3.2 TRANSPORT IN ANIMALS

WHAT THE SPEC SAYS:-

- A) why multicellular animals need transport systems,
- B) the different types of circulatory systems,
- C) the structure and functions of different blood vessels,
- D) the formation of tissue fluid from plasma,
- E) the internal and external structure of the mammalian heart,
- F) the cardiac cycle and its coordination,
- G) how to interpret electrocardiogram traces,
- H) the role of haemoglobin in transporting O2 and CO2,

A)

- Very small animals can simply supply themselves with enough oxygen and nutrients by diffusion because all of their cells are surrounded by the environment in which they live. However, larger animals will have more than two layers of cells and this means that the diffusion distance becomes too long and too slow to supply the needed nutrients. There are three main factors that influence the need for a transport system:

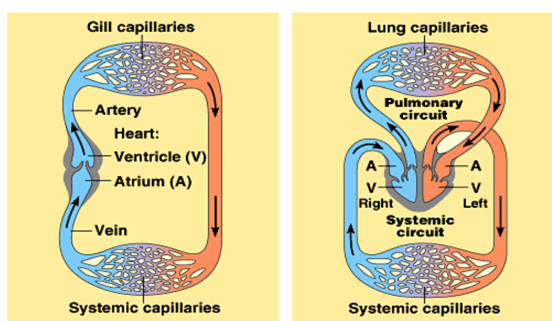
- **SIZE:** inside a large organism, the cells are further from its surface which means that the diffusion pathway is increased and diffusion rate is reduced. This means that diffusion will be too slow to supply all the requirements. Secondly, there will be multiple layers of cells and so the outer layers of cells will use up the supplies that do get diffused; leaving less for the cells deep inside the body.
- **SURFACE AREA TO VOLUME RATIO:** large animals have a smaller SA :V compared to that of small animals. The surface area to volume ratio is easy to work out-

$$\frac{SA}{V} = X \qquad = (X : 1)$$

- **METABOLIC ACTIVITY:** This is the speed at which chemical reactions take place in the body. Animals need energy so that they can move around. This energy is found in food and released by aerobic respiration which requires oxygen. The more an animal moves around, the more nutrients and oxygen it needs for aerobic respiration so that it can release energy for the activity.

B)

- **SINGLE CIRCULATORY SYSTEM** is what fish have. This is where the blood flows around a circuit in one direction. In each circuit the blood flows through the heart once. HEART -> GILLS -> BODY -> HEART.
- **DOUBLE CIRCULATORY SYSTEM** is what mammals have. This system has two separate circuits. One that is called pulmonary circulation: carries blood to the lungs to pick up oxygen. The second is called systemic circulation: carries the oxygenated blood around the body to the tissues. This means that blood flows through the heart twice for each circuit of the body.
HEART -> BODY -> HEART -> LUNGS -> HEART



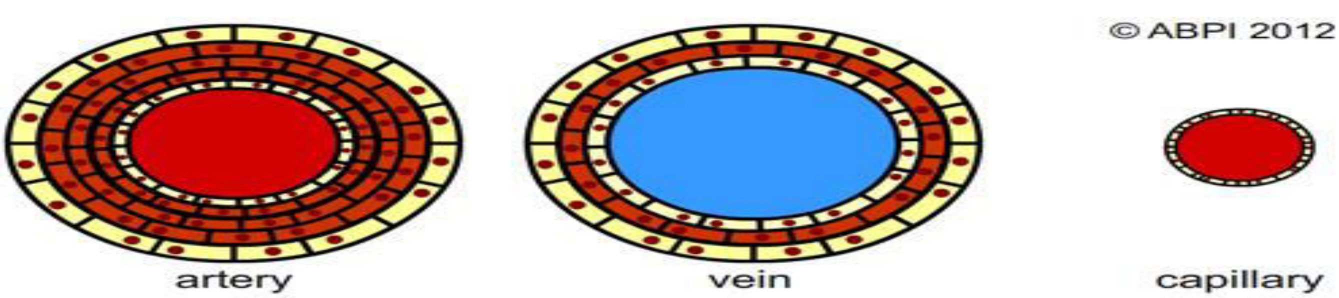
(a) Fish (c) Mammal

SINGLE CIRCULATORY SYSTEM	DOUBLE CIRCLATORY SYSTEM
the blood pressure drops as blood passes through the tiny capillaries of the gills	the blood pressure in the pulmonary circulation drops so that delicate capillaries of the lungs are not damaged
blood has a low pressure as it flows towards the body meaning that it will not flow very quickly	the heart can increase the pressure of blood flow after it has passed through the lungs so that it can flow more quickly through the body
therefore, the rate that oxygen and nutrients are delivered to tissues and carbon dioxide and urea are removed, is limited	the systemic circulation can carry blood at a higher pressure than the pulmonary circulation can

- OPEN CIRCULATORY SYSTEM is what many animals such as insects have and means that the blood is not always held within blood vessels; hence the word 'open.' Instead, the blood fluid circulates through the body cavity, so that the tissues and cells are bathed directly in blood. This system in some animals relies on movement because movements of the body help to circulate the blood.
- **CLOSED CIRCULATORY SYSTEM** in larger animals such as humans, the blood stays entirely inside vessels, leaving tissue fluid to bathe the tissues and cells. This is good because it means blood can flow through at a higher pressure therefore it is faster and so there is a more rapid delivery of oxygen and nutrients, which means also a more rapid removal of carbon dioxide as well as transport being independent of body movements.

C)

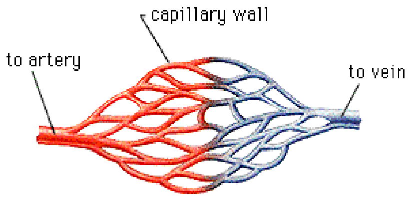
- In a closed circulatory system blood flows through a series of vessels and each is adapted to its particular role in relation to its distance from the heart. This means that each type of vessel is slightly different. However, they all have an inner lining made of a single layer of cells called the endothelium. This is particularly smooth to reduce friction with the flowing blood.



- **ARTERIES:** carry blood away from the heart (think of **a**rtery and **a**way.) The blood is at high pressure which is maintained by the small lumen, and so the artery wall must be thick in order to withstand this pressure. The inner wall is folded to allow the lumen to expand as blood flow increases. The wall consists of three layers: inner layer made of elastic fibres, middle layer consisting of smooth muscle and the outer layer made of collagen fibers.
- **ARTERIOLES:** are small blood vessels that distribute blood from an artery to a capillary. These walls contain a layer of smooth muscle and contraction of this muscle will constrict the diameter of the arteriole. This constriction is used to divert blood flow to regions of the body that are more demanding of oxygen.
- **VEINS:** carry blood at a low pressure to the heart and so the walls do not need to be thick like those of arteries. To help maintain this low pressure the lumen is relatively large so that the flow of blood is eased. The difference between arteries and veins is that veins have valves to prevent the backflow of blood. Contraction of the surrounding skeletal muscle flattens the vein walls leading to applied pressure to the blood, forcing the blood to move along a direction determined by the valves.
- **VENULES:** are small blood vessels that collect blood from the capillary bed and lead into the veins. The venule wall consists of thin layers of muscle and elastic tissue outside the endothelium, and a thin outer layer of collagen.
- **CAPILLARIES:** these allow exchange of materials between the blood and tissue fluid. The lumen is very narrow so that red blood cells can be squeezed against the walls of the capillary as they pass along; this helps the transfer of oxygen, because it reduces the diffusion path to the tissues. The walls are also adapted to this function by consisting of a single layer of flattened endothelial cells which again reduce the diffusion distance. The walls are also leaky to allow blood plasma and dissolved substances to leave the blood.

D)

- In a closed circulatory system blood is the fluid held in our blood vessels which consists of liquid called plasma. Tissue fluid is similar to blood plasma but does not contain most of the cells found in blood and plasma proteins because they are too large to pass through the gaps in the capillary wall. Tissue fluid is formed by the plasma leaking from the capillaries. It surrounds the cells in the tissue and this is how they are supplied with the oxygen and nutrients that they require by mass flow. This can work in the opposite direction by waste products entering the capillary; as some of the tissue fluid returns to the capillary.



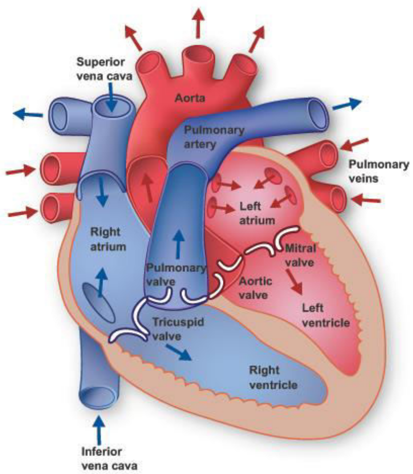
-**FORMATION:** when an artery reaches the tissues it branches into small arterioles, and then into a network of capillaries. These eventually link up with the venules to carry blood back to the veins. Therefore, blood flowing into an organ or tissue is contained in the capillaries.

- At the arterial end of a capillary, the blood is at a relatively high hydrostatic pressure (this is the pressure that a fluid exerts when pushing against the sides of a vessel or container) this pressure tends to push the blood fluid out of the tiny gaps between the cells in the capillary wall. The blood pressure at the venous end of the capillary is much lower which allows some of the tissue fluid to return to the capillary.
- Hydrostatic pressure of the blood is not the only influence on the movement of fluid in and out of the capillaries. For example, tissue fluid also has its own hydrostatic pressure, and the oncotic pressure (pressure created by the osmotic effects of the solutes) also has an influence.

- The tissue fluid surrounds the body cells, so exchange of gases and nutrients can occur across the plasma membranes. This exchange can be by: diffusion, facilitated diffusion and active uptake.
- Excess tissue fluid is directed into a tubular system called the lymphatic system. This drains the excess tissue fluid out of the tissues and returns it to the blood system in the subclavian vein in the chest.

E)

- The mammalian heart is a muscular pump and is divided into two sides. The right side pumps deoxygenated blood to the lungs to be oxygenated. Whilst the left side pumps oxygenated blood to the rest of the body. To make the blood travel, the heart squeezes to put it under pressure and this pressure is what forces the blood along the arteries and through the circulatory system.
- **EXTERNAL:** the main part of the heart consists of firm, dark red muscle called cardiac muscle. Lying over the surface of this muscle are coronary arteries that supply oxygenated blood to the heart muscle itself. If these arteries become constricted, it can have severe consequences for the health of the heart. For example, restricted blood flow to the heart muscle can cause angina or a myocardial infarction. At the top of the heart are a number of tubular blood vessels. These are the veins that carry blood into the atria and the arteries that carry blood away from the heart.
- **INTERNAL:** the heart is divided into four chambers: the upper chambers the atria and the lower chambers the ventricles. The atria receive blood from the major veins such as deoxygenated blood from the vena cava into the right atrium and oxygenated blood flows through the pulmonary vein into the left atrium. From the atria, blood flows down through the atrio-ventricular valves into the ventricles. Tendinous cords are attached to the valves and prevent them from turning inside out when the ventricle walls contract. The septum is a wall of muscle that separates the ventricles from each other. This ensures that the oxygenated blood in the left side and deoxygenated blood in the right side are kept separate. Deoxygenated blood that leaves the right ventricle flows into the pulmonary artery leading to the lungs and oxygenated blood leaving the left ventricle flows into the aorta which then carries blood into arteries so that it can travel around the body. Where the major arteries exit the heart, are the semilunar valves and these prevent blood returning to the heart as the ventricle relax.



F)

- The cardiac cycle is defined as the sequence of events in one full beat of the heart.
- **ATRIAL SYSTOLE:** this is when the ventricles are relaxed and the atria contract meaning that the volume of the atria chambers decreases and pressure inside the chambers increases because blood is being pushed from the atria into the ventricles through the atrioventricular valves. There’s a slight increase in ventricular pressure and chamber volume as the ventricles receive the ejected blood from the contracting atria.
- **VENTRICULAR SYSTOLE:** the atria now relax whilst the ventricles contract and so decreasing their volume and increasing their pressure so that it is higher in the ventricles than the atria, which forces the atrioventricular valves shut to prevent back-flow. The pressure in the

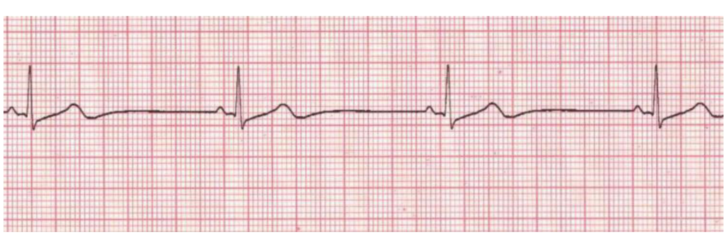
ventricles is also higher than in the aorta and pulmonary artery, which forces open the semilunar valves and blood is forced out into these arteries.
- **DIASTOLE:** this is when the ventricles and atria both relax. Now that the blood is in the pulmonary artery and the aorta the pressure is high and so the semilunar valves close to prevent back-flow into the ventricles. Blood returns to the heart and the atria fill again due to the higher pressure in the vena cava and pulmonary vein. The atria contract, and the whole process begins again.
- **COORDINATION OF ATRIAL SYSTOLE:** at the top of the right atrium, near the point where the vena cava empties blood into the atrium, is the sino-atrial node. This is a small patch of tissue that generates electrical activity. The SAN initiates a wave of excitation at regular intervals. In a human, this occurs 55-80 times a minute. The SAN is also known as the pacemaker. The wave of excitation quickly spreads over the walls of both atria, along the membranes of the muscle tissue and as it passes, it causes the cardiac muscle to contract which is known as atrial systole.
- **COORDINATION OF VENTRICULAR SYSTOLE:** because the tissue at the base of the atria is unable to conduct the wave of excitation, it cannot spread directly down to the ventricle walls. This means that there is another node- the atrio-ventricular node (AVN.) The wave of excitation is delayed in this node which allows time for the atria to finish contracting and for the blood to flow down into the ventricles before they begin to contract. After this short delay, the wave is carried away from the AVN and down specialised conducting tissue called the purkyne tissue. This then runs down the interventricular septum. At the base of the septum, the wave spreads out over the walls of the ventricles and then spreads upwards from the base (apex) of the ventricles, it causes the muscles to contract which means that the ventricles contract from the base upwards. This pushes the blood up towards the major arteries at the top of the heart.

G)

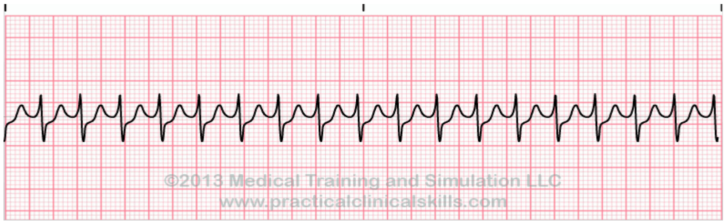
- Electrocardiograms (ECGs) can be used to monitor the electrical activity of the heart. This involves attaching a number of sensors to the skin. This works because some of the electrical activity generated by the heart spreads through the tissues next to the heart and outwards to the skin. The sensors on the skin pick up the electrical excitation created by the heart and convert this into a trace. ECGs produce a series of waves that can be labelled: P,Q,R,S and T.

- P = shows the excitation of the atria,
- QRS = indicates the excitation of the ventricles,
- T = shows diastole,

Sinus rhythm (normal)



Bradycardia (slow heart rate)



Tachycardia (fast heart rate)

Atrial fibrillation (atria beating more freq than ventricles)

Ectopic heartbeat (feels like a heartbeat has been missed)

H)

- **TRANSPORT OF OXYGEN:** oxygen is transported in the erythrocytes. These cells contain the protein haemoglobin and when this takes up oxygen, it becomes oxyhaemoglobin. The haem group in haemoglobin is said to have a strong affinity (attraction) for oxygen as each haem group can hold one molecule meaning a single haemoglobin molecule can carry four oxygen molecules. Oxygen is absorbed into the blood as it passes the alveoli in the lungs. It diffuses into the blood plasma and then enters the red blood cells so that it can become associated with the haemoglobin. When the blood travels around the body it must be able to release the oxygen. This is called dissociation. The ability of haemoglobin to release oxygen depends on the concentration of oxygen in the surrounding tissues.
- **TRANSPORT OF CARBON DIOXIDE:** CO2 is transported in three ways: 5% is dissolved directly in the plasma, 10% is combined directly with haemoglobin to form a compound called carbaminohaemoglobin, about 85% us transported in the form of hydrogencarbonate ions. The Bohr Effect describes the effect that an increasing concentration of CO2 has on the haemoglobin. When more carbon dioxide is present, haemoglobin becomes less saturated with oxygen which results in more oxygen being released where more carbon dioxide is produced in respiration. This is what the muscles need for aerobic respiration.