1 Human gas exchange

1.1 Human gas exchange

The human gas exchange surface consists of the lungs. They are specialised for exchange of gases by having:

- Large surface area, to maximise diffusion.
- Thin surface distance; the surface is only one cell thick so as to minimise distance for diffusion, maximising diffusion rate.
- They are well supplied with capillaries so as to diffuse as much oxygen into the blood and as much carbon dioxide out of the blood as possible. The lungs take in sufficient air so as to cause maximum diffusion as well.

In the atmosphere, **the proportions of gases** present follow: 21% of oxygen O_2 , 0.04% of carbon dioxide (C_2O). These are the gas proportions that we breathe in, i.e., that we inspire. The air that we breathe out, exhale or expire consists of the following compositing: 16% oxygen, 4% carbon dioxide and very high amount of water vapour, compared to that inhaled.

The respiratory tract consits of the larynx, trachea, bronchus and bronchioles. Once air has entered through our noses, it passes the larynx or the voice box. It then goes through the trachea. The trachea splits into two bronchi (bronchus, singular) which branch out into bronchioles further into grape like structures called alveoli. It is these alveoli through which gaseous exchange in humans occur. These are balloon-like in that they blow up when we inhale, and deflate when we exhale.

Inside these alveoli, gases accumulate when we breathe in, and around these there are capillaries enveloping it. The alveolar wall is only one cell thick, and is moist, so as to minimise the distance oxygen has to travel to diffuse into the blood in the surrounding capillaries. The surface area in contact with the blood vessels is also large so as to maximise diffusion. They are constantly supplied with blood so that blood can be oxygenated. They also have a good supply of oxygen from our constant breathing in and out, also called ventilation.

The ribs are the cage-like bones surrounding our lungs and heart. That which is enveloped by the ribs is called the thorax. In between and around each rib-bone there are intercostal muscles, which are arranged antagonistically[1], namely the external and internal intercostal muscles. Beneath the ribs, there is the diaphragm, which is a muscle separating the thorax, i.e. the chest cavity from the abdominal cavity.

Breathng in occurs when the pressure inside the thorax, i.e. the lungs lowers to below that of atmospheric pressure. Air from outside the body rushes in through the nose and mouth into the alveoli when this happens. To do this, the volume of the thorax must be maximised, which is done by contraction of the diaphragm from its relaxed dome shape. Alongside that, the external intercostal

[1] A pair of muscles where, when one contracts the other relaxes and vice versa.

muscles contract, relaxing the internal intercostal muscles. This results in the ribs moving up and outwards, decreasing internal pressure and causing air to rush into the lungs.

To **breathe out** the exact opposite must occur. The thorax's volume must lower, so as to increase lung pressure to be greater than that of the surrounding atmosphere. To do so, the thorax relaxes into its dome shape and the internal intercostal muscles relax whereas the external intercostal muscles relax, causing the ribs to move down and in. As a result, air rushes out of the lungs into the atmosphere.

Physical activity has effects on the rate and depth of breathing. When performing physical tasks, such as running, our body needs lots of oxygen as fast as possible to respire aerobically, to produce energy for muscle contraction. This is why we breathe faster, at a higher rate, and take deeper breaths, to maximise oxygen in our blood. Often, this oxygen demand is not met, and the body has to compensate by performing anaerobic respiration, which releases less energy in comparison to aerobic respiration. Anaerobic respiration produces lactic acid, which accumulates in the blood and muscles. To break down this lactic acid, we continue breathing in quicker and deeper even after we have completed the physical task, as the breakdown of lactic acid requires oxygen. This is known as **paying off the oxygen debt**, this breakdown occurs in the liver and we can say we borrowed oxygen when we performed anaerobic respiration, and we are paying it off by taking in the oxygen we need. The rate and depth of breathing is controlled by the brain, which, when it senses that the pH of blood has lowered due to lactic acid, stimulates the diaphragm and intercostal muscles to contract and relax harder and more often. Faster and deeper breaths result.

The trachea, bronchi, even the inside of the nose is lined with **goblet cells and cilia**. Goblet cells produce mucus, a chemical which traps any pathogen or particle that enters the respiratory tract. Cilia are hair like structures which continuously beat upward, pushing mucus upward toward the top of the throat to be swallowed. Once they are, the acid in the stomach destroys any possibly harmful pathogen that may have been stuck in that mucus.

2 Respiration

2.1 Respiration

Respiration is the chemical process by which energy is released from glucose in all living cells. This energy is required for many processes, including:

- Muscle contraction
- Protein synthesis
- Cell division
- Active transport
- Growth
- Passage of electrical nerve impulses
- Maintenance of a constant body temperature (homeostasis).

2.2 Aerobic respiration

Aerobic respiration is the breaking of glucose using oxygen to release energy. Given below, are the word and chemical equations denoting the process of respiration:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$$

2.3 Anaerobic respiration

Anaerobic respiration is the breaking of glucose without oxygen to release a relatively little amount of energy. In humans, the breakdown occurs as follows:

$$\text{glucose} \rightarrow \text{lactic acid}$$

In yeast, the following happens:

$$\text{glucose} \rightarrow \text{alcohol} + \text{carbon dioxide}$$

The parts concerning Excess Post-exercise Oxygen Consumption (EPOC), otherwise known as paying of the oxygen debt is given in the last part of Section 9.

During exercise, the heart rate is fast so as to supply oxygen to all the parts that need it as quickly as possible. After exercise, the heart rate remains fast for some time to transport lactic acid to the liver where it can be broken down using oxygen.

3 Transport in humans

3.1 Circulatory system

A **circulatory system** consists of a network of blood vessels, a pump or heart to keep the blood flowing and valves which ensure the flow is in one direction only.

A **double circulatory system** is that in which blood passes through the heart twice for a complete circulation. In such a system, blood at low pressure is sent to the lungs, and its pressure is raised once again after it arrives at the heart and is sent off to the body.

3.2 Heart

The **mammalian heart** is essentially a muscle with four chambers. To prevent backflow, valves are present at specific locations around the heart. The thickness of the muscles of each chambers varies depending on the distance they must pump the blood. The atria are significantly less thick than ventricles as they need only pump blood to the ventricles which are right beneath them. The left[2] ventricle is significantly thicker than the right, as the left pumps blood to the whole body whereas the right only pumps to the lungs.

The heart is composed of two sides, the left and the right, separated by the septum. On the top of each side is an atrium and on the bottom, a ventricle. Seperating the two are atrio-ventricular valves. **The functioning of the heart** consists of the following steps:

1. Deoxygenated blood from the body flows into the right atrium, simultaneously oxygenated blood from the lungs flow into the left atrium. At this moment, the atrio-ventricular valves on both sides are closed.

2. The atria contract, pressuring blood through the atrio-ventricular valves into their respective ventricles. The valves ensure blood does not flow back into the atria.

3. The ventricles contract, the atrio-ventricular valves stay closed, the semilunar valves that are at the entrance of the aorta and pulmonary artery of the left and right heart respectively open to allow blood to flow through those blood vessels[3]

Note that, the atrio-ventricular valve of the left side of the heart is called the bicuspid valve and that on the right is called the tricuspid valve.

The above events occur multiple times every minute, and the number of times it occurs is called the **heart rate**. It can be measured in the following ways:

[2]Note that the left and right sides of the heart is reversed, as we consider the right to be the right side of whose heart we are observing.

[3]Note that, blood is pumped away from the heart in blood vessels called arteries and toward the heart in those called veins.

- The heart makes a lub-dub sound when it beats, caused by the opening and closing of the valves. Counting the number of times lub-dub is heard per unit time can give heart rate.
- Pulse rate can be measured by placing one's hand on any artery, and counting the number of times it pulses per unit time.
- An echocardiograph (ECG) can be used to measure and record electrical activity in the heart using electrodes stuck into the person's body.

Coronary heart disease (CHD) occurs when the arteries that supply the heart itself with blood, called the coronary arteries, become blocked in some way. It can occur due to the following factors:

- Diet: Eating high amounts of saturated fats results in high cholesterol concentration.
- Sedentary lifestyle: Those with lethargic lifestyles tend to run a higher risk to develop CHD.
- Stress: Leading a high stress lifestyle may also result in CHD.
- Smoking: Smoking greatly increases risk of CHD.
- Genetic predisposition: Many carry hereditary genes which make them susceptible to CHD, such an individual must lead a healthy lifestyle so as to avoid suffering from the disease.
- Age and gender: Older people run a greater risk of contracting CHD, and men are more prone to CHD than women.

Regular exercise and having a healthy diet is the key to combat CHD. Regular exercise keeps the mind and body fit, keeps the blood pressure at a good value, reduces chance of excessive weight gain. They make one feel fit. Other than that, avoiding fatty, greasy, animal-based foods is the key to preventing CHD as such foods contain saturated fats which increase cholesterol levels in the body leading to CHD.

3.3 Blood vessels

It is through the aorta that oxygenated blood flows out of the heart and to the rest of the body parts. Through the inferior and superior vena cava, deoxygenated blood enters the right side of the heart. The hepatic vein and artery carry blood to and from the heart and liver, respectively. The hepatic portal vein is a blood vessel going from the small intestine to the liver, carrying nutrients to be assimilated in the liver. The renal artery and vein carry blood to and from the heart and the kidneys, respectively.

Arteries carry blood away from the heart. They mostly contain oxygenated blood, except the pulmonary artery. They have thick, muscular walls with elastic tissue, that bounce back with the flow of blood to allow the blood to flow smoothly. The lumen of an artery is relatively small, but not as small as capillaries.

Veins carry blood to the heart. They mostly contain deoxygenated blood, except the pulmonary vein. They have thin walls, also composed of muscles and elastic fibres. They have a relatively large lumen and have valves to prevent backflow of blood. Veins do not carry particularly high pressure blood, so, such as to not slow down speed of blood flow they have a large lumen. They need not thick walls as they carry not high pressure blood.

Capillaries are very thin blood vessels which surround cells, they are the middle ground between an artery and a vein. They have very small lumens and walls only one cell thick. It is through capillaries nutrients, oxygen, etc. diffuse in and out of the blood and cells. They are small so as to penetrate every part of the body and supply it with blood as it requires.

3.4 Blood

Blood is a mixture consisting of plasma, red and white blood cells, and platelets. Red blood cells are biconcave and lack all cell organelle. White blood cells are of two types, lymphocytes and phagocytes. Phagocytes have lobed nuclei, whereas lymphocytes have nuclei that take up almost the whole cell. Platelets are tiny structures, smaller than both the blood cells.

Red blood cells contain haemoglobin, which is a substance to which oxygen binds to form oxyhaemoglobin. It is in this form that oxygen is transported around the body. Red blood cells lack any cell organelle to maximise space for oxyhaemoglobin. They are biconcave in shape to maximise surface area for diffusion of oxygen.

White blood cells are involved in immunity of the body. Lymphocytes are cells that produce antibodies to kill any and all pathogens and phagocytes engulf those pathogens to kill them.

Platelets are involved in blood clotting. When a blood vessel is broken, the platelets release a substance to convert soluble fibrinogen present in blood to fibrin, an insoluble protein that forms a mesh-like structure around the wound. Blood cells get trapped in this mesh, preventing excessive blood loss.

Plasma is a substance consisting of mostly water, in which many substances are dissolved for transport. Such as: glucose, amino acids, mineral ions, hormones, carbon dioxide, urea, vitamins and plasma proteins.

Oxygenated blood flows in from arteries into capillaries. Here, oxygen diffuses out from inside red blood cells, into cells and carbon dioxide diffuses into the plasma. Such exchanges occur before the branched capillaries congregate into veins carrying deoxygenated blood. Plasma leaks out from capillaries during this exchange. This leaked plasma is called tissue fluid and it helps in diffusion of substances.

4 Disease and immunity

4.1 Disease

A pathogen is any microorganism that causes disease. A disease that can pass from one host to another is called a transmissible disease. This transmission can occur in two modes: directly or indirectly.

Direct transmission occurs when an infected person comes in direct contact with an uninfected person. This may be in the form of sexual or salivary exchange, or even blood transfusion with an infected person.

Indirect transmission occurs when pathogens come in indirect contact with uninfected people. This may be in the form of pathogen containing droplets in the air, touching a surface touched by an infected person, consuming contaminated substances or animals carrying the disease.

There are **physical barriers** in the body to prevent infection. The skin blocks any pathogen's entry into the body. Hairs in the nose trap any such pathogen. **Chemical barriers** include mucus secreted by the lining of the respiratory tract in which pathogens become trapped. Stomach acid kills any pathogen that has been ingested.