's defense system to certain environmental antigens called allergens.

The most common allergies involve antibodies of the IgE class e.g. hay fever and other allergies caused by pollen allergens.

The IgE antibodies attach by their tails to mast cells which are non-circulating cells found in connective tissue. In this way, a susceptible person becomes sensitized to the specific foreign antigen later.

When a pollen grain binds to the IgE and bridges the space between 2 IgE monomers, the mast cells responds with rapid reaction called degranulation releasing histamine and other chemicals.



NB.

a) Histamine causes dilation and increased permeability of the small blood vessels. In an allergy response, histamine causes symptoms like sneezing, a runny nose and smooth muscle contraction that often result into breathing difficulty.

b) Antihistamines are drugs that interfere with action of histamine

c) Upon first exposure to an allergy. The plasma cells secrete the IgE specific for the allergy. Some of these antibodies are attached by their cells to the mast cells. When upon second exposure, the allergen binds to IgE already on the mast cell. It triggers the degranulation of the cell.

d) Degranulation releases histamine leading to most of the symptoms at allergy.

IMMUNE DEFICIENCY

Certain individuals are inherently deficient (lack) in either humoral or cell medicated immune defenses.

In a congenital disorder, this is known as severe combined immune deficiency. For people with this genetic disease, long term survival requires a successful bone marrow transplant that will continue to supply functional lymphocytes.

Adaptation of mammals to oxygen deprivation

Diving mammals e.g. seals, dolphins and whales.

- They have a large spleen which can store large volumes of blood e.g. the seals spleen stores 24l of blood after the dive has begun, the spleen contracts and supplies the blood in circulation with additional erythrocytes that are highly leached with oxygen.
- Have high concentration of myoglobin in their muscles. Myoglobin is an oxygen storing protein.
- Mammals during the diving reflex slow down the pulse as the heart beat is also slowed down in order to effect an overall reduction on oxygen consumption since there is reduced cardiac output to the tissues.
- Store oxygen in their blood as oxyhaemoglobin and this is achieved by having concentration of haemoglobin.
- Blood supply to muscles is restricted and completely cut off during the longest dives hence encouraging anaerobic instead of aerobic respiration. In this way, the muscles use sparingly oxygen stored in their myoglobin.

Mammals living at high altitudes

- These possess an improved capillary network in the lungs which coupled with their deeper breathing (hyperventilation) insures increased oxygen uptake.
- They have an increased red blood cell which increases the amount of oxygen transported by blood.
- Increased haemoglobin concentration in the red blood cells which improves the amount of oxygen transported by the blood.
- Changes in haemoglobin affinity for oxygen. Mammals living at altitudes about 3500m have their oxygen dissociation curves shifted to the left this favors their survival by promoting an increased affinity for oxygen by haemoglobin.
- Increased myoglobin levels in muscles myoglobin has a higher affinity for oxygen than haemoglobin. This facilitates the exchange of oxygen from the blood to the tissues making oxygen available to the tissues.

THE LYMPHATIC SYSTEM

The lymphatic system returns tissue fluid to the blood and also plays a role in the body defense.

As blood passes through the capillaries, there is a cumulative loss of fluid which is effected by ultra-filtration of blood and this forms tissues fluid that bathes cells. The lost fluid is similar to blood in composition except that of lacks blood plasma-proteins and cells.

The lost fluid returns to blood via the lymphatic system. It enters the system by diffusion into tiny lymph capillaries which are intermingled among the capillaries of the cardio vascular system.

Once inside the lymphatic system, the fluid is called lymph.

The lymphatic system drains into the circulator system near the shoulders where it pours its contents in the subclavian vein that leads to the anterior vena cava.

Along the lymph vessels are specialized swellings called lymph nodes. These filter the lymph and attack bacteria, virus infected cells and other antigens using the lymphocytes in them.

When the body is infected by an antigen the cells in the lymph nodes multiply rapidly and the lymph nodes become swollen and tender.

Like the veins of the cardio vascular system lymph vessels have valves which prevent back flow of fluids towards the capillaries. In the same way, lymph vessels depend on the movement of skeletal muscles to squeeze the fluid along the vessel.

FUNCTIONS OF THE LYMPHATIC SYSTEM

- Defend the body against infection.
- Maintains the level of interstitial fluid (tissue fluid).
- Transports fats from the digestive tract to the circulatory system (the lymph capillaries called lacteals) penetrate the villi of the small intestine which absorb the fatty acids and glycerol.

Whenever the interstitial fluid accumulates rather than being returned to the blood by lymphatic system, the tissues and body cavities become swollen a condition known as oedema.

VACCINES

Vaccines are toxic chemicals or killed or attenuated (weakened) microbes introduced into the body of an organism to make it produce very many antibodies against a certain pathogen.

The killed microbes are usually viruses and bacteria.

The attenuated microbes are living microbes which are inactivated and they lack powers to infect the body due to the chemical or temperature treatment given to them.

Note; toxins are toxic chemicals produced by microbes and therefore can work as antigens

BLOOD TRANSFUSION

This is the transfer of compatible blood from the donor to the recipient.

Blood transfusion based on the ABO system of grouping blood

Blood group A has antigen A on the surface of its red blood cells and antibody b in the blood plasma of that person.

Blood group B has antigen B on the surface of its red blood cells and antibody a in the blood plasma of that person.

Blood group AB has antigen B and A on the surface of its red blood cells and no antibody in the blood plasma of that person.

Blood group O has no antigen on the surface of its red blood cells and both antibodies b and a in the blood plasma of that person.

Blood group	Antigen on the red blood cell membrane	Antibody on plasma
A	A	b
B	B	a
AB	A and B	Lacks antibodies
O	No antigens	a and b

Blood plasma permanently contains antibodies depending on a particular blood group. However, these antibodies do not correspond to a specific antigen, if they correspond then agglutination occurs (precipitation of blood).

That is why an individual with blood A having antigen A cannot donate blood to an individual with blood group B having antibody a in the plasma which corresponds to antigen A to cause agglutination.

Similarly, blood groups A and B cannot donate blood to an individual of blood group O because antigen A will be attacked by antibody a in blood group O and antigen B will be attacked by antibody b in blood group O to precipitate the recipient's blood. The table below summarizes the possible blood transfusions and the impossible ones.

Blood group compatibilities

Recipient		Donor's blood group			
Blood group	Antibody in plasma	A	B	AB	O
A	B	✓	X	X	✓
B	A	X	✓	X	✓
AB	None	✓	✓	✓	✓
O	a and b	X	X	X	✓

✓ = compatible with recipients blood

X = Incompatible with recipient i.e. agglutination ocurs

NOTE; the recipient's antibody is the one expected to attack and react with the corresponding antigen in the donor's blood.

Whenever the antigen of the donor corresponds with the antibody of the recipient's blood group, an antibody-antigen reaction occurs, leading to agglutination (precipitation or clotting of blood).

Individuals with blood group O are called **universal donors** because they lack antigens which would react with the corresponding antibodies in the recipient's blood.

Individuals with blood group AB are called **universal recipients** because they lack antibodies in their blood plasma which would have reacted with the corresponding antigens in the donor's blood.

RHESUS FACTOR (D-Antigens)

These are antigens which were first observed in the bodies of the Rhesus monkeys. These antigens are also carried on the surface of the erythrocytes of some human beings.

Those people with D-antigens on the surface of their red blood cells are called Rhesus positive (Rh+) while individuals missing such D-antigens are called Rhesus negative (Rh-).

The bodies of individuals do not have already manufactured antibodies against the D-antigens.

One problem associated with the rhesus system arises in pregnancy.

As blood groups are genetically determined, it is possible for the fetus to inherit from the father a blood group which is different from that of the mother. The fetus may for example be rhesus positive when the mother is rhesus negative.

Towards the end of pregnancy especially around birth, fragments of blood cells may cross from the fetus to the mother. The mother responds by producing the rhesus antibody d in response to the rhesus antigen D on the fetal red blood cells.

These antibodies are able to cross the placenta. As the build-up and transfer of rhesus antibodies takes some time, and as the problem only arises during later stages of pregnancy, their concentration is rarely sufficient to have any effect on the first child.

The production of rhesus antibodies by the mother continues for only a few months, but subsequent fetuses may again induce production and are therefore subject to a greater influx of rhesus antibodies. These break down the fetal red blood cells a condition known as **Haemolytic disease** of the new born.

This disease results into acute anaemia which can lead to death of the foetus.

The first born rarely dies because the time is too short for the mother to produce enough antibodies that can pass to the foetus to cause death but subsequent Rh+ foetus can die due to the many antibodies of the mother entering its circulation to cause agglutination.

However, if this is the case and the father is known to be rhesus positive, antibodies (d) from blood-donors are injected into the mother immediately after the first birth. These destroy any fetal cell fragments with antigen D, which may have entered her blood, before they induce the mother to manufacture her own antibodies. The injected antibodies are soon broken down by the mother, and in the absence of new ones being produced subsequent fetuses are not at risk.

NB. If blood with the antigen (rhesus positive) is transfused into a person without the antigen (rhesus negative), antibody d production is induced in line with the usual immune response. For this reason, before transfusion, blood is matched with respect to Rhesus factor as well as ABO system.

This means you can be 1 of 8 blood groups:

A RhD positive (A+)

A RhD negative (A-)

B RhD positive (B+)

B RhD negative (B-)

O RhD positive (O+)

O RhD negative (O-)

AB RhD positive (AB+)

AB RhD negative (AB-)

In most cases, O RhD negative blood (O-) can safely be given to anyone. It's often used in medical emergencies when the blood type is not immediately known.

It's safe for most recipients because it does not have any A, B or RhD antigens on the surface of the cells, and is compatible with every other ABO and RhD blood group.

END