CAIE Biology A-level

Topic 8: Transport in mammals

Notes

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Circulatory systems can either be open, for instance in insects, or closed, like in fish and mammals where the blood is confined to blood vessels only. Closed circulatory systems come in two forms, either a single form which consists of a heart with two chambers meaning the blood passes through the heart once for every circuit of the body, or double, where the heart has four chambers and blood passes through the heart twice for every circuit of the body. Mammals have a closed double circulatory system which consists of the heart, blood vessels and blood.

Important structures and their functions

- Arteries – adapted to carrying blood away from the heart to the rest of the body, thick walled to withstand high blood pressure, contain elastic tissue which allows them to stretch and recoil thus smoothing blood flow, contain smooth muscle which enables them to vary blood flow, lined with smooth endothelium to reduce friction and ease flow of blood

- Arterioles – branch off arteries, have thinner and less muscular walls, their role is to feed blood into capillaries

- Capillaries – smallest blood vessels, site of metabolic exchange, only one cell thick for fast exchange of substances. They are adapted for efficient diffusion by having a narrow lumen, a large surface area, and a slow blood flow to allow more time for exchange.

- Venules – larger than capillaries but smaller than veins

- Veins – carry blood from the body to the heart, contain a wide lumen to maximum volume of blood carried to the heart, thin walled as blood is under low pressure, contain valves to prevent backflow of blood, no pulse of blood meaning there's little elastic tissue or smooth muscle as there is no need for stretching and recoiling.

Tissue Fluid

Tissue fluid is a liquid containing dissolved oxygen and nutrients which serves as a means of supplying the tissues with the essential solutes in exchange for waste products such as carbon dioxide. Therefore, it enables exchange of substances between blood and cells.

Hydrostatic pressure is created when blood is pumped along the arteries, into arterioles and then capillaries. This pressure forces blood fluid out of the capillaries to form tissue fluid. Only substances which are small enough to escape through the gap in capillary are components of the tissue fluid – this includes dissolved nutrients and oxygen.

The fluid is also acted on by hydrostatic pressure which pushes some of the fluid back into the capillaries. As both the tissue fluid and blood contain solutes, they have a negative

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water potential. However, the potential of tissue fluid is less negative therefore meaning that water moves down the water potential gradient from the tissue fluid to the blood by osmosis.

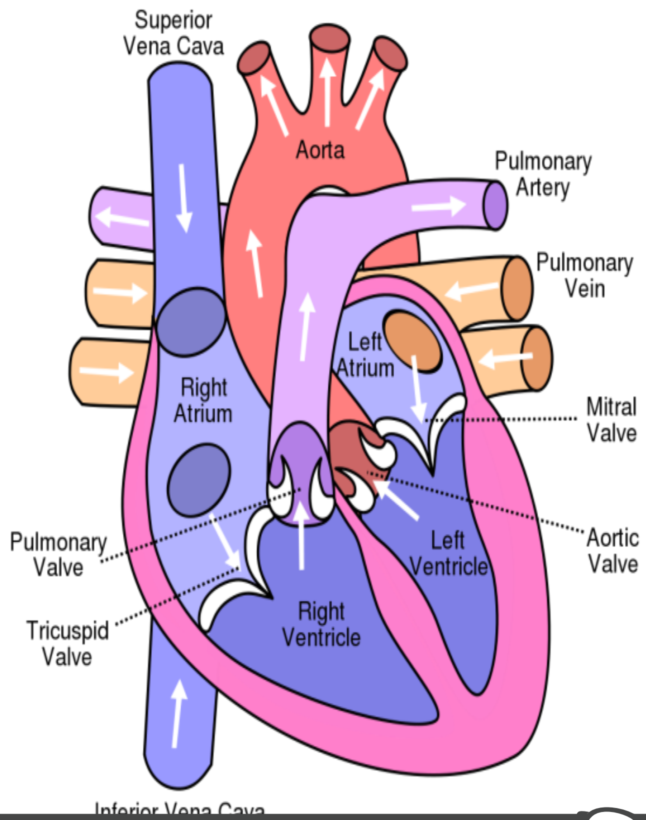
The remaining tissue fluid which is not pushed back into the capillaries is carried back via the lymphatic system. The lymphatic system contains lymph fluid, similar in content to tissue fluid. However, lymph fluid contains less oxygen and nutrients compared to tissue fluid, as its main purpose is to carry waste products. The lymph system also contains lymph nodes which filter out bacteria and foreign material from the fluid with the help of lymphocytes which destroy the invaders as part of the immune system defences.

Water is the main component of tissue fluid (and blood). The properties of water allow it to be a good transport medium in mammals.

- It can act as a solvent (so it can carry solutes) and has a high specific heat capacity making it an efficient transport medium.

Mammalian heart and cardiac cycle

The hearts main blood vessels:
Aorta - connects to the left ventricle and carries oxygenated blood all around the body except the lungs
Pulmonary artery - connects to the right ventricle and carries deoxygenated blood to the lungs where it is oxygenated.
Pulmonary vein - connects to the left atrium and takes oxygenated blood back to the lungs
Vena cava - connects to the right atrium and brings deoxygenated blood back from the tissues except the lungs



The ventricle pumps blood at high pressure. The ventricle wall is a lot thicker than the atria so that it can withstand the high pressure. The left ventricle wall is thicker than the right ventricle wall because it pumps blood from the lungs to the rest of the body - to ensure it reaches all the body the blood is pumped at a high pressure.

Due to the heart's ability to initiate its own contraction, it is referred to as myogenic. In the wall of the right atrium there is a region of specialised fibres called the sinoatrial node which is the pacemaker of the heart, as it initiates a wave of electrical stimulation which causes the atria to contract at roughly the same time. The ventricles do not start contracting until the atria have finished due to the presence of tissue at the base of the atria which is unable to conduct the wave of excitation. The electrical wave eventually reaches the atrioventricular node located between the two atria which passes on the excitation to ventricles, down the bundle of His to the apex of the heart. The bundle of His branches into the Purkyne fibres which carry the wave upwards. This causes the ventricles to contract, thus emptying them.

There are 3 stages of the cardiac cycle:

1) Atrial systole – during atrial systole the atria contract and this forces the atrio-ventricular valves open and blood flows into the ventricles.

2) Ventricular systole – contraction of the ventricles causes the atrio-ventricular valves to close and semi-lunar valves to open thus allowing blood to leave the left ventricle through the aorta and right ventricle through the pulmonary artery.

3) Cardiac diastole – atria and ventricles relax**,** elastic recoil of the heart lowers the pressure inside the heart chambers and blood is drawn from the arteries and veins thus causing semilunar valves in the aorta and pulmonary arteries to close, preventing backflow of blood.

Haemoglobin

Haemoglobin is a water soluble globular protein which consists of two beta polypeptide chains and a haem group. It carries oxygen in the blood as oxygen can bind to the haem (Fe2+) group and oxygen is then released when required. Each molecule can carry four oxygen molecules.

The affinity of oxygen for haemoglobin varies depending on the partial pressure of oxygen which is a measure of oxygen concentration. The greater the concentration of dissolved oxygen in cells the greater the partial pressure. Therefore, as partial pressure increases, the affinity of haemoglobin for oxygen increases, that is oxygen binds to haemoglobin tightly. This occurs in the lungs in the process known as loading. During respiration, oxygen is used up therefore the partial pressure decreases, decreasing the affinity of oxygen for haemoglobin. As a result, oxygen is released in respiring tissues where it is needed. After the unloading process, the haemoglobin returns to the lungs where it binds to oxygen again.

Dissociation curves illustrate the change in haemoglobin saturation as partial pressure changes. The saturation of haemoglobin is affected by its affinity for oxygen, therefore in the case where partial pressure is high, haemoglobin has high affinity for oxygen and is therefore highly saturated, and vice versa.

Carbonic anhydrase is an enzyme found in the blood. Its job is to help haemoglobin dissociate from oxygen and bind to carbon dioxide to form carbaminohaemoglobin instead**.** Carbonic anhydrase catalyses a reaction between carbon dioxide and water to produce carbonic acid. Carbonic acid, when in a solution, releases hydrogen ions. When these hydrogen ions combine with haemoglobin, **haemoglobinic acid** forms. This encourages dissociation of oxygen from haemoglobin.

Saturation can also have an effect on affinity, as after binding to the first oxygen molecule, the affinity of haemoglobin for oxygen increases due to a change in shape, thus making it easier for the other oxygen molecules to bind.

Fetal haemoglobin has a different affinity for oxygen compared to **adult haemoglobin**, as it needs to be better at absorbing oxygen because by the time oxygen reaches the placenta, the oxygen saturation of the blood has decreased. Therefore, fetal haemoglobin must have a **higher affinity for oxygen** in order for the foetus to survive at low partial pressure.

The affinity of haemoglobin for oxygen is also affected by the **partial pressure of carbon dioxide**. Carbon dioxide is released by **respiring cells** which require oxygen for the process to occur. Therefore, in the presence of carbon dioxide, the affinity of haemoglobin for oxygen decreases, thus causing it to be released. This is known as the **Bohr effect.**

When at a **high altitude, red blood cell count increases**. This is because there are fewer oxygen molecules, thus the partial pressure of oxygen decreases. Consequently, more red blood cells are made so that there is more haemoglobin for the oxygen to bind to.

Another process that takes place in the red blood cells is the **chloride shift**. This helps maintain the **cell's electrical balance**.

- When blood reaches the lung tissue it has a relatively **low carbon dioxide concentration**
- **Carbonic anhydrase** catalyses the reaction breaking down carbonic acid into water and carbon dioxide
- **Bicarbonate** diffuses into the red blood cells and reacts with the **hydrogen ions**. This forms carbonic acid.
- When carbonic acid is broken down by carbonic anhydrase **free carbon dioxide is released**. This diffuses from the blood into the lungs.
- **Chloride ions** then move from the red blood cells into the **plasma** - **down an electrochemical gradient**