Transport in Animals

Grade 10 Biology study notes, Section 3.2. Every sentence is written to make sense on its own, and every figure is taken from the class textbook.

A. Importance of transport in animals

- Transport is the movement of substances from one part of an animal's body to another.
- Transport carries nutrients, oxygen and water from the environment to the cells that need them.
- Transport also carries metabolic wastes from the cells that make them to the organs that remove them.
- Most animals are multicellular and large, so diffusion alone is too slow to serve every cell.
- Nutrients and oxygen must reach all tissues and cells continuously.
- Glucose and oxygen are needed by cells for energy production.
- Carbon(IV) oxide can poison cells if carbon(IV) oxide is allowed to build up in the body.
- Nitrogenous wastes are highly toxic, so nitrogenous wastes must be removed as soon as they form.
- A transport system in most animals has three parts: a transport fluid, vessels and a means of pumping the fluid.
- The transport system of animals is also called the circulatory system because the transport fluid circulates continuously in vessels.

B. Structure of transport systems in different animals

Insects: open circulatory system

- Insects, like all arthropods, have an open circulatory system.
- In an open system, the transport fluid is called haemolymph.
- Haemolymph is held in the general body cavity, which is called the haemocoel.
- Haemolymph is in direct contact with the tissues, so cells exchange materials directly with the haemolymph.
- Haemolymph loses pressure once haemolymph enters the haemocoel, so haemolymph flows slowly.

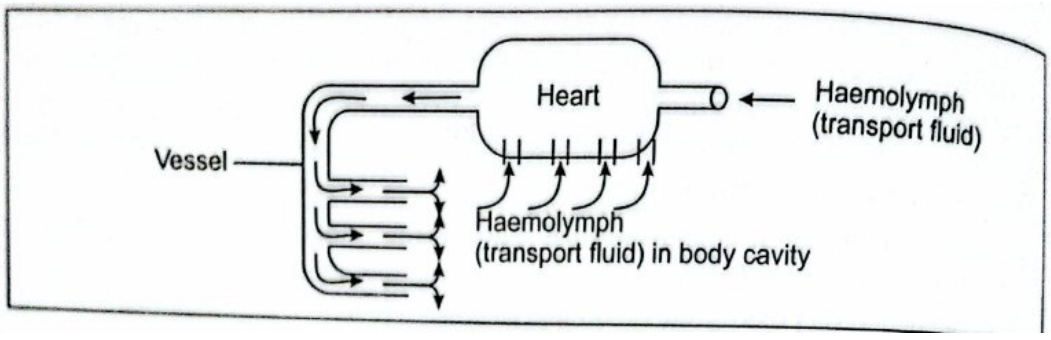


Figure 1: Open circulatory system

- A typical insect such as a cockroach has a tubular heart lying above the alimentary canal.
- The insect heart has thirteen chambers: three in the thorax and ten in the abdomen.
- The front segment of the heart joins the aorta.
- The aorta empties haemolymph into sinuses in the head.
- The sinuses continue into the thorax and abdomen to form the haemocoel.

- Each heart chamber has a pair of side openings called ostia (singular: ostium).
- Ostia have valves that let haemolymph flow into the heart but not out of it.
- The front of every chamber has a pair of valves that prevent backflow of haemolymph.
- Haemolymph contains dissolved food substances and ions.
- Haemolymph carries these substances to all tissues and carries metabolic wastes from cells to excretory organs.
- Insects do not use haemolymph to transport respiratory gases.
- Oxygen and carbon(IV) oxide move through the tracheal system, which is a network of air-filled tubes.
- The tracheal tubes branch into the smallest tubes, which are called tracheoles.
- Gaseous exchange between the tracheoles and the cells happens by diffusion.

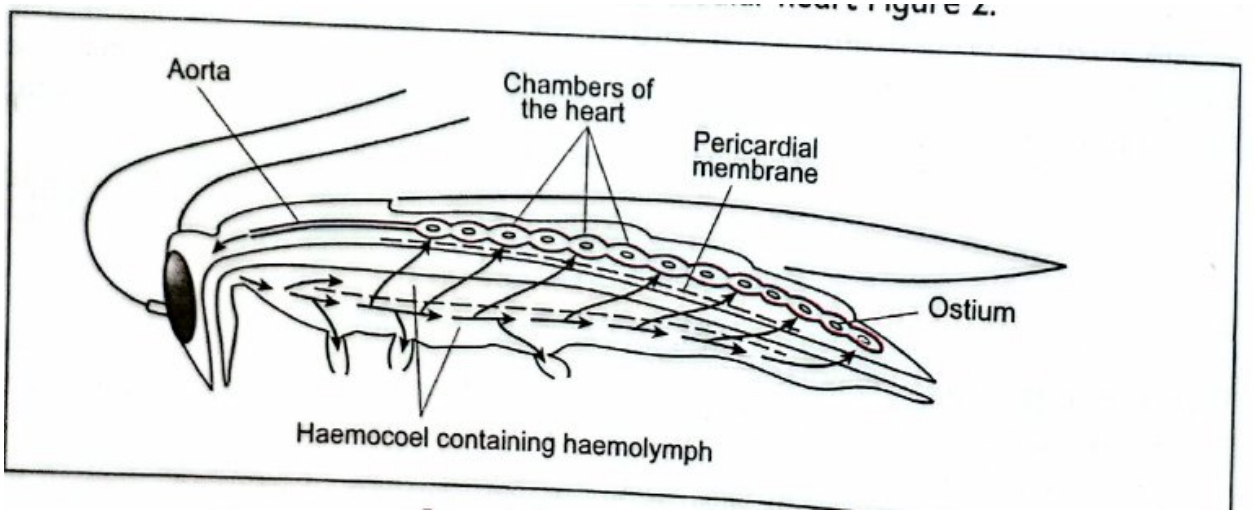


Figure 2: Open circulatory system of an insect

Closed circulatory system and types of circulation

- A closed circulatory system is found in all vertebrates.
- In a closed system, blood is confined inside blood vessels.
- A powerful muscular heart pumps blood into the body tissues and back to the heart.
- Blood in a closed system does not touch the tissues directly, so exchange of materials is indirect through tissue fluid.

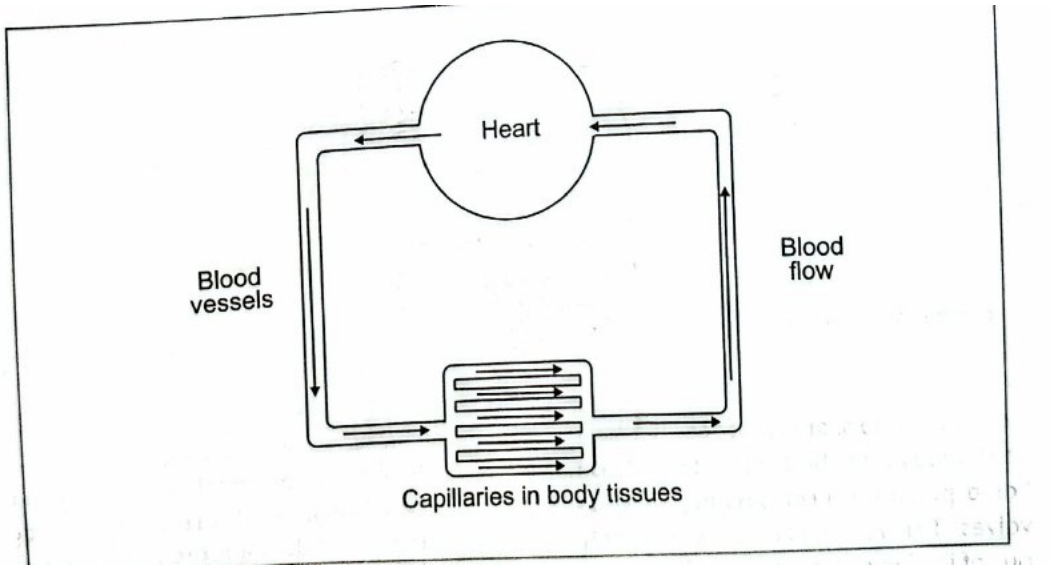


Figure 3: Closed circulatory system

Open circulatory system	Closed circulatory system
Haemolymph is pumped into the general body cavity (haemocoel).	Blood is pumped into closed vessels.
Haemolymph loses pressure and flows slowly, so supply of materials and removal of wastes is slow and animals are less active.	High blood pressure is maintained, so blood flows fast, supply and removal are faster and animals are more active.
Haemolymph is in direct contact with body tissues.	Blood has no direct contact with tissues; exchange is through tissue fluid.

- A single circulation is a closed system in which blood flows through the heart once in every complete circuit.
- A double circulation is a closed system in which blood flows through the heart twice in every complete circuit.
- In single circulation, blood pressure falls sharply at the capillaries of the gas exchange surface.
- Because of that pressure drop, blood in a single circulation reaches the body tissues at low pressure and flows slowly.
- Transport of materials to tissues and cells is therefore less efficient in single circulation.
- In double circulation, blood returns to the heart after gas exchange and is pumped again at high pressure to all body systems.
- Animals with double circulation supply materials and remove wastes more effectively, so these animals are more active than animals with single circulation.

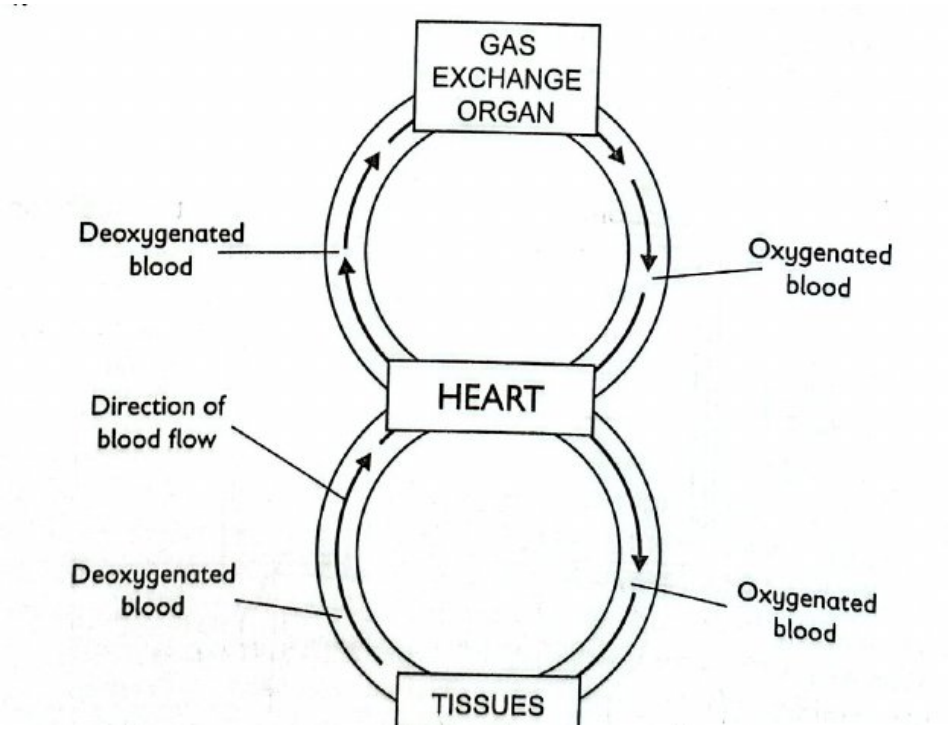


Figure 4: Illustration of double circulation in animals

Fish

- Fish have a single closed circulation.
- The fish heart has two chambers: one atrium and one ventricle.
- Blood from the body tissues flows into the atrium and then into the ventricle.
- The ventricle pumps deoxygenated blood to the capillaries of the gills.
- Blood leaving the gills is oxygenated and flows on to the body tissues.
- Deoxygenated blood from the body tissues then returns to the heart, and the circuit is complete.
- Dissolved food substances are also carried in the blood to all tissues and cells.

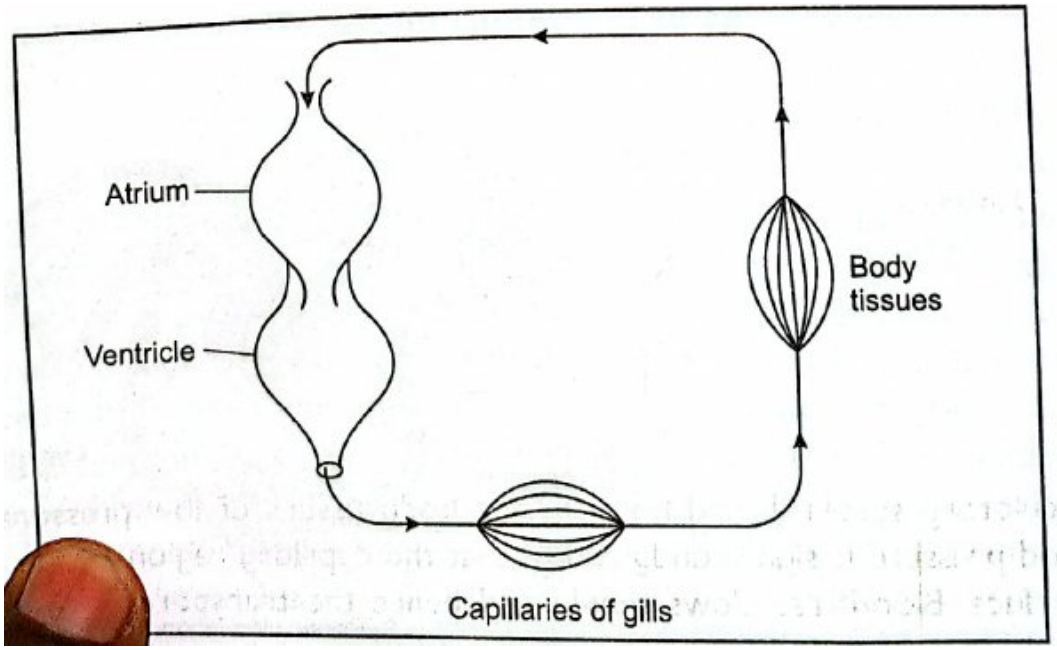


Figure 5: Single circulation in fish

Amphibians

- Amphibians are animals that live partly in water and partly on land, for example newts, salamanders, frogs and toads.
- An amphibian heart has three chambers: two atria and one ventricle.
- Amphibians have double circulation.
- One circulatory route takes blood to the lungs and skin for oxygenation.
- The other circulatory route takes oxygenated blood to the rest of the body.
- The left atrium receives oxygenated blood from the lungs and skin.
- The right atrium receives deoxygenated blood from the rest of the body.
- Oxygenated and deoxygenated blood mix in the single ventricle, which lowers the efficiency of oxygenation.
- A ridge in the ventricle reduces the mixing by sending oxygenated blood to the body and deoxygenated blood to the lungs and skin.

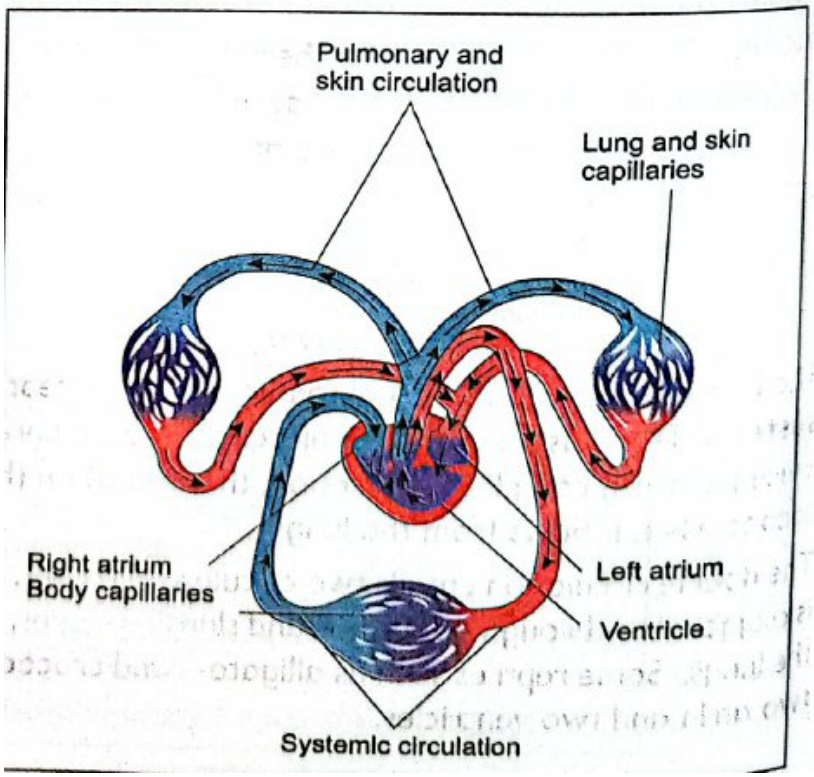


Figure 6: Circulatory system in amphibians

Reptiles

- Reptiles are animals with dry, scaly skin, for example turtles, tortoises, crocodiles, lizards and chameleons.
- Most reptiles have a three-chambered heart with two atria and one ventricle.
- The reptile ventricle is partly divided by a septum.
- The septum greatly reduces the mixing of oxygenated and deoxygenated blood.
- Some reptiles, such as crocodiles and alligators, have a four-chambered heart with two atria and two ventricles.
- Reptiles have a closed circulatory system with double circulation.
- Reptile blood is oxygenated through the lungs only, unlike amphibian blood, which is oxygenated through the lungs and the skin.

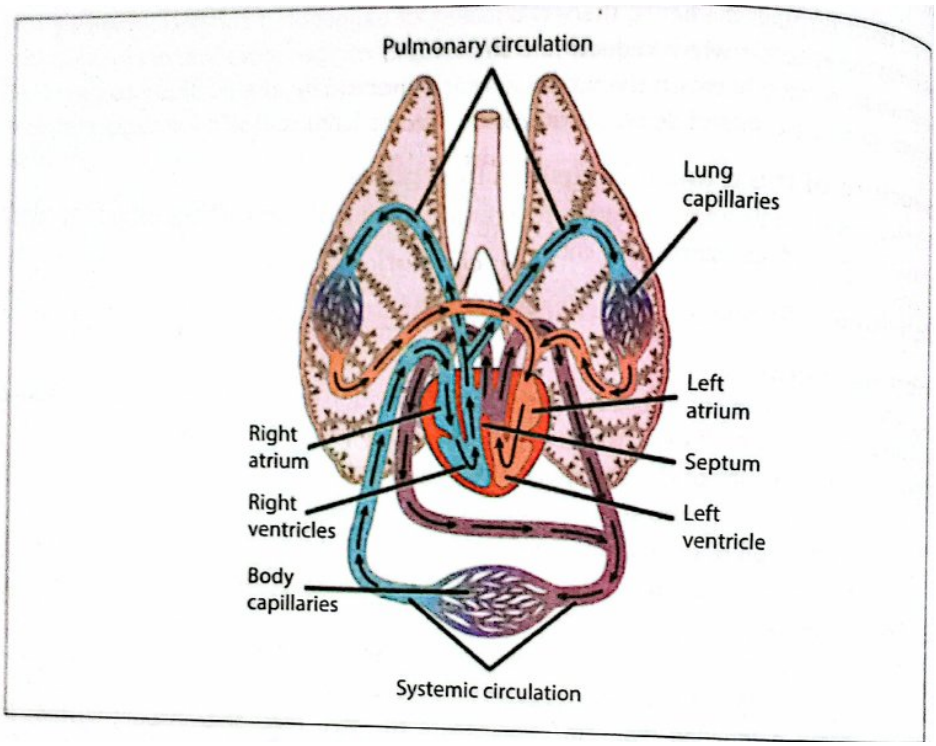


Figure 7: Circulation in the heart of a reptile

Mammals

- Mammals have a double circulatory system with a four-chambered heart: two atria and two ventricles.
- In pulmonary circulation, deoxygenated blood flows from the heart to the lungs through the pulmonary artery.
- Oxygenated blood then returns from the lungs to the heart through the pulmonary vein.
- In systemic circulation, oxygenated blood is pumped from the heart to all parts of the body through the aorta.
- Deoxygenated blood from the body tissues returns to the heart through the vena cava.
- Coronary circulation is part of systemic circulation and supplies blood to and from the heart itself.

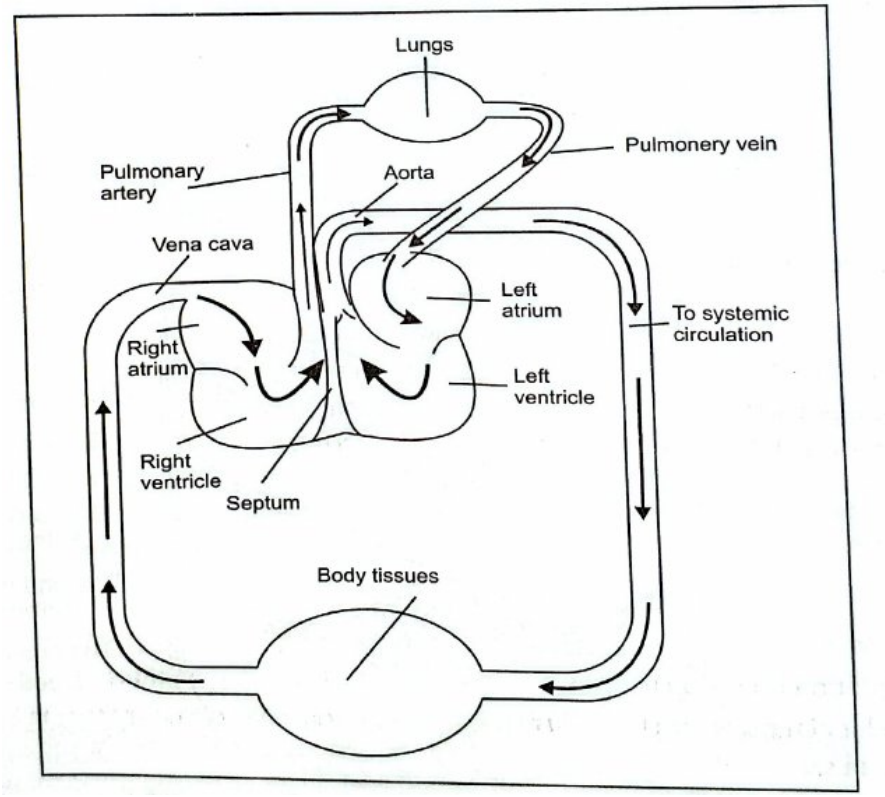


Figure 8 (a): Double circulation in mammals

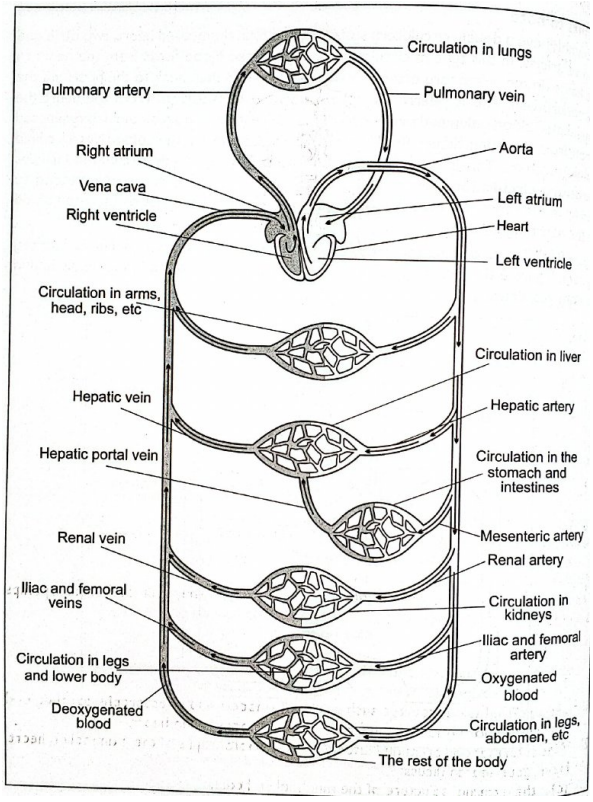


Figure 8 (b): General blood circulation in mammals

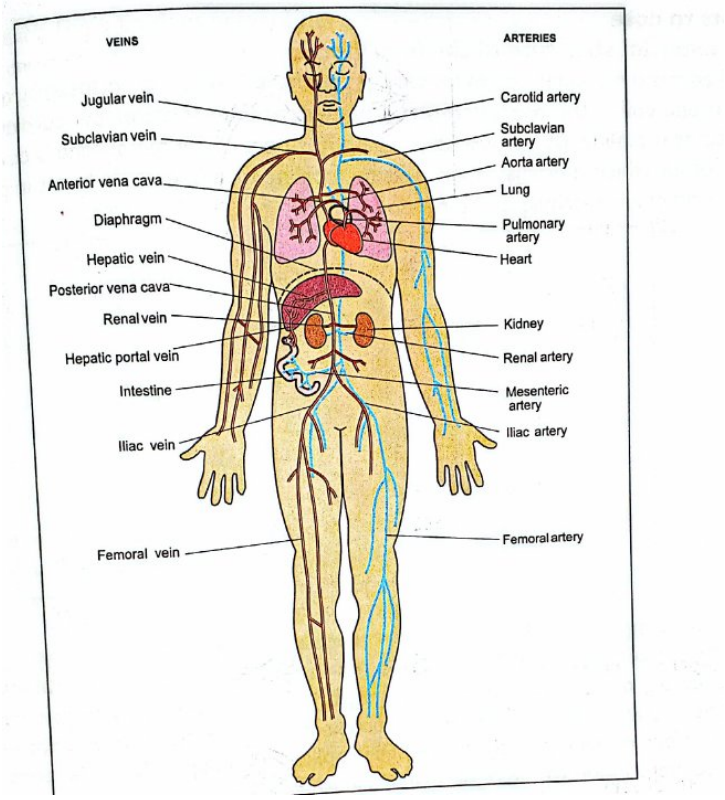


Figure 8 (c): General blood circulation in humans

External structure of the mammalian heart

- The heart is a muscular organ in the chest cavity between the lungs.
- The heart pumps blood to the whole body.
- The pericardium is a translucent membrane that encloses the heart.
- The pericardium secretes pericardial fluid, which lubricates the heart as the heart works.
- The outer part of the pericardium is covered with a layer of fat that absorbs shock.
- The pericardium keeps the heart in position and prevents the heart from overstretching.
- The heart is made of cardiac muscle, which has special interconnected muscle fibres.
- The coronary artery supplies the heart muscle with blood.
- The coronary artery branches from the aorta just beyond the semilunar valves.
- The coronary artery divides into capillaries in the heart muscle.
- These capillaries join to form the coronary vein, which carries blood to the right atrium.

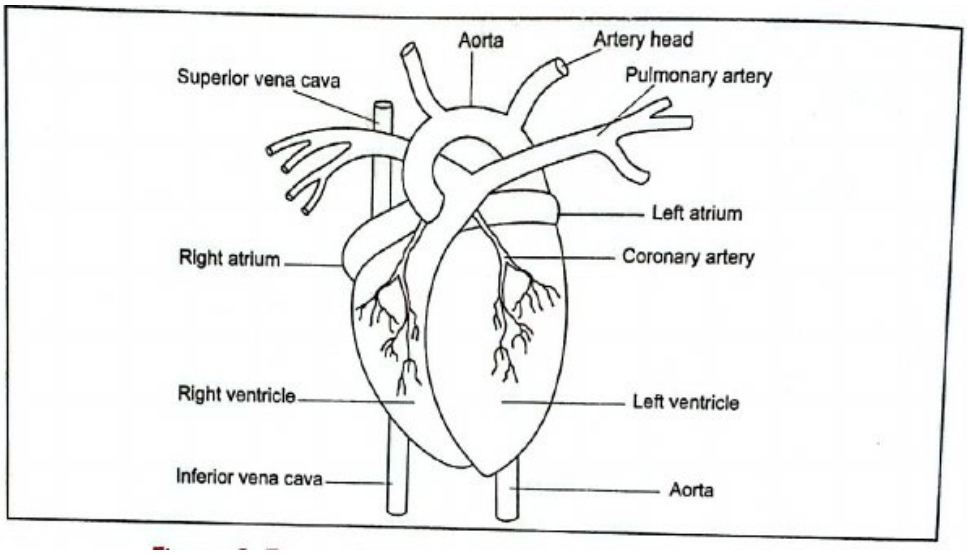


Figure 9: External structure of the mammalian heart

Internal structure of the mammalian heart

- The mammalian heart has four chambers: two atria and two ventricles.
- The atria are the upper chambers and the ventricles are the lower chambers.
- The atria are thin-walled and smaller in volume than the ventricles.
- The right atrium receives deoxygenated blood from the body organs, except the lungs.
- The left atrium receives oxygenated blood from the lungs through the pulmonary vein.
- The ventricles have thick walls made of cardiac muscle.
- The wall of the left ventricle is thicker than the wall of the right ventricle.
- The thicker left ventricle wall generates the high pressure needed to push blood to distant body tissues.
- The right ventricle only pumps blood a short distance to the lungs.
- A thick wall called the septum separates the left half of the heart from the right half.
- The septum prevents oxygenated and deoxygenated blood from mixing.
- Atrioventricular (cuspid) valves lie between the atria and the ventricles.
- The tricuspid valve is on the right side and the bicuspid valve is on the left side.
- Atrioventricular valves prevent blood from flowing back into the atria when the ventricles contract.
- Tendons attached to the ventricle walls support the valves and stop the valves from turning inside out.
- Semilunar valves are cup-like valves at the base of the pulmonary artery and the aorta.
- Semilunar valves open when the ventricles contract and close when the ventricles relax.
- Semilunar valves prevent blood from flowing back into the ventricles.

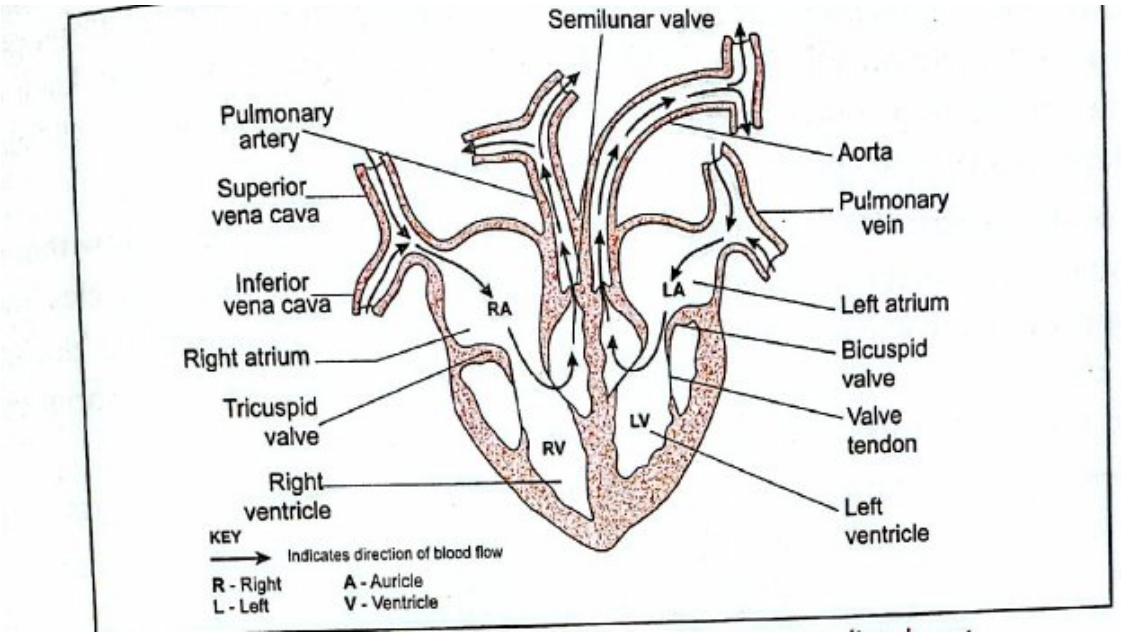


Figure 10: Longitudinal section of the mammalian heart

C. Pumping mechanism of the mammalian heart

- Every heartbeat consists of rhythmic contraction, called systole, and relaxation, called diastole.
- One complete sequence of systole and diastole is called the cardiac cycle.
- In cardiac diastole, both atria and both ventricles are relaxed and filling with blood.
- During diastole, the atrioventricular valves are open.
- In atrial systole, the atria contract and push blood through the open atrioventricular valves into the ventricles.
- During atrial systole, the ventricles are still relaxed.
- In ventricular systole, the ventricles contract after filling with blood.
- Ventricular contraction raises pressure, which closes the atrioventricular valves and produces the first heart sound, "lub".
- The high pressure also opens the semilunar valves.
- Blood is then pumped out of the heart through the pulmonary artery and the aorta.
- At the end of ventricular systole, pressure in the ventricles falls below pressure in the aorta and pulmonary artery.
- The semilunar valves then close, which produces the second heart sound, "dub".
- Closure of the semilunar valves marks the end of one cardiac cycle and the start of a brief diastole.

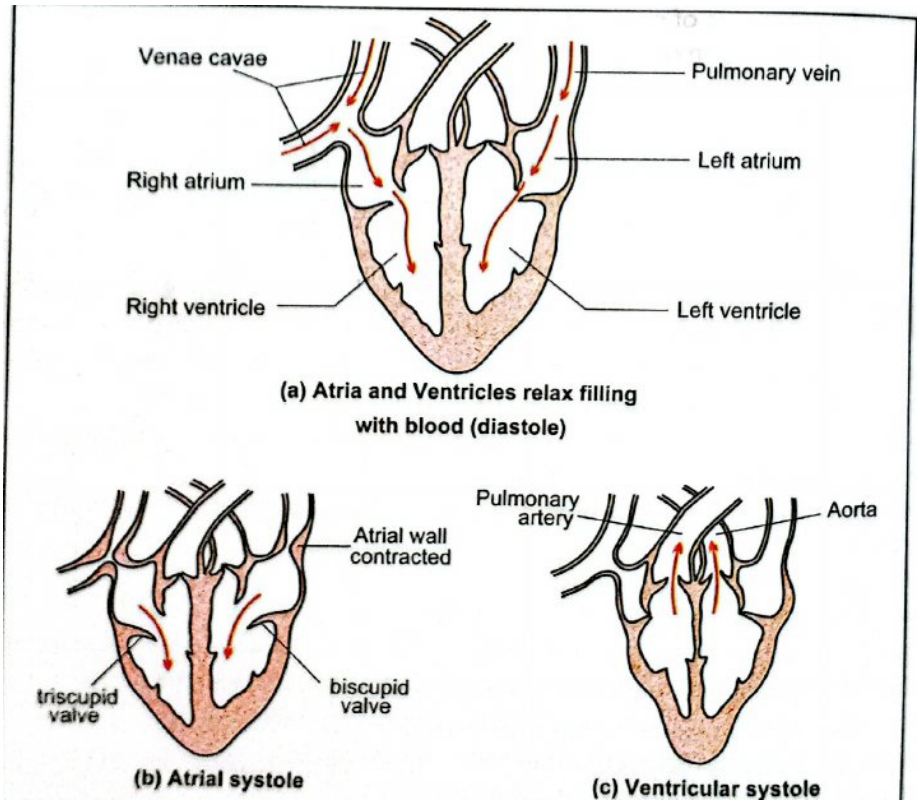


Figure 11: Representation of a cardiac cycle

- Blood leaves the heart into the aorta and other arteries at high pressure in rhythmic waves called pulses.
- A pulse is caused by the widening of arteries and matches the heartbeat.
- A pulse can be felt where a large artery near the skin is pressed against a bone, for example at the wrist.



Figure 14: Pressing at the wrist to identify an artery

Control of the heartbeat

- Cardiac muscle contracts and relaxes rhythmically without becoming tired.
- Cardiac muscle cells are interconnected, so waves of contraction travel through the whole muscle mass.

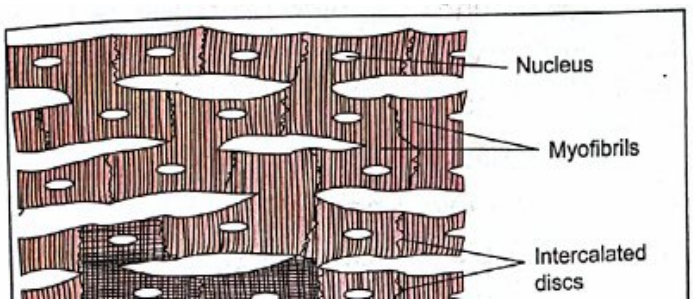


Figure 12: Structure of the cardiac muscle

- The heartbeat starts inside the heart muscle without nervous stimulation, so heart muscle is described as myogenic.
- The pacemaker, called the sinoatrial node (SAN), starts each heartbeat.
- The SAN is a small area of specialised cardiac muscle in the wall of the right atrium near the vena cava.
- The SAN sends a wave of excitation across the atria.
- The wave of excitation reaches the atrioventricular node (AVN) near the septum.
- The wave then travels down the Purkinje tissue to the bottom of the heart and spreads to the ventricles.
- This spread causes the ventricles to contract (ventricular systole).
- The vagus nerve slows down the heartbeat.
- The sympathetic nerve speeds up the heartbeat.
- The normal heart rate in humans is about 72 beats per minute.
- Heart rate varies with activity, age and health.
- A stethoscope is the instrument used to monitor the heartbeat.

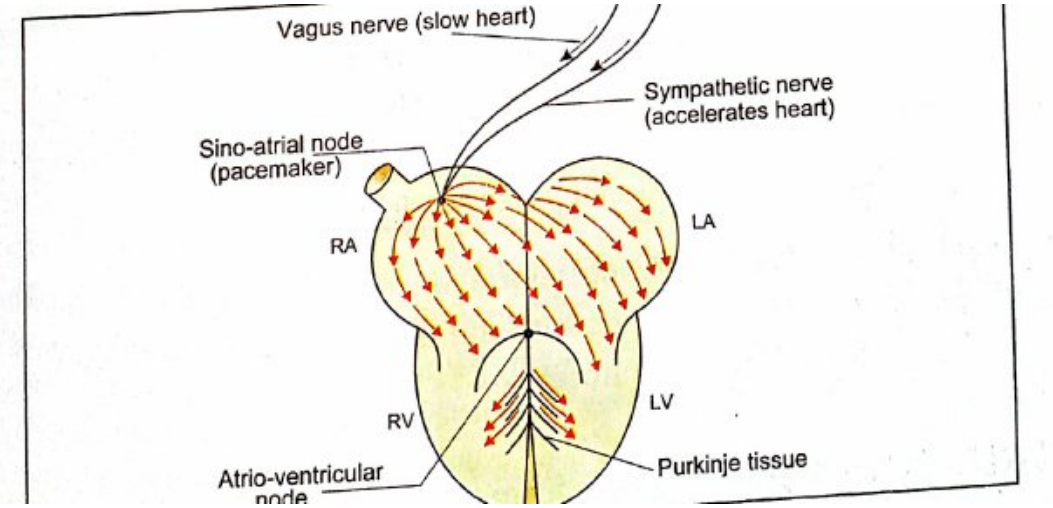


Figure 13: Electrical excitation that follows the contraction of the heart

Blood vessels

- The blood vessels are arteries, veins and capillaries.

Arteries

- Arteries are blood vessels that carry blood away from the heart.
- Arteries lie deep in the muscles.
- Blood in arteries flows under high pressure from the pumping of the heart.
- The aorta carries oxygenated blood from the heart to all parts of the body except the lungs.

- The pulmonary artery carries deoxygenated blood from the heart to the lungs.
- Arteries have thick muscular walls and a narrow lumen to withstand high pressure.
- The artery wall has three layers.
- The innermost layer is the endothelium, a smooth lining of cells that offers the least resistance to blood flow.
- The middle layer is made of elastic fibres and smooth muscle.
- The outer layer is made of inelastic collagen fibres.
- When the ventricles contract, the arteries stretch outwards to receive blood.
- When the ventricles relax, the muscular layer of the arteries contracts and forces blood forward, which produces the pulsating action.
- Nerves and hormones control the muscular wall of arteries, which changes the diameter of the lumen and regulates blood flow to organs.
- The aorta is the main artery leaving the heart.
- The aorta branches into arteries that divide into small vessels called arterioles.
- Arterioles branch further into blood capillaries that spread through the body tissues.

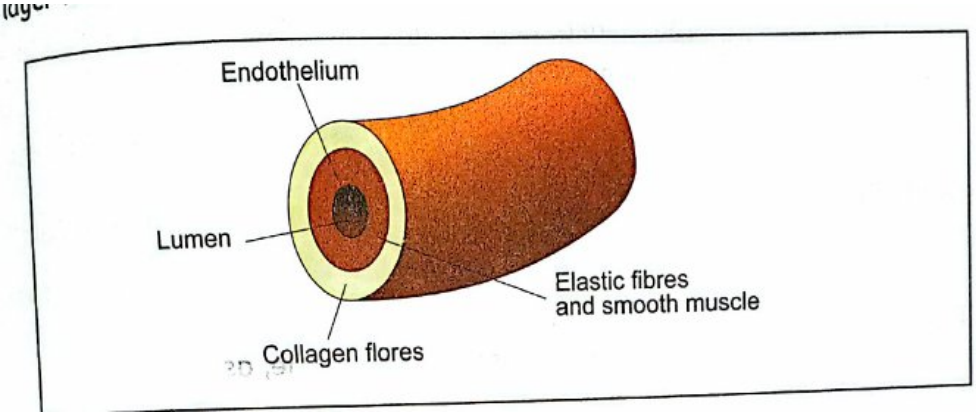


Figure 15: Structure of the artery

Capillaries

- Capillaries are the smallest blood vessels.
- Capillaries are numerous and lie so close to the tissues that every cell is near a capillary.
- The capillary wall is a single layer of endothelium, one cell thick.
- A wall one cell thick gives the shortest distance for exchange of substances between blood and cells.

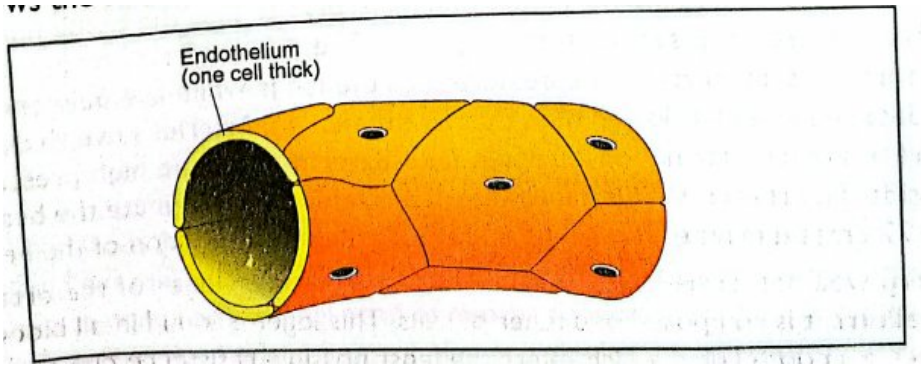


Figure 16 (a): Portion of a capillary

- Capillary walls are permeable to water and to small molecules in solution.
- Arterioles branch into many narrow capillaries, which increases surface area and pressure.
- High pressure forces the fluid part of the blood out through the capillary walls into the spaces between cells.

- This process is called ultrafiltration or pressure filtration.
- The fluid formed is called tissue fluid.
- Tissue fluid is similar to plasma but lacks proteins, red blood cells and some white blood cells.
- Phagocytic white blood cells can squeeze between capillary wall cells into the tissue fluid.
- Cells take glucose, amino acids, vitamins, hormones and mineral ions from tissue fluid.
- Cells release metabolic wastes such as carbon(IV) oxide and urea into tissue fluid.
- At the venule end of the capillary bed, blood pressure is lower than the pressure of the tissue fluid.
- Proteins kept in the capillaries create a high osmotic pressure at the venule end.
- This osmotic pressure draws much of the tissue fluid back into the blood by osmosis.
- Carbon(IV) oxide and other substances also diffuse back into the blood.
- The remaining tissue fluid drains into blind-ending lymph vessels and becomes lymph.
- Lymph eventually joins the blood through the subclavian vein in the neck region.
- Venules from the capillary bed join to form larger vessels called veins.

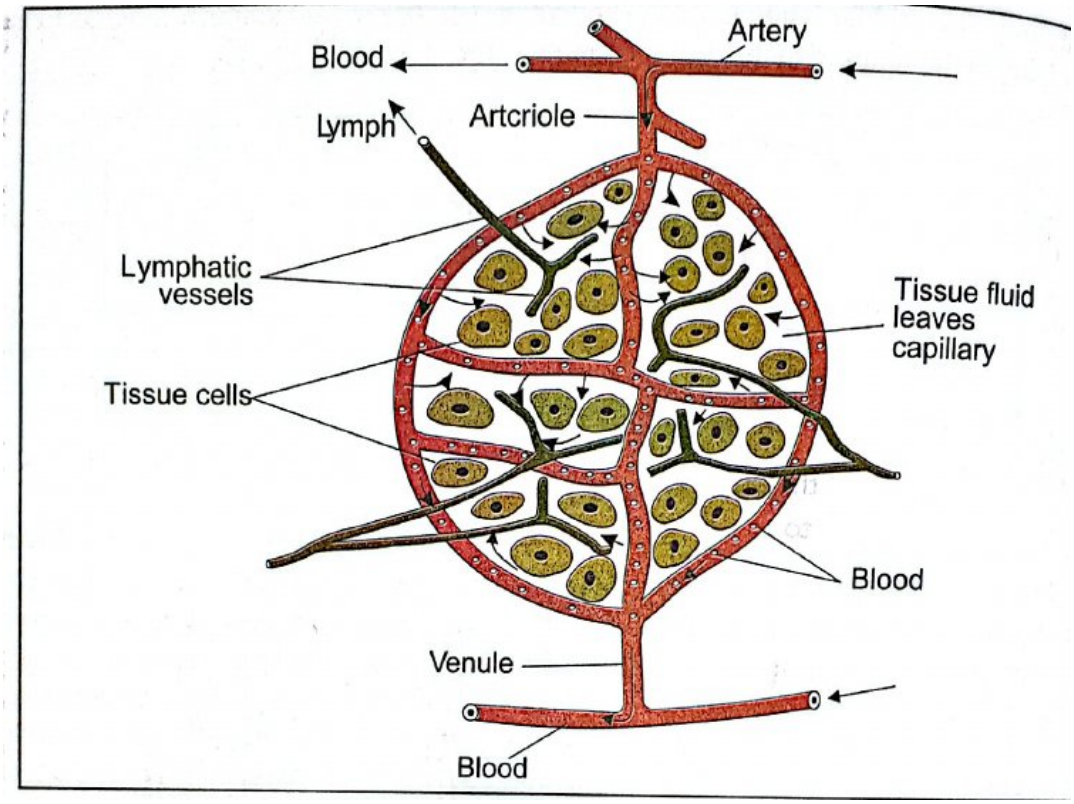


Figure 16 (b): Relationship between capillaries, cells and lymphatics

Veins

- Veins are blood vessels that carry blood from all parts of the body back to the heart.
- Veins lie close to the body surface, just under the skin.
- Veins at the back of the hand bulge and become visible when a tourniquet slows blood flow.
- Vein walls are thin and have fewer elastic fibres.
- Veins have a relatively wide lumen, which offers little resistance to blood flow.
- Blood pressure in veins is very low because of the strong resistance to flow at the capillary bed.
- Veins have valves along their length to prevent backflow, so blood flows only towards the heart.
- Contraction of skeletal muscles squeezes the large veins in the legs and arms and pushes blood towards the heart.
- This muscle action explains why physical activity is important.

- All veins carry deoxygenated blood except the pulmonary vein, which carries oxygenated blood from the lungs to the heart.
- Blood in veins generally has high levels of metabolic wastes and low levels of nutrients.
- The renal vein is an exception because blood in the renal vein has low nitrogenous waste after the kidney has removed the waste.
- The hepatic portal vein is an exception because the hepatic portal vein carries blood rich in nutrients from the digestive gut to the liver.

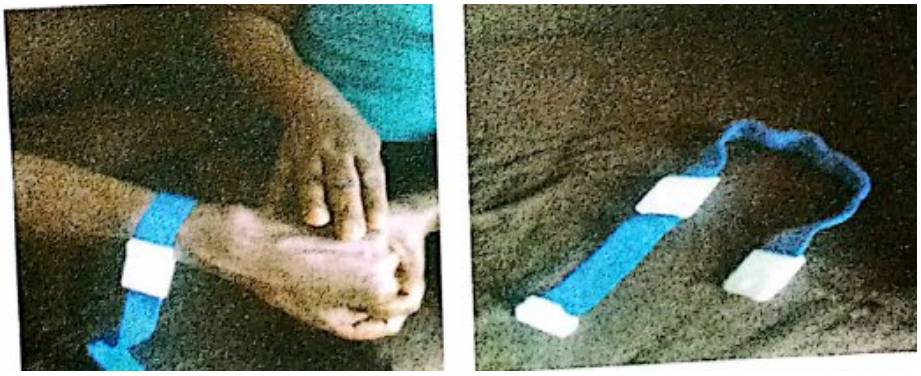


Figure 17: Exposing hand veins with a tourniquet (left) and a tourniquet (right)

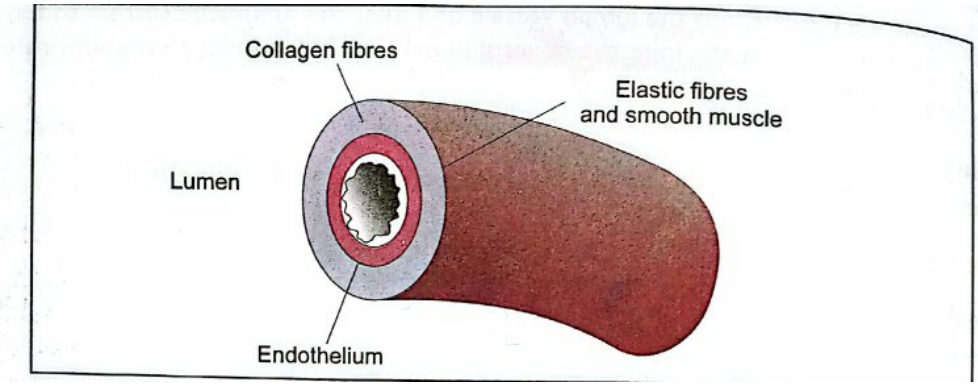


Figure 18 (a): Structure of a vein

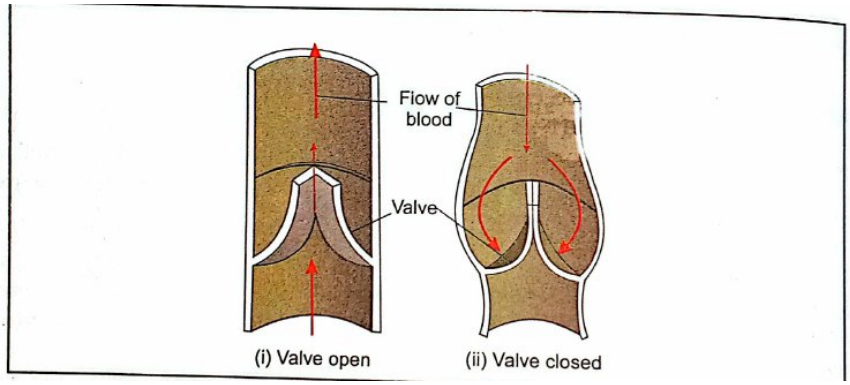


Figure 18 (b): Valves in veins, open (left) and closed (right)

Arteries	Veins
Walls are thick, muscular, with more elastic fibres.	Walls are thin, less muscular, with fewer elastic fibres.
Have no valves except at the base of the large arteries leaving the heart.	Have valves at intervals along their length.
Narrow lumen.	Wide lumen.
Carry blood away from the heart.	Carry blood towards the heart.
Carry oxygenated blood except the pulmonary artery.	Carry deoxygenated blood except the pulmonary vein.

Arteries	Veins
Blood flows rapidly under high pressure, in pulses.	Blood flows slowly under low pressure, smoothly with no pulses.
Can constrict and dilate to change lumen diameter.	Cannot change lumen diameter.

Composition of blood

- Mammalian blood is a tissue made of plasma with cells suspended in the plasma.
- The cells are red blood cells (erythrocytes), white blood cells (leucocytes) and platelets (thrombocytes).

Plasma

- Blood plasma is a pale yellow fluid that is about 90% water.
- Plasma contains glucose, amino acids, hormones, some enzymes, vitamins, lipids, urea and carbon(IV) oxide.
- Plasma also contains plasma proteins such as antibodies, albumin and fibrinogen.
- Serum is plasma from which fibrinogen and cells have been removed.
- Plasma carries blood cells, which contain oxyhaemoglobin, to the tissues.
- Plasma is the main medium that carries dissolved substances to the liver and other tissues.
- Plasma carries metabolic wastes such as urea and carbon(IV) oxide to the excretory organs.
- Plasma carries hormones from endocrine glands to their target organs.
- Plasma carries a small amount of oxygen and carbon(IV) oxide because these gases are only slightly soluble in water.
- Plasma helps to regulate the pH of body fluids.
- Plasma distributes heat around the body and so helps to regulate temperature.

Red blood cells (erythrocytes)

- Red blood cells contain a red respiratory pigment called haemoglobin.
- A human has about 5 million red blood cells in each cubic millimetre of blood.
- Adult red blood cells are made in the bone marrow of short bones such as the sternum, ribs and vertebrae.
- In the embryo, red blood cells are made in the liver and spleen.
- Mature red blood cells have no nucleus and have a sunken centre, so each cell looks like a biconcave disc.
- The absence of a nucleus and most organelles leaves room to pack more haemoglobin, so each cell can carry more oxygen.
- The biconcave shape increases the surface area for diffusion of respiratory gases.
- The biconcave shape also makes red blood cells flexible enough to squeeze through narrow capillaries.
- Red blood cells live for about four months and are then broken down in the liver and spleen.
- Iron released from broken-down red blood cells is used to make new red blood cells.

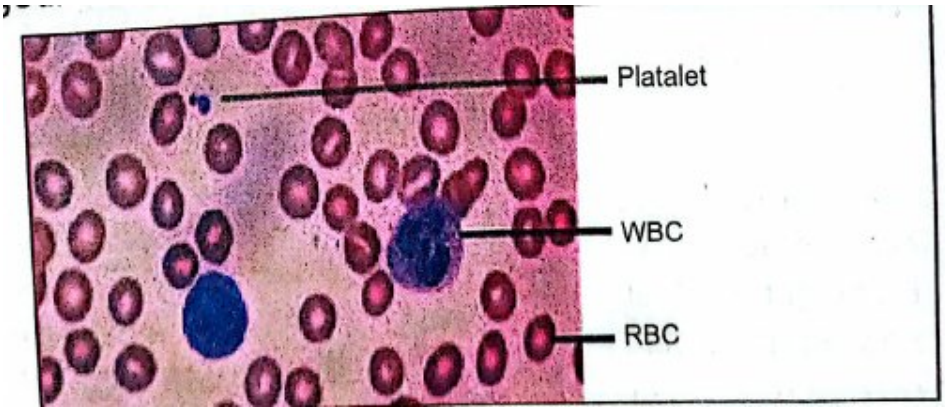


Figure 19: Blood smear showing platelets, white blood cells and red blood cells

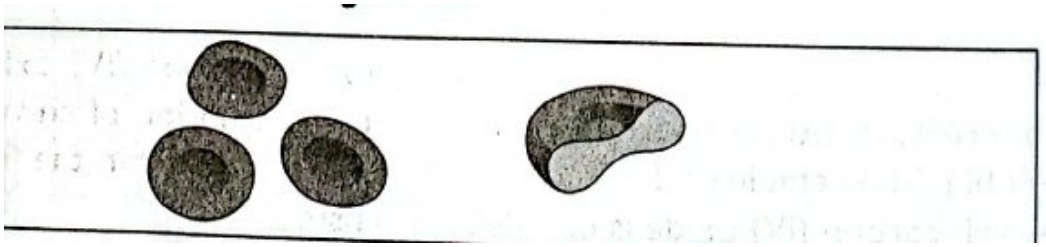


Figure 20: Red blood cells

Functions of red blood cells

- Haemoglobin combines readily with oxygen at the lungs, where oxygen concentration is high, to form oxyhaemoglobin.
- Oxyhaemoglobin releases oxygen in the tissues, where oxygen concentration is low.
- The reaction is: haemoglobin + oxygen ⇌ oxyhaemoglobin (forms in the lungs, splits in the tissues).
- People living at high altitude make more red blood cells and more haemoglobin, which raises the oxygen-carrying capacity of the blood.
- Haemoglobin also combines with carbon(II) oxide to form carboxyhaemoglobin.
- Carboxyhaemoglobin does not release the gas easily, so less haemoglobin is left to carry oxygen.
- Carbon(II) oxide (carbon monoxide) is a respiratory poison that can be fatal if breathed in for a long time.
- Charcoal stoves must not be burned in poorly ventilated rooms because burning charcoal produces carbon(II) oxide.
- Carbon(IV) oxide from cellular respiration is toxic and must be removed before carbon(IV) oxide builds up.
- The enzyme carbonic anhydrase in red blood cells speeds up the reaction of carbon(IV) oxide with water to form weak carbonic acid.
- About 85% of carbon(IV) oxide is transported as carbonic acid products.
- About 10% of carbon(IV) oxide is carried as carbaminohaemoglobin, which is carbon(IV) oxide combined with haemoglobin.
- About 5% of carbon(IV) oxide is dissolved in plasma.

White blood cells (leucocytes)

- White blood cells have a nucleus and no haemoglobin, so the cytoplasm looks colourless.
- White blood cells are larger and fewer than red blood cells, at about 7000 per cubic millimetre of blood.
- The number of white blood cells rises greatly during an infection.

- White blood cells are formed in the bone marrow of long bones and in lymph nodes.
- White blood cells protect the body against disease-causing micro-organisms and their secretions.
- Granulocytes (phagocytes) have lobed nuclei and granular cytoplasm and are made in the bone marrow.
- Granulocytes move by amoeboid movement through capillary walls into affected tissues.
- Granulocytes engulf and digest pathogens by phagocytosis.
- Dead phagocytes and dead micro-organisms together form pus.
- Agranulocytes have no granules in the cytoplasm and are of two types: monocytes and lymphocytes.
- Monocytes have large lobed nuclei, move by amoeboid movement and engulf pathogens, so monocytes are phagocytic.
- Lymphocytes have rounded nuclei and are made in the thymus and lymph glands.

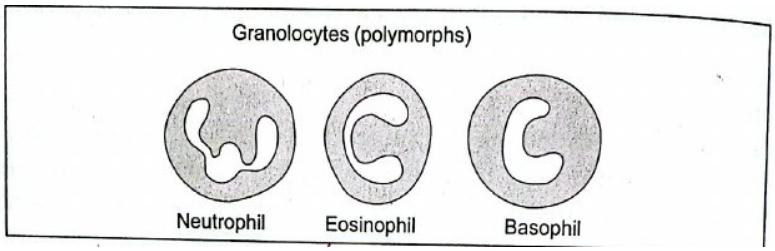


Figure 21 (a): Granulocytes

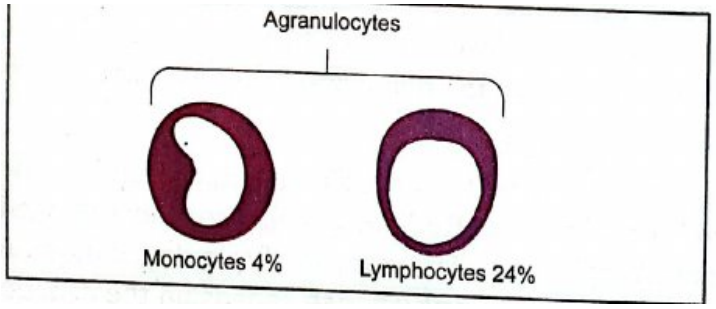


Figure 21 (b): Agranulocytes

- Lymphocytes protect the body by making antibodies when micro-organisms invade.
- Antitoxins are antibodies that neutralise the toxins made by pathogens.
- Agglutinins are antibodies that make pathogens clump together, which stops the pathogens multiplying so that phagocytes can ingest them.
- Lysins are antibodies that destroy pathogens by digesting their cell membranes or walls.
- Opsonins are antibodies that stick to the surface of micro-organisms, which makes the micro-organisms easier for phagocytes to ingest.
- After recovery from an infection, the level of antibodies falls gradually.

Platelets (thrombocytes)

- Platelets are fragments of large cells in the bone marrow.
- Platelets are disc-shaped, have no nucleus, and look star-shaped in blood taken from the body.
- Blood contains about 2.5 million platelets per cubic millimetre.
- Platelets play an important role in blood clotting when a blood vessel is injured.

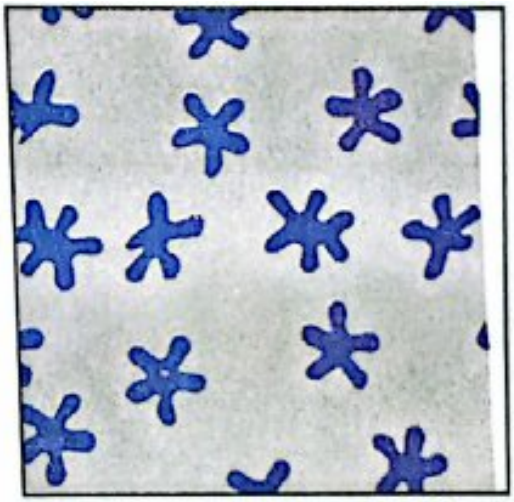


Figure 22: Blood platelets

Dissection of a small mammal (Activity 13)

- Wear surgical gloves, handle sharp instruments carefully and dispose of tissue remains responsibly.
- Lay the freshly killed mammal on a dissecting tray with the ventral side uppermost and pin the limbs out with slanting pins.
- Lift the skin of the abdomen with forceps and cut along the mid-line from the mouth to the anus, then remove the skin.
- Cut the abdominal wall along the edge of the ribs and towards the anus, then pull the wall to the sides.
- Cut the oesophagus, remove the alimentary canal and tie off the main mesenteric blood vessel before removing fat to expose the heart and vessels.

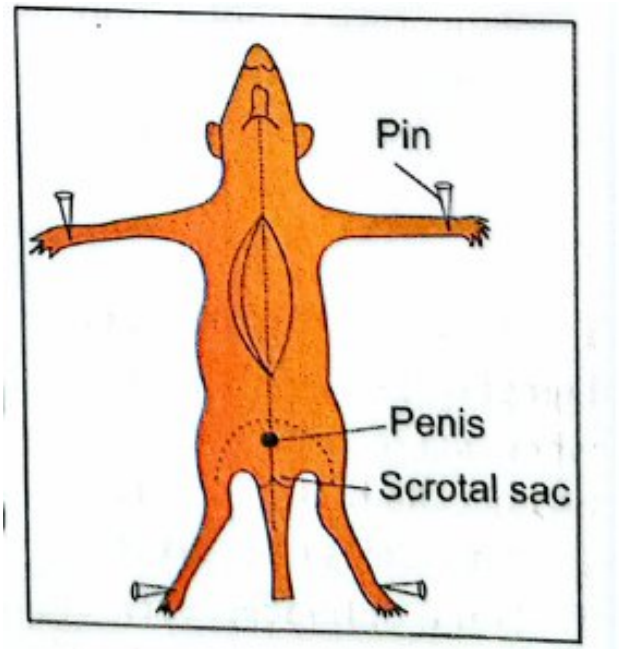


Figure 23 (a): Mammal pinned out for dissection

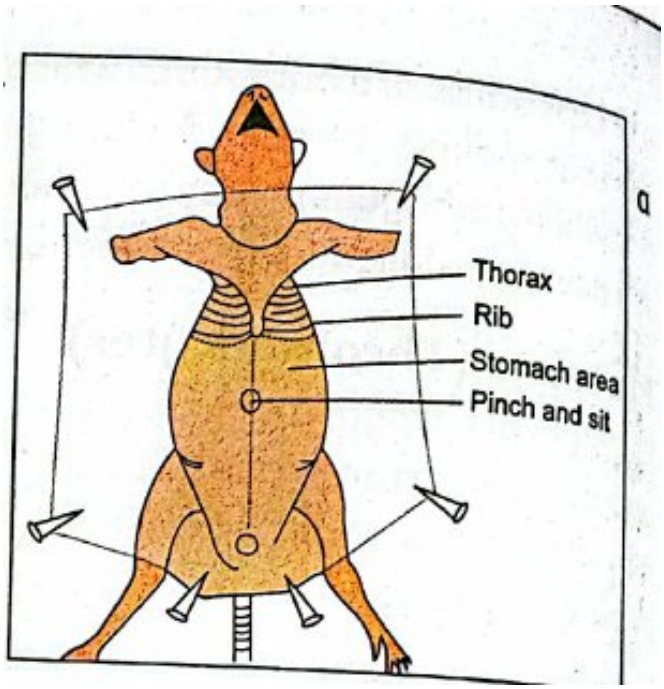


Figure 23 (b): Cutting lines on the abdominal wall

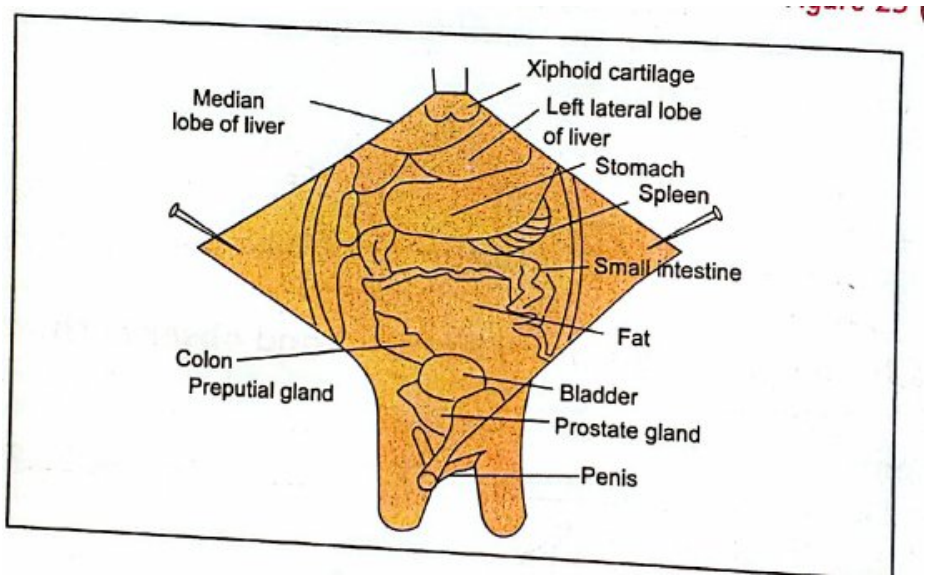


Figure 23 (c): Organs after the abdominal wall is pulled aside

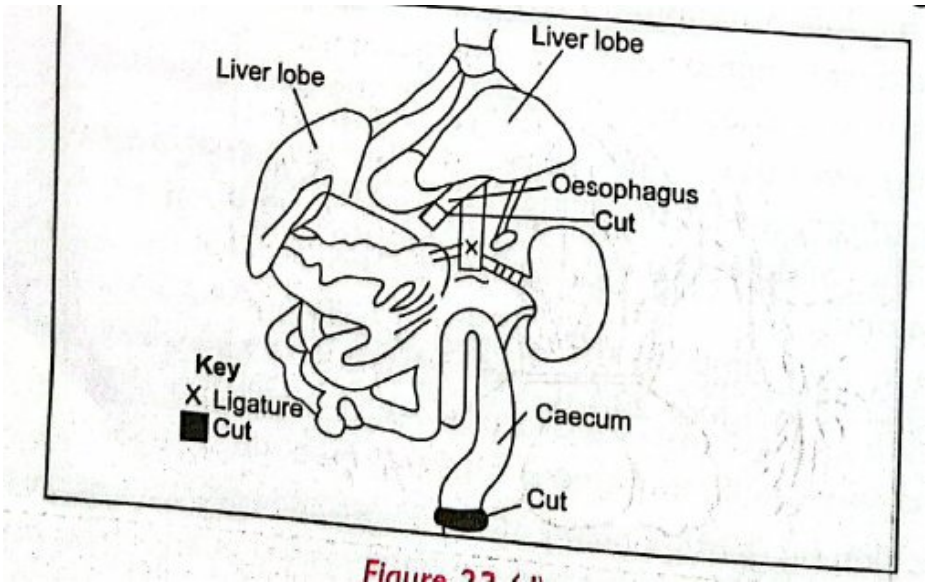


Figure 23 (d): Removing the alimentary canal

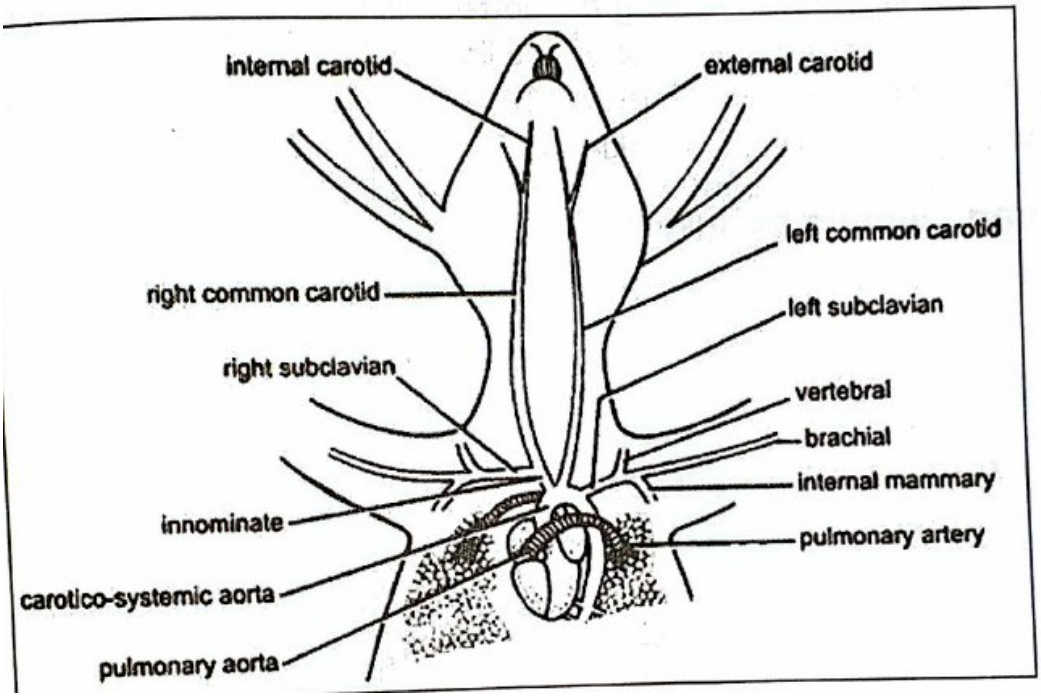


Figure 23 (e): Blood vessels in the chest and head region

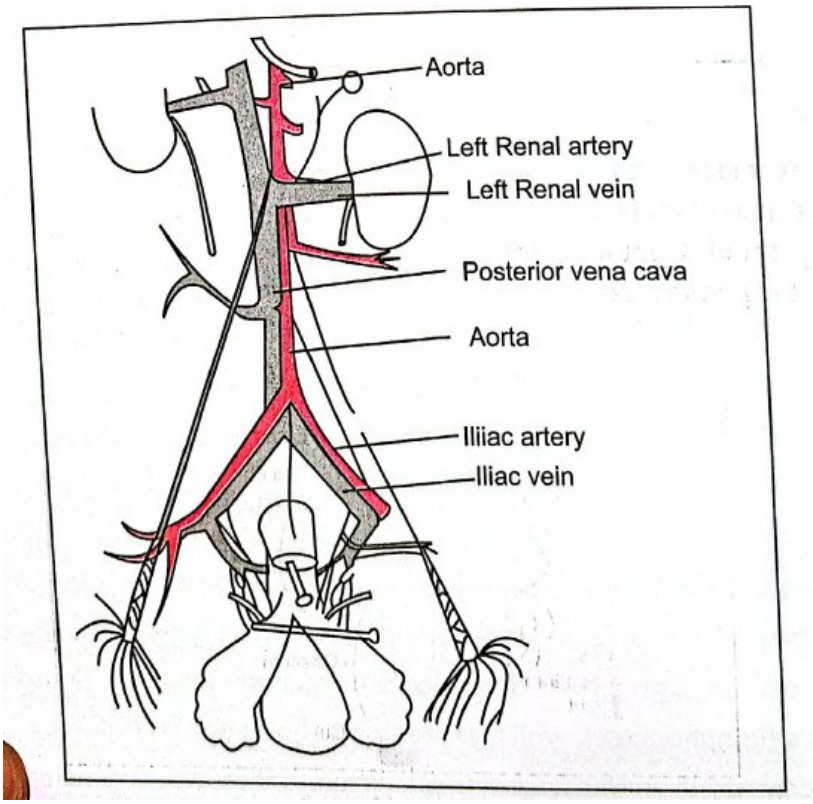


Figure 23 (f): Blood vessels in the abdomen and lower part of the body

D. Lymphatic system, immune system and blood clotting

Lymphatic system

- The lymphatic system is a network of lymph vessels spread to all tissues and cells.
- The lymphatic system includes tissues and organs such as the tonsils, thymus, spleen, bone marrow and lymph nodes.
- The lymphatic system keeps fluid balance in the body and protects the body against infection.
- Lymph is the fluid that flows through the lymphatic system.
- Lymph is the extracellular (interstitial) fluid that drains from cells and tissues.
- Lymph has almost the same composition as tissue fluid.
- Lymph also carries fatty acids and glycerol and contains lymphocytes and small amounts of nutrients and oxygen.
- The lymphatic system empties lymph into the bloodstream near the neck through the subclavian vein.
- Lymph nodes are small lumps of tissue that contain lymphocytes, which protect the body against infection.
- Most lymph nodes are in the neck, groin, underarm and behind the ears.
- Lymph nodes swell during infection.
- The spleen is a sac-like mass of lymphatic tissue that contains white blood cells and antibodies that destroy pathogens.
- The tonsils lie at the back of the throat and trap pathogens that enter through the nose and mouth.
- The tonsils contain many white blood cells that destroy the trapped pathogens.

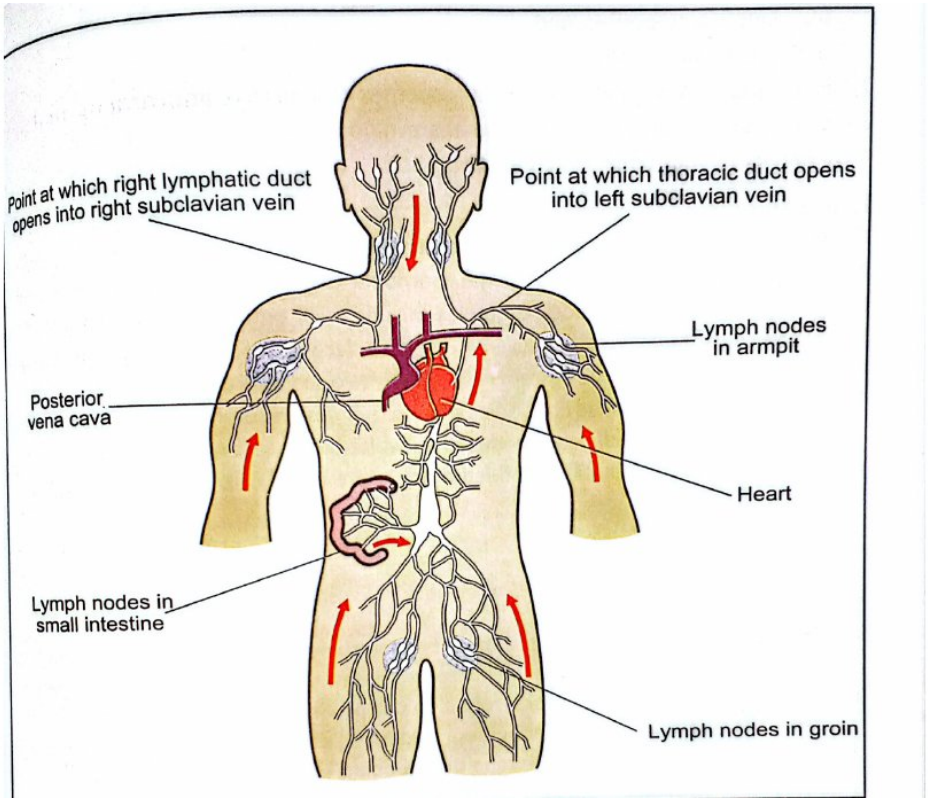


Figure 24: The human lymphatic and immune system

Immune system and types of immunity

- The immune system is the body's first line of defence against pathogens.
- The immune system includes all body parts that detect, recognise and destroy foreign substances.
- Pathogens are disease-causing micro-organisms that make toxins.
- Plasmodium species cause malaria, Vibrio cholerae causes cholera and Salmonella typhi causes typhoid.
- The immune system responds by making antibodies, which destroy or inactivate pathogens.
- Lymphocytes are the white blood cells that make antibodies.
- The immune system also responds by using phagocytes to engulf and feed on pathogens.
- Natural active immunity develops when a person suffers a disease and recovers.
- In natural active immunity, the pathogens stimulate the body to make antibodies, and the body makes antibodies again automatically at later exposure.
- Natural active immunity can give lifetime protection against infections such as measles, mumps, chicken pox and polio.
- Natural passive immunity occurs when antibodies pass from the mother's blood to the foetus through the placenta.
- After birth, antibodies pass to the baby in breast milk, and colostrum is especially rich in antibodies.
- Natural passive immunity gives immediate protection but only for a short time.
- Artificial passive immunity happens when antibodies from one individual are extracted and injected into another individual.
- Artificial passive immunity gives immediate but short-lived protection.
- Artificial active immunity happens when a weakened pathogen, called a vaccine, is introduced into the body.

- The weakened pathogen acts as an antigen and stimulates the immune system to make antibodies against the real pathogen.
- Artificial active immunity can give the body lifetime protection.

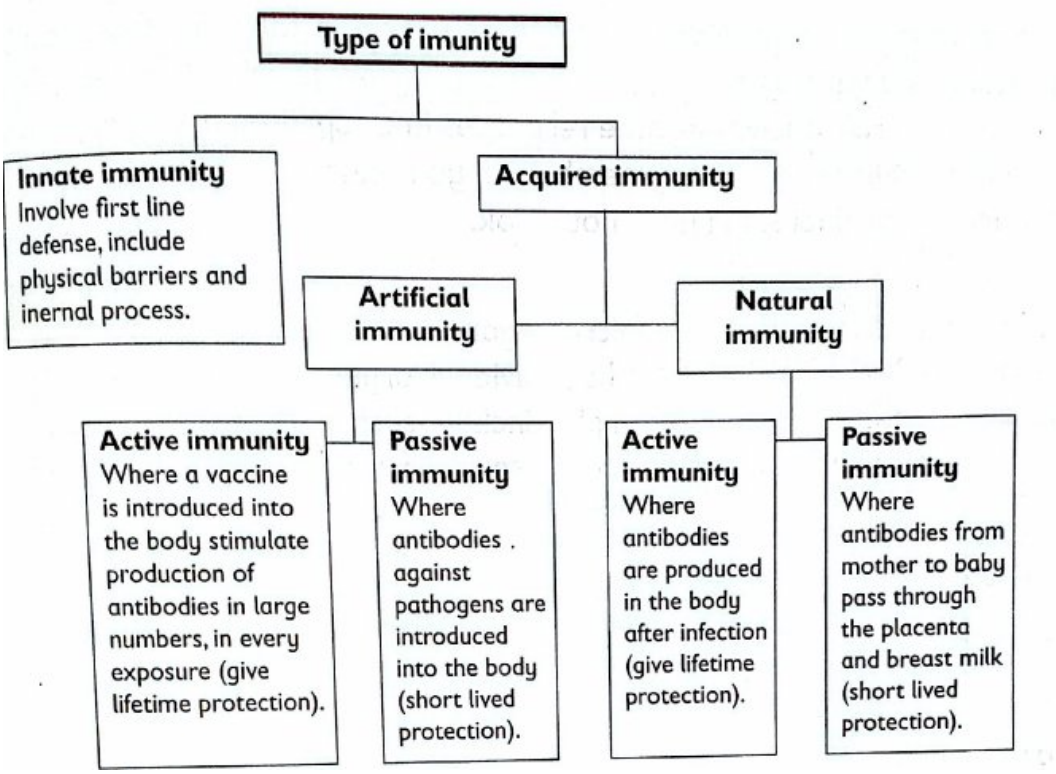


Figure 25: Types of immunity

Passive immunity	Active immunity
Acquired when antibodies from one individual are introduced into another.	Acquired when the body is stimulated to make its own antibodies, naturally or artificially.
Gives immediate protection.	Takes some time to build up protection.
Protection usually lasts a short time.	Protection lasts a long time, mostly for life.

Vaccination

- Vaccination is the introduction of a weakened pathogen to stimulate the immune system to make antibodies before the pathogen causes disease.
- Vaccination also prevents infections from spreading during an epidemic.
- A vaccine can be given by mouth or by injection.
- Vaccination in Kenya protects children from polio, yellow fever, tuberculosis, diphtheria, whooping cough, measles, hepatitis B and pneumonia.

Age	Vaccination against
Birth	BCG (tuberculosis) and oral polio vaccine.
6 weeks	Diphtheria/pertussis/tetanus/hepatitis B/Hib, oral polio, pneumococcal conjugate and rotavirus vaccines.
10 weeks	Oral polio, diphtheria/pertussis/tetanus/hepatitis B/Hib, pneumococcal conjugate and rotavirus vaccines.
14 weeks	Oral and inactivated polio (IPV), diphtheria/pertussis/tetanus/hepatitis B/Hib, pneumococcal conjugate and rotavirus vaccines.
9 months	Measles.
18 months	Measles.

Allergic reactions

- An antigen is any substance that reacts with a matching antibody to form a clump (agglutination).
- An allergen is anything that causes an immune response in an allergic reaction.
- In an allergy, the immune system over-reacts to harmless allergens by making antibodies against the allergens.
- This immune response makes cells burst open and release histamine.
- Histamine causes swelling (inflammation) in tissues.
- Symptoms of an allergic reaction include skin rashes, itching, sneezing, coughing, vomiting and redness.
- Common allergens include dust, pollen, some foods and cold air.

Organ transplants

- A transplant is an organ or tissue used to replace a damaged organ or tissue.
- Transplants come from other people or from animals such as pigs.
- Kidneys, cornea, liver and bone marrow are commonly transplanted.
- A donor must be immunologically compatible with the recipient.
- The recipient's immune system may reject an incompatible transplant by making antibodies that destroy the graft.
- Drugs that suppress the immune response are used to prevent rejection.
- Immunosuppressive drugs can lower the body's defence against infections.
- An autograft is tissue moved from one part of the body to another part of the same person, for example skin grafting.
- An isograft is a transplant between genetically identical individuals such as identical twins, and rejection is unlikely.
- An allograft is a graft between genetically different individuals of the same species, and rejection is possible.
- A xenograft is an organ or tissue transplanted between different species, for example an eye cornea from a sheep or pig.

Blood clotting

- Blood clotting is the conversion of the soluble plasma protein fibrinogen into a mass of insoluble fibrin fibres.
- Clotting happens when a blood vessel is damaged and platelets are exposed to air.
- Ruptured platelets and damaged tissue release thromboplastin (thrombokinase), which starts the clotting process.
- Thromboplastin neutralises heparin, the anti-clotting factor.
- Thromboplastin, together with calcium ions, activates the change of prothrombin (inactive enzyme) to thrombin (active enzyme).
- Vitamin K is needed to form prothrombin.
- Thrombin activates the change of soluble fibrinogen to insoluble fibrin.
- Fibrin forms a meshwork of fibres over the cut surface and traps red blood cells to form a clot.
- The clot dries into a scab that stops bleeding and blocks entry of disease-causing micro-organisms.
- Undamaged blood vessels contain heparin, which prevents prothrombin from changing to thrombin.

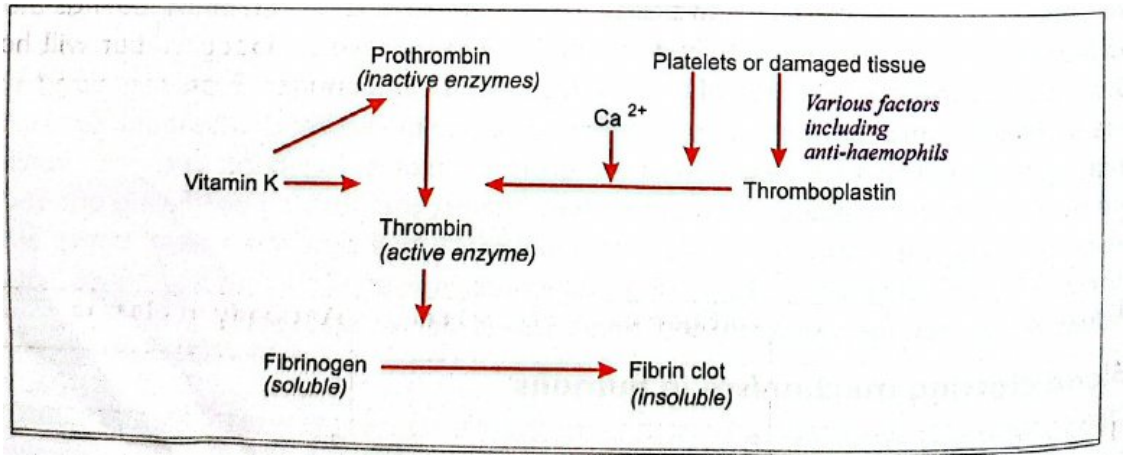


Figure 28: Simplified flow diagram of blood clotting

E. ABO and Rhesus blood grouping systems

- Blood grouping is used in blood transfusion, in settling disputed paternity or maternity, and in solving crimes.
- Red blood cell membranes carry antigens called A or B.
- A person whose red blood cells carry antigen A has blood group A.
- A person whose red blood cells carry antigen B has blood group B.
- A person whose red blood cells carry both antigens has blood group AB.
- A person whose red blood cells carry neither antigen has blood group O.
- Blood plasma contains antibodies called a and b.
- A plasma can never contain the antibody that matches an antigen on the same person's red cells.
- Antigens react with matching antibodies to make red blood cells clump, which is called agglutination.

Blood group	Antigen on red blood cells	Antibody in plasma
A	A	b
B	B	a
AB	A and B	None
O	None	Both a and b

Blood transfusion

- Blood transfusion is the transfer of blood from a donor to the circulatory system of a recipient.
- A recipient can receive donor blood only if the recipient has no antibodies against the donor's antigens.
- Agglutination occurs in the recipient's blood if a matching antigen and antibody meet.

Recipient / Donor	A	B	AB	O
A	Compatible	Not compatible	Not compatible	Compatible
B	Not compatible	Compatible	Not compatible	Compatible
AB	Compatible	Compatible	Compatible	Compatible
O	Not compatible	Not compatible	Not compatible	Compatible

- People with blood group AB are universal recipients because their blood has neither antibody a nor antibody b.

- People with blood group O are universal donors because their red blood cells have neither antigen A nor antigen B.
- Donor blood is screened for diseases and for compatibility before transfusion, for the safety of the recipient.
- A blood donor must be at least 18 years old and below 65 years old.

Rhesus factor

- The Rhesus antigen (antigen D) is another antigen on red blood cells.
- A person whose blood has antigen D is Rhesus positive (Rh^+).
- A person whose blood lacks antigen D is Rhesus negative (Rh^-).
- When Rh^+ blood is given to an Rh^- recipient, the recipient makes Rhesus antibodies, and the first dose has little effect.
- A second dose of Rh^+ blood within about two weeks causes agglutination of red blood cells.
- When an Rh^- mother carries an Rh^+ baby, fragments of foetal red blood cells with Rhesus antigens cross the placenta into the mother's blood.
- The mother's immune system then makes anti-Rhesus antibodies that cross the placenta after the first birth.
- These antibodies destroy the red blood cells of later Rh^+ foetuses, which causes haemolytic disease of the newborn (erythroblastosis foetalis).
- A newborn baby with this disease can be saved by replacing its blood with Rh^- blood.
- Blood transfusion of the foetus while still in the uterus is now possible.
- Haemolytic disease of the newborn can be prevented by injecting the mother with anti-Rhesus globulin in the 28th week of pregnancy.
- The mother can also be injected with anti-Rhesus globulin 72 hours after birth.
- After this treatment, the mother's immune system does not treat Rhesus antigens as foreign, so no antibodies form.

F. Diversity of transport systems in animals

- Transport systems differ between animals because of differences in body size, activity and the materials transported.
- Every transport system moves materials to body tissues and cells and moves metabolic wastes out of the body.
- Without a transport system, a multicellular organism would have limited access to essential materials and toxic wastes would build up in cells.
- A closed circulatory system is faster and supports more active animals than an open circulatory system.
- Double circulation supports more active animals than single circulation.
- Mammals have the most efficient circulatory system of the animals studied.
- Mammalian cells can access more oxygen and nutrients for energy production, so mammals can maintain a high body temperature.

Assessment questions (with answers)

1. **Explain why it is necessary for animals to have an elaborate transport system.**
   Answer: Most animals are large and multicellular, so diffusion is too slow. Cells need a constant supply of oxygen and glucose. Toxic wastes such as carbon(IV) oxide and urea must be removed quickly.

2. **What are the three components of a circulatory system?**
   Answer: A transport fluid, vessels, and a means of pumping (the heart).

3. **Explain the terms (i) open circulatory system and (ii) closed circulatory system.**
   Answer: (i) Haemolymph is pumped into the haemocoel and bathes cells directly, at low pressure. (ii) Blood stays inside vessels, is pumped at high pressure, and exchanges materials with cells through tissue fluid.

4. **Which animals exhibit (i) single circulation and (ii) double circulation?**
   Answer: (i) Fish. (ii) Amphibians, reptiles and mammals.

5. **State the number of heart chambers in fish, amphibians, most reptiles and mammals.**
   Answer: Fish: 2. Amphibians: 3. Most reptiles: 3 (crocodiles and alligators: 4). Mammals: 4.

6. **Give the disadvantage of single circulation.**
   Answer: Blood pressure drops at the gill capillaries, so blood flows slowly to the body tissues and transport of materials is less efficient.

7. **Why is the wall of the left ventricle thicker than the wall of the right ventricle?**
   Answer: The left ventricle must generate high pressure to pump blood to distant body tissues, while the right ventricle pumps blood only a short distance to the lungs.

8. **State the function of valves in the heart and in veins.**
   Answer: Valves keep blood flowing in one direction and prevent backflow.

9. **Describe ventricular systole.**
   Answer: The ventricles contract and pressure rises. The atrioventricular valves close, producing "lub". The semilunar valves open and blood is pumped into the aorta and pulmonary artery.

10. **Describe how the heartbeat is started and spread through the heart.**
    Answer: The SAN in the right atrium starts the wave of excitation. The wave spreads over the atria to the AVN and then down the Purkinje tissue to the ventricles, which contract.

11. **Which nerves change the heart rate, and how?**
    Answer: The vagus nerve slows the heart. The sympathetic nerve speeds the heart up.

12. **State four structural differences between arteries and veins.**
    Answer: Arteries have thick, muscular, elastic walls, a narrow lumen and no valves (except at the base of the large arteries leaving the heart). Veins have thin walls, a wide lumen and valves along their length.

13. **How is a capillary adapted to its function?**
    Answer: The wall is one cell thick, which gives a short diffusion distance. Capillaries are narrow and numerous, which gives a large surface area. The wall is permeable to water and small molecules.

14. **Explain how tissue fluid is formed and returned to the circulation.**
    Answer: High pressure at the arteriole end forces plasma out by ultrafiltration. At the venule end, proteins in the blood draw water back by osmosis. The remaining fluid drains into lymph vessels and joins the blood at the subclavian vein.

15. **What are the differences between red blood cells and white blood cells?**
    Answer: Red cells have no nucleus, contain haemoglobin, are smaller and more numerous, and carry gases. White cells have a nucleus, contain no haemoglobin, are larger and fewer, and defend the body.

16. **Why is carbon(II) oxide dangerous?**
    Answer: Carbon(II) oxide combines with haemoglobin to form carboxyhaemoglobin, which does not release the gas easily, so less oxygen is carried to tissues.

17. Describe how (i) lymphocytes and (ii) phagocytes protect the body against infection.

Answer: (i) Lymphocytes make antibodies: antitoxins, agglutinins, lysins and opsonins. (ii) Phagocytes engulf and digest pathogens.

18. Distinguish between active and passive immunity, with an example of each.

Answer: Active immunity is when the body makes its own antibodies; it is slow to build and long-lasting (vaccination). Passive immunity is when ready-made antibodies are received; it is immediate but short-lived (colostrum).

19. Explain what is meant by (i) foreign antigen, (ii) antibody, (iii) immunity and (iv) pathogen.

Answer: (i) A substance that is not part of the body and triggers an immune response. (ii) A protein made by lymphocytes that destroys or inactivates pathogens. (iii) The body's ability to resist infection. (iv) A disease-causing micro-organism.

20. Outline the process of blood clotting and state why clotting is important.

Answer: Damaged tissue and platelets release thromboplastin. With calcium ions and vitamin K, thromboplastin activates prothrombin to thrombin. Thrombin changes fibrinogen to fibrin, which traps red cells to form a clot. Clotting stops blood loss and prevents entry of micro-organisms.

21. Explain why blood does not clot while flowing in intact blood vessels.

Answer: Undamaged vessels contain heparin, which prevents prothrombin from changing to thrombin.

22. Explain why (i) blood group AB people are universal recipients and (ii) blood group O people are universal donors.

Answer: (i) AB blood has no antibody a or b, so donor red cells are not clumped. (ii) O red cells have no antigen A or B, so no recipient antibody can clump them.

23. Describe how haemolytic disease of the newborn arises and how it is prevented.

Answer: An Rh^- mother carrying an Rh^+ baby makes anti-Rhesus antibodies after fragments of foetal blood enter her blood. In a later pregnancy the antibodies cross the placenta and destroy the red cells of an Rh^+ foetus. Anti-Rhesus globulin at 28 weeks and within 72 hours after birth prevents the antibodies forming.

24. Name the blood vessel that carries blood to (i) the lungs, (ii) the heart, (iii) the liver from the intestines, (iv) the heart wall from the aorta and (v) the kidney from the aorta.

Answer: (i) Pulmonary artery. (ii) Vena cava (and pulmonary vein to the left atrium). (iii) Hepatic portal vein. (iv) Coronary artery. (v) Renal artery.

25. Explain why double circulation in mammals is more efficient than single circulation in fish.

Answer: Blood returns to the heart after the lungs and is pumped again at high pressure, so tissues receive materials faster, which supports high activity and a high body temperature.