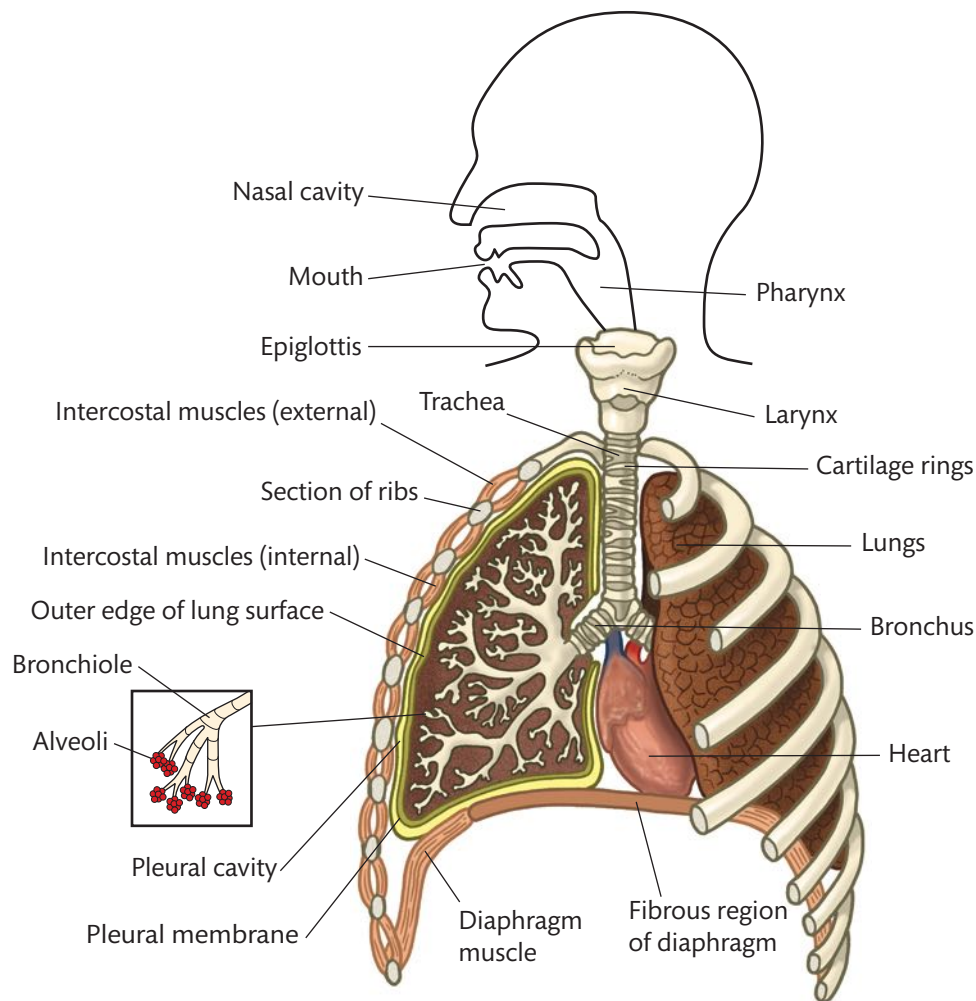


Structure and functions of the respiratory system

Air is drawn into your body via the nose and sometimes via the mouth, and passes through a series of airways to reach the lungs. This series of airways is referred to as the **respiratory tract** and can be divided into two main parts. The upper respiratory tract includes the nose, nasal cavity, mouth, pharynx and larynx. The lower respiratory tract consists of the trachea, bronchi and lungs.



► **Figure 1.12:** Bronchi, bronchial tree and lungs

Nasal cavity

When you breathe in, air enters the nasal cavity by passing through the nostrils. Hairs within the cavity filter out dust, pollen and other foreign particles before the air passes into the two passages of the internal nasal cavity. Here the air is warmed and moistened before it passes into the nasopharynx. A sticky mucous layer traps smaller foreign particles, which tiny hairs called cilia transport to the pharynx to be swallowed.

Pharynx

Commonly called the throat, the pharynx is a small tube that measures approximately 10–13 cm from the base of the skull to the level of the sixth cervical vertebra. The muscular pharynx wall is composed of skeletal muscle throughout its length. The funnel-shaped pharynx connects the nasal cavity and mouth to the larynx (air) and oesophagus (food). It is a passageway for food as well as air, so special adaptations are required to prevent choking when food or liquid is swallowed.

Larynx

The larynx, or voice box, has rigid walls of muscle and cartilage, contains the vocal cords and connects the pharynx to the trachea. It extends for about 5 cm from the level of the third to sixth vertebra.

Trachea

The trachea or windpipe denotes the start of the lower respiratory tract. It is about 12 cm long and 2 cm in diameter. It contains rings of cartilage to prevent it from collapsing, and it is flexible. It travels down the neck in front of the oesophagus and branches into the right and left bronchi.

Epiglottis

The epiglottis is the small flap of cartilage at the back of the tongue which closes the top of the trachea when you swallow to ensure food and drink pass into your stomach and not your lungs.

Lungs

Your lungs are the organ that allows oxygen to be drawn into the body. The paired right and left lungs occupy most of the thoracic cavity and extend down to the diaphragm. They hang suspended in the right and left pleural cavities straddling the heart. The left lung is smaller than the right.

Bronchi

The bronchi branch off the trachea and carry air to the lungs. By the time inhaled air reaches the bronchi, it is warm, clear of most impurities and saturated with water vapour.

Once inside the lungs, each bronchus subdivides into lobar bronchi: three on the right and two on the left. The lobar bronchi branch into segmental bronchi, which divide again into smaller and smaller bronchi. Overall, there are approximately 23 orders (sizes) of branching bronchial airways in the lungs. Because of this branching pattern, the bronchial network within the lungs is often called the **bronchial tree**.

Bronchioles

Bronchioles are small airways that extend from the bronchi and connect the bronchi to small clusters of thin-walled air sacs, known as alveoli. Bronchioles are about 1 mm in diameter and are the first airway branches of the respiratory system that do not contain cartilage.

Alveoli

At the end of each bronchiole is a mass of air sacs called alveoli. In each lung there are approximately 300 million gas-filled alveoli. These are responsible for the transfer of oxygen into the blood and the removal of waste such as carbon dioxide out of the blood. This process of transfer is known as **gaseous exchange**. Combined, the alveoli have a huge surface area for maximal gaseous exchange to take place – roughly the size of a tennis court. Surrounding each alveolus is a dense network of **capillaries** to facilitate the process of gaseous exchange. For more on gaseous exchange, see page 32.



PAUSE POINT

Explain how air enters the body and how it is used.

Hint

List the journey of air from the mouth to the alveoli.

Extend

Draw a diagram of the journey of air from the nose to the alveoli. Label each part of the respiratory system on your diagram.

Diaphragm

The diaphragm is a flat muscle that is located beneath the lungs within the thoracic cavity and separates the chest from the abdomen. The diaphragm is one of several components involved in breathing, which is the mechanism of drawing air – including oxygen – into the body (inhalation) and removing gases including carbon dioxide (exhalation). Contraction of the diaphragm increases the volume of the chest cavity, drawing air into the lungs, while relaxation of the diaphragm decreases the volume of the chest cavity, pushing air out.

Thoracic cavity

This is the chamber of the chest that is protected by the thoracic wall (rib cage). It is separated from the abdominal cavity by the diaphragm.

Internal and external intercostal muscles

The intercostal muscles lie between the ribs. To help with inhalation and exhalation, they extend and contract.

- ▶ The **internal intercostal** muscles lie inside the ribcage. They draw the ribs downwards and inwards, decreasing the volume of the chest cavity and forcing air out of the lungs when breathing out.
- ▶ The **external intercostal** muscles lie outside the ribcage. They pull the ribs upwards and outwards, increasing the volume of the chest cavity and drawing air into the lungs when breathing in.

Mechanisms of breathing

Breathing or **pulmonary ventilation** is the process by which air is transported into and out of the lungs, and it can be considered to have two phases. It requires the thorax to increase in size to allow air to be taken in, followed by a decrease to allow air to be forced out.

Inspiration

Inspiration is the process of breathing air into the lungs. The intercostal muscles between the ribs contract to lift the ribs upwards and outwards, while the diaphragm is forced downwards. This expansion of the thorax in all directions causes a drop in pressure within the lungs to below atmospheric pressure (the pressure of the air outside the body), which encourages air to be drawn into the lungs.

Expiration

The opposite of inspiration is expiration, and this occurs when the intercostal muscles relax. The diaphragm relaxes, moving upwards, and the ribs move downwards and inwards. Pressure within the lungs is increased and air is expelled or pushed out of the body.

During sport or exercise, greater amounts of oxygen are required, so the intercostal muscles and diaphragm must work harder. This results in an increase in your breathing rate and an increase in the force of your breath.

Control of breathing

Neural control

Breathing is a complex process that is largely under involuntary control by the respiratory centres of your brain. Inspiration is an active process, as the diaphragm muscle is **actively** contracting which causes air to enter the lungs. Expiration is a passive process, as the diaphragm muscle **relaxes** to allow air to exit the lungs. This process is controlled by neurones (cells that conduct nerve impulses) in the brain stem. Neurones in two areas of the **medulla oblongata** are critical in respiration.

Key term

Medulla oblongata – located in the middle of your brain, this is responsible for involuntary functions such as breathing, heart beat and sneezing.

These are the dorsal respiratory group (DRG) and the ventral respiratory group (VRG). The VRG is thought to be responsible for the rhythm generation that allows rhythmic and continuous breathing.

Chemical control

Other factors that control breathing are the continually changing levels of oxygen and carbon dioxide in the blood. Sensors responding to such chemical fluctuations are called **chemoreceptors**. These are found in the medulla and in the **aortic arch** and **carotid arteries**. These chemoreceptors detect changes in blood carbon dioxide levels as well as changes in blood acidity, and send signals to the medulla that will make changes to breathing rates.

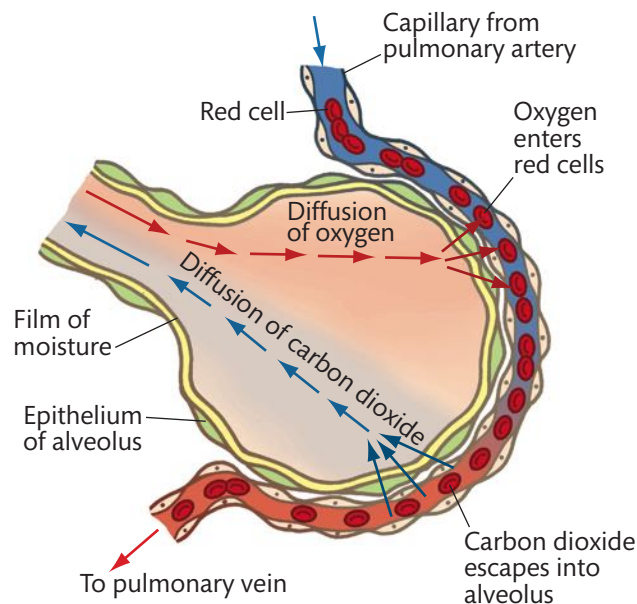
Key term

Diffusion – the process by which a substance such as oxygen passes through a cell membrane either to get into the cell or to get out of the cell. Substances move by diffusion from an area where they are more concentrated to an area where they are less concentrated.

Gaseous exchange

Gaseous exchange is the process by which one type of gas is exchanged for another. In the lungs, gaseous exchange occurs by **diffusion** between air in the alveoli and blood in the capillaries surrounding their walls. It delivers oxygen from the lungs to the bloodstream and removes carbon dioxide from the bloodstream to the lungs.

The alveolar and capillary walls form a **respiratory membrane** that has gas on one side and blood flowing past on the other. Gaseous exchange occurs readily by simple diffusion across the respiratory membrane. Blood entering the capillaries from the pulmonary arteries has a lower oxygen concentration and a higher carbon dioxide concentration than the air in the alveoli. Oxygen diffuses into the blood via the surface of the alveoli, through the thin walls of the capillaries, through the red blood cell membrane and finally latches on to haemoglobin. Carbon dioxide diffuses in the opposite direction, from the blood plasma into the alveoli.

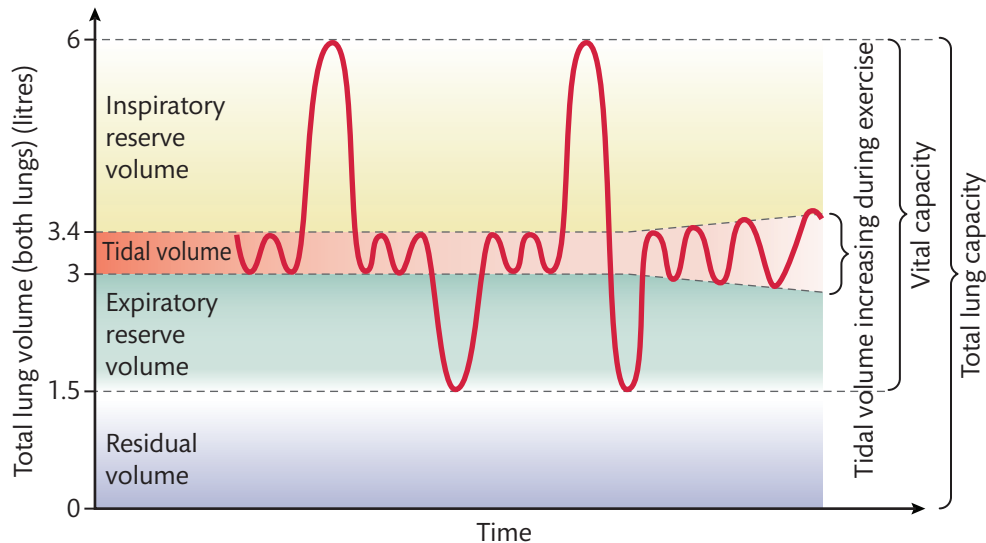


► **Figure 1.13:** Gaseous exchange in action in an alveolus

Lung volumes

What happens to your breathing when you are exercising or training? Your lungs are designed to take in more air during exercise so that more oxygen can reach the alveoli and more carbon dioxide can be removed. Your breathing will become deeper and more frequent to cope with the demands that exercise puts on your body.

Your **respiratory rate** is the amount of air you breathe in one minute. For a typical 18-year-old, this represents about 12 breaths per minute at rest, during which time about 6 litres of air passes through the lungs. It can increase significantly during exercise, by as much as 30–40 breaths per minute.



► **Figure 1.14:** Lung volume and capacities of a healthy adult

Tidal volume

Tidal volume is the term used to describe the volume of air breathed in and out with each breath. Under normal conditions this represents about 500 cm³ of air breathed, both inhaled and exhaled. Of this, approximately two-thirds (350 cm³) reaches the alveoli in the lungs where gaseous exchange takes place. The remaining 150 cm³ fills the pharynx, larynx, trachea, bronchi and bronchioles and is known as dead or stationary air.

During exercise, tidal volume increases to allow more air to pass through the lungs. The volume of air passing through the lungs each minute is known as the **minute volume** – it is determined by the breathing rate and the amount of air taken in with each breath.

- The lungs normally contain about 350 cm³ of fresh air, 150 cm³ of dead air and 2500 cm³ of air that has already undergone gaseous exchange with the blood.
- The lungs are never fully emptied of air, otherwise they would collapse. The air that remains in the lungs after maximal expiration, when you breathe out as hard as you can, is referred to as **residual volume**. The volume is around 1200 cm³ for an average male.
- **Vital capacity** is the amount of air that can be forced out of the lungs after maximal inspiration. The volume is around 4800 cm³.
- By breathing in deeply, it is possible to take in more air than usual so that more oxygen can reach the alveoli. This is especially important during exercise. You can breathe in up to an additional 3000 cm³ of fresh air in addition to the normal tidal volume – this is known as the **inspiratory reserve volume**.
- The **expiratory reserve volume** is the amount of additional air that can be breathed out after normal expiration. This can be up to 1500 cm³. At the end of a normal breath, the lungs contain the residual volume plus the expiratory reserve volume. If you then exhale as much as possible, only the residual volume remains.
- **Total lung volume** is your total lung capacity after you have inhaled as deeply and as much as you can, after maximal inspiration. It is normally around 6000 cm³ for an average-sized male.



PAUSE POINT

Can you remember the different lung volumes?

Hint

Write a list of the different lung volumes and briefly describe each one.

Extend

Think about how your breathing changes during exercise. Explain what is happening to each specific lung volume.

Responses of the respiratory system to a single sport or exercise session

Your body is surprisingly insensitive to falling levels of oxygen, yet it is sensitive to increased levels of carbon dioxide. The levels of oxygen in arterial blood vary little, even during exercise, but carbon dioxide levels vary in direct proportion to the level of physical activity. The more intense the exercise, the greater the carbon dioxide concentration in the blood. To combat this, your breathing rate increases to ensure the carbon dioxide can be expelled through expiration.

Increased breathing rate

Exercise results in an increase in the rate and depth of breathing. During exercise your muscles demand more oxygen, and the corresponding increase in carbon dioxide production stimulates faster and deeper breathing. The capillary network surrounding the alveoli expands, increasing blood flow to the lungs and pulmonary diffusion.

A minor rise in breathing rate prior to exercise is known as an anticipatory rise. When exercise begins there is an immediate and significant increase in breathing rate, believed to be a result of receptors working in both the muscles and joints.

After several minutes of aerobic exercise, breathing continues to rise, though at a slower rate, and it levels off if the exercise intensity remains constant. If the exercise is maximal, the breathing rate will continue to rise until exhaustion. After exercise the breathing rate returns to normal, rapidly to begin with and then slowly.

Increased tidal volume

During exercise, tidal volume increases to allow more air to pass through the lungs. Tidal volume is elevated by both aerobic and anaerobic exercise. During exercise, oxygen is depleted from your body, triggering a deeper tidal volume to compensate.

During strenuous exercise, oxygen diffusion may increase by as much as three times above the resting level. Likewise, minute ventilation depends on breathing rate and total volume. During exercise adults can generally achieve minute ventilation approximately 15 times greater than the resting values.

Adaptations of the respiratory system to exercise

Like the cardiovascular system, the respiratory system undergoes specific adaptations in response to an organised and regular training programme. These adaptations help to maximise the efficiency of the respiratory system; oxygen can be delivered to the working muscles to meet the demands of the exercise while waste products can be removed quickly.

Increased vital capacity

Your vital capacity increases in response to long-term physical training to provide an increased and more efficient supply of oxygen to working muscles.

Increased strength of respiratory muscles

The diaphragm and intercostal muscles increase in strength, allowing for greater expansion of the chest cavity. This will mean that it is easier to take deeper breaths as the stronger and more pliable muscles will allow the chest cavity to expand further.

Increase in oxygen and carbon dioxide diffusion rate

Your respiratory system adapts to regular training, allowing oxygen and carbon dioxide to diffuse more rapidly. An increase in diffusion rates in tissues means that you can train longer and harder, as your muscles will be supplied with more oxygen and the increased carbon dioxide will be removed more quickly.



PAUSE POINT

Why is the respiratory system so important to sports performance?

Hint

Describe how the respiratory system adapts to long-term exercise.

Extend

Explain why each adaptation can improve sport and exercise performance.

Additional factors affecting the respiratory system

Although regular training will improve the efficiency of your respiratory system, there are a number of additional considerations that can affect this system.

Asthma

Asthma is a common condition where the airways of the respiratory system can become restricted, making it harder for air to enter the body, resulting in coughing, wheezing or shortness of breath.

During normal breathing, the bands of muscle that surround the airways are relaxed and air moves freely. However, asthma makes the bands of muscle surrounding the airways contract and tighten so that air cannot move freely in or out of the body. Asthma can have a negative effect on sports performance as people with the condition will not be able to get enough oxygen into their lungs to supply their muscles, especially with the increased amounts required during exercise.

However, regular exercise will strengthen your respiratory system and help prevent asthma. Regular aerobic training can help to improve breathing and muscular strength, and endurance training will also improve oxygen uptake.

Safety tip

If you suffer from asthma always carry your inhaler. If you begin to experience the symptoms of asthma then stop the exercise immediately.

Research

For more information about asthma, see NHS Choices – www.nhs.uk/Livewell/asthma.

Case study

Paula Radcliffe

World record marathon runner Paula Radcliffe has had exercise-induced asthma all of her life. However, through determination and the correct medication, she has been able to compete successfully at the highest level and is currently the world record holder for the women's marathon with her time of 2 hours, 15 minutes and 25 seconds.

To ensure that she is able to train and compete, Paula always warms up gently and gradually so that her asthma does not interfere. When training she will use her preventer inhaler first thing in the morning and then her reliever inhaler before she starts exercising.

Paula's message is clear: 'control your asthma, don't let it control you'.

Check your knowledge

- 1 How does asthma affect sporting performance?
- 2 What is the difference between a preventer inhaler and a reliever inhaler?



► Paula Radcliffe is one of many elite athletes who compete successfully despite suffering from asthma