Section 4.1 – Structure of the human gas-exchange system

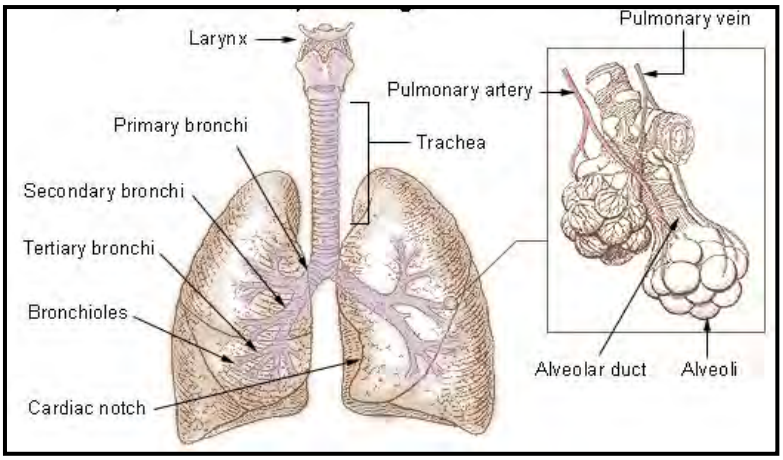
All aerobic organisms require a constant supply of oxygen to release energy in the form of ATP during respiration.

The volumes of oxygen that need to be absorbed and the volumes of carbon dioxide that need to be removed are large in mammals, because there are a large amount of respiring cells. Mammals must also maintain a high temperature and therefore have high metabolic and respiratory rates.

Lungs provide efficient surface area for effective gas exchange.

Mammalian Lungs

- Lungs are kept inside the body because air is not dense enough to support and protect these delicate structures. In addition to this, keeping them inside the body prevents loss of water and so they will not dry out easily.



- The lungs are a pair of lobed structures made up of a series of bronchioles, which end in tiny sacs called alveoli.

- The trachea (windpipe) branches into two smaller airways: the left and right bronchi, which lead to the two lungs. The left lung is longer, narrower, and has a smaller volume than the right lung it shares space in the left side of the chest with the heart. The right lung is divided into three lobes and each lobe is supplied by one of the secondary bronchi. It has an indentation, called the cardiac notch, on its medial surface for the apex of the heart. The left lung has two lobes.

- The bronchi themselves divide many times before branching into smaller airways called bronchioles. These are the narrowest airways – as small as one half of a millimetre across. The larger airways resemble an upside-down tree, which is why this part of the respiratory system is often called the bronchial tree. The airways are held open by flexible, fibrous connective tissue called cartilage. Circular airway muscles can dilate or constrict the airways, thus changing the size of the airway.

- At the end of each bronchiole are thousands of small air sacs called alveoli. Together, the millions of alveoli of the lungs form a surface of more than 100 square meters. Within the alveolar walls is a dense network of tiny blood vessels called capillaries. The extremely thin barrier between air and

capillaries allows oxygen to move from the alveoli into the blood and allows carbon dioxide to move from the blood in the capillaries into the alveoli.

- Each lung is enclosed by a double-layered serous membrane, called the pleura. The visceral pleura is firmly attached to the surface of the lung. At the hilum, the visceral pleura is continuous with the parietal pleura that lines the wall of the thorax. The small space between the visceral and parietal pleurae is the pleural cavity. It contains a thin film of serous fluid that is produced by the pleura. The fluid acts as a lubricant to reduce friction as the two layers slide against each other, and it helps to hold the two layers together as the lungs inflate and deflate.

- The lungs are soft and spongy because they are mostly air spaces surrounded by the alveolar cells and elastic connective tissue. They are separated from each other by the mediastinum, which contains the heart. The only point of attachment for each lung is at the hilum, or root, on the medial side. This is where the bronchi, blood vessels, lymphatics, and nerves enter the lungs.

Section 4.2 – The mechanism of breathing

To maintain a steep concentration gradient, air must be constantly moved into and out of the lungs.

The process of breathing is called ventilation.

Air pressure in the atmosphere is greater than the air pressure in the lungs, air is drawn in. This is known as inspiration.

When air pressure in the lungs is greater than the air pressure of the outside atmosphere, air is forced out. This is called expiration.

There are two types of intercostals muscles that lie between the ribs. There is internal muscles and external muscles.

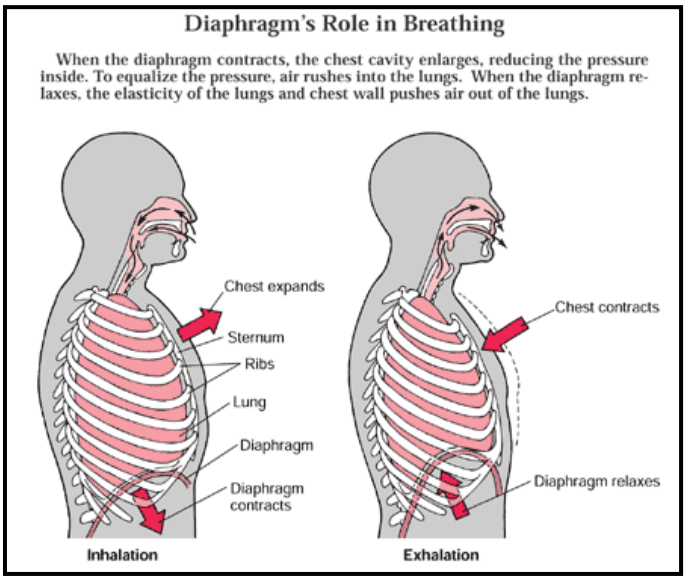
During inspiration, the external muscles contract. During expiration, the external muscles relax and the internal muscles contract.

Inspiration

Inspiration is an active process (requires energy)

In order to respire, the internal muscles relax whilst the external muscles contract. The ribs, as a result move upwards and outwards, thus increasing the volume. The diaphragm muscle contracts, and flattens. This further increases the volume.

Due to the increase in volume, the air pressure drops, and is then lower than the air pressure outside of the lungs. Due to this, air is drawn in.



Expiration

Normally, breathing out is a passive process (requires no energy) this is because the force of gravity and the recoil of elastic muscle fibres pull the rib cage downwards and inwards.

The internal muscles contract while the external muscles relax, this decreases the volume. The diaphragm relaxes and moves back into its domed shape. This further decreases the volume. The decrease in volume causes an increase in pressure and so air is pushed out.

Pulmonary Ventilation

Pulmonary ventilation = tidal volume x ventilation rate

($dm^3 min^{-1}$) (dm^3) (min^{-1})

Section 4.3 – Exchange of gas in the lungs

Gas exchange is the process by which O_2 moves in to the blood and CO_2 moves out.

Cellular respiration creates a constant demand for oxygen.

The movement of O_2 is independent of the movement of CO_2.

Diffusion occurs when there is a difference in concentration.

Particles move down a concentration gradient.

Breathing in air when there is a high concentration of CO_2 can be lethal even when there is a rich supply of oxygen.

CO_2 will not diffuse out if the concentration is higher outside the lungs.

Gas exchange surface - where gas enters and leaves the lungs.

Single-celled organisms can use their cell membrane as a surface for gas exchange.

Many organisms have developed specialised gas exchange structures called lungs.

Alveoli.

Mammals exchange respiratory gases mainly through the alveoli.

Each alveoli is approximately 75 – 300 micrometers across.

The delicate surface area is protected from damage by being tucked away inside the chest.

Ficks law

$$\text{Rate of diffusion} = \frac{\text{surface area of the membrane} \times \text{difference in concentration}}{\text{length of diffusion path}}$$

Having a vast number of capillaries is very important.

Walls of the alveoli are very thin and close together. This allows for efficient gas exchange.

Cells in the alveoli wall are flattened with only a thin layer of cytoplasm between the cell membranes. This reduces the distance for diffusion.

The lumen of the capillary is so narrow that the red blood cells slow down as they pass through it. They are flattened against the alveoli. This brings haemoglobin very close to the air in the alveoli.

The inner surface of the alveoli wall is covered in water, this is because the plasma membranes of its cells are permeable to water.

The film of water slows down the rate of diffusion because it has increased the distance the gases need to travel.

For a membrane to be permeable to oxygen it must also be permeable to water.

Epithelium and endothelium

Epithelial cells – cells from epithelium tissue that lines the internal and external cavity.

Endothelium is a specialised type of epithelium that lines the inner surface of blood vessels.

Alveoli structure

The wall of the alveoli is made of epithelial cells.

Surfactant

Surfactant prevents the alveoli from collapsing or sticking together.

Alveoli must be kept open to increase their surface area.

Lung surfactant reduces the surface tension so that the alveoli remain open.

Section 4.4 – Pulmonary tuberculosis

Tb is an infectious disease caused by an airborne, rod-shaped pathogen called mycobacterium tuberculosis.

Most commonly affects the lungs, causing pulmonary TB.

Almost any part of the body can be infected by the pathogen (extra pulmonary tb).

TB is the leading cause of death from bacterial infection.

The disease affects almost 1.7 billion people world wide.

It kills approximately 2 million people each year.

It is the biggest killer of women of reproductive age.

It has an extremely slow growth rate. Divides once every 16-20 hours.

Droplets of MTB can remain suspended in air for several hours.

It is very resistant, can survive several weeks in dry state.

Can survive weak disinfectants.

When a person coughs or sneezes, droplets of water are expelled and may contain the bacteria.

The disease only develops if the bacterium reaches the alveoli.

TB is referred to as invasive because it enters and spreads into tissue.

Contracting TB

Most people with TB only exhale a few bacteria in each breath. You can only contract the disease after prolonged exposure.

People who are most at risk are:
People who have HIV
Those taking immune suppressant drugs
Those under going cancer treatment
The very young/old
Those who live in LDCs
Those who inject drugs or drink too much alcohol

Skin test – the doctor would inject a very dilute extract of the bacterium into your skin. If the person has been exposed to the TB bacterium, the immune response will cause an area of inflammation.

Treatment

MTB is a bacterium that can be treated with antibiotics.

Most TB is curable using a combination of 4 different types of antibiotics.

The antibiotics are affective against most strains of the bacteria.

The drug is taken for 6 – 9 months.

Symptoms

Persistent cough
Chest pain
Coughing up blood
Chill + fever
Night sweat
Loss of appetite
Unexplained weight loss
Fatigue

Death – occurs when the sufferer has lost too much weight.

When you are most at risk

When you are in regular contact with those who have the disease
When your immune system is compromised, the bacteria could break out of the tubercles in the alveoli. They can then affect other regions of the lungs.
If the bacterium enters the blood, other areas of the body can be infected. This is called active tuberculosis.

Bacteria destroy the lung tissue, resulting in cavities and scar tissue where the lungs repair.
The loss of S.A can reduce the efficiency of gas exchange.
Fluid collects in the lungs and breathing becomes difficult.

Disease progression

Your immune system kills the bacteria and no further symptoms are experienced.

Immune system responds, bacteria are then engulfed by a type of white blood cell called macrophages which do not actually destroy the bacteria.

Tb bacteria have a cell wall made of a complex, waxy material that protects it from the macrophages.

The infection can lead to inflammation and enlargement of the lymph nodes responsible for that area of the lung.

After 3 – 6 weeks another white blood cell called T-lymphocytes arrive at the site and activate the macrophages so they can destroy the bacteria.

Lysosomes in the macrophages contain enzymes that break down the waste materials.

In a healthy person there are few, if any symptoms and the infection is controlled within a few weeks.

Active TB

The bacteria can multiply within the macrophages and eventually cause the cell to burst, releasing the bacteria.

These bacteria are then engulfed by more macrophages and the cycle continues.

Section 4.5 – Fibrosis, asthma and Emphysema

Infection

Can be caused by environmental agents such as asbestos, silica and some gases
Exposure to ionising radiation
Autoimmune response to inhaling gas containing bacterial, fungal or animal products.
Often linked with occupation

Most contaminants that reach the bronchi and bronchioles are trapped in the mucus. Air laden with fine dust is drawn into the alveoli where there is no cilia to sweep away the particles.

White blood cells near the alveoli are called alveoli macrophages. They engulf bacteria and foreign particles.

Pulmonary fibrosis

Occurs when scars form on the epithelium causing them to become irreversibly thickened.

Patients suffering from the disease cannot diffuse oxygen into their blood as efficiently.

Diagnosed by a lung biopsy.

The fibrous tissue also reduces the elasticity of the lungs. This makes it harder to ventilate the lungs.

Shortness of breath – occurs due to the lack of oxygen diffusing into the blood as a result of the lengthened pathway and shallower concentration gradient.

Chronic dry cough – bodies reflex to try and remove fibrous tissue. However, the tissue is virtually irremovable.

Pain and discomfort in the chest – caused by the pressure and damage caused by the tissue.

Asthma

Allergens cause a chemical called histamine to be produce, which causes the airways to become thickened.

The lining of these airways become inflamed

Goblet cells secrete more mucus.

Fluid leaves capillaries and enters the lungs.

The muscles surrounding the bronchi and bronchioles contract

Difficulty breathing – due to constriction of airways

A wheezing sound when breathing – caused by air passing through restricted airways

A tight feeling in the chest – consequence of not being able to ventilate the lungs properly

Emphysema

In emphysematous tissue the elastin has become permanently stretched and the lungs are no longer able to force all the air out of the alveoli.

Shortness of breath – air cannot be ventilated as effectively. This causes the concentration gradient to become shallower. As a result, the rate of diffusion is reduced and less gas exchange will take place.

Chronic cough – bodies reflex to try and remove damaged tissue.

Bluish skin colouration – due to the lower levels of oxygen within the blood as a result of poor gas exchange