The circulatory system

Structure of the circulatory system

The structure of the circulatory system consists of the heart and blood vessels (arteries, veins and capillaries). The heart consists of two muscular pumps known as the left and right ventricles, which pump blood throughout the body. The blood vessels are intricate networks of hollow tubes that transport blood throughout the entire body. The function of the human circulatory system is to transport blood around the body. At rest, the average heart pumps about five litres of blood throughout the body every minute.

Major components of the circulatory system

The major components of the circulatory system are the heart, blood and blood vessels. Each play a significant role in the structure and function of the circulatory system to maintain bodily functions.

The heart is a major organ in the circulatory system. It is about the size of a fist, and lies beneath the sternum, slightly to the left. It consists of four chambers, and as assisted through cardiac muscles, the heart pumps oxygenated blood around the body and deoxygenated blood back to the lungs. The blood first receives deoxygenated blood through the superior and inferior vena cava after this blood has travelled through the body delivering nutrients and removing wastes. After being pumped through the right atrium and right ventricle, this blood is sent to the lungs to be oxygenated through the pulmonary artery. This oxygen-rich blood is returned to the heart via the pulmonary vein, processed through the left atrium and left ventricle, and finally pumped through the aorta to once again deliver oxygen and nutrients to the body.

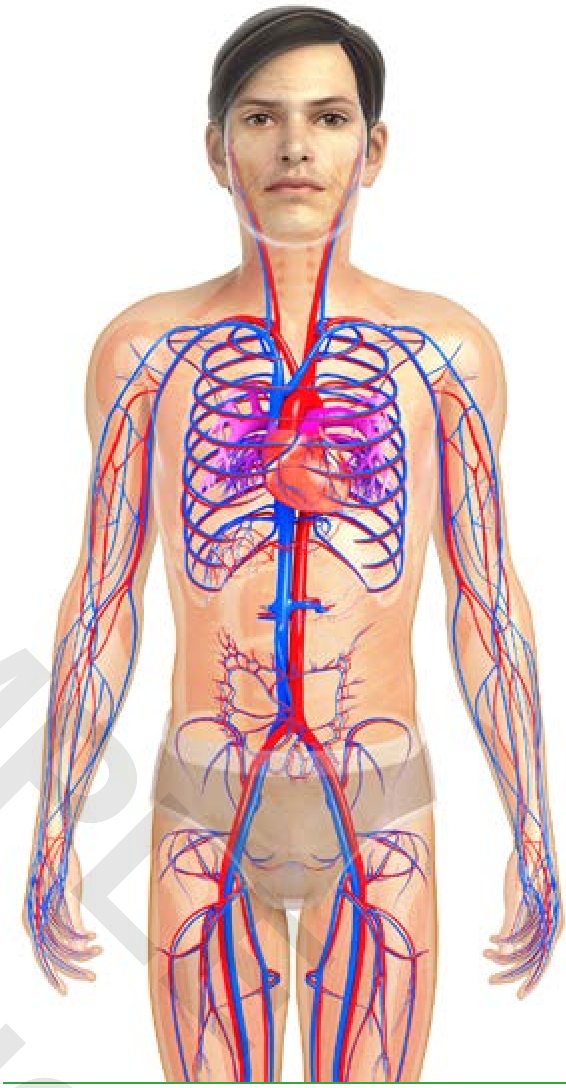

Figure 1.28:
The circulatory system.

Blood is also a major component in the circulatory system. It consists of four significant structures: red blood cells to carry the oxygen in haemoglobin, white blood cells to form part of the immune system, platelets to be used for blood clotting (for example, forming a scab when the skin has a cut) and plasma to carry these components plus other nutrients and wastes in a liquid.

The blood vessels allow this blood to be transported to all cells in the body. There are three types of blood vessels: arteries, veins and capillaries. Once the blood has been pumped out of the heart through the aorta, it travels first through arteries and is continually pumped, as a result of heart contractions, all over the body. The blood then arrives at various networks of capillaries, which are the smallest blood vessels, and is distributed in various pathways to arrive at cells for nutrient transfer. Capillaries are also connected to veins, so waste from cells are also transferred into blood simultaneously. Veins carry wastes back to the heart to be sent to the lungs to be re-oxygenated.

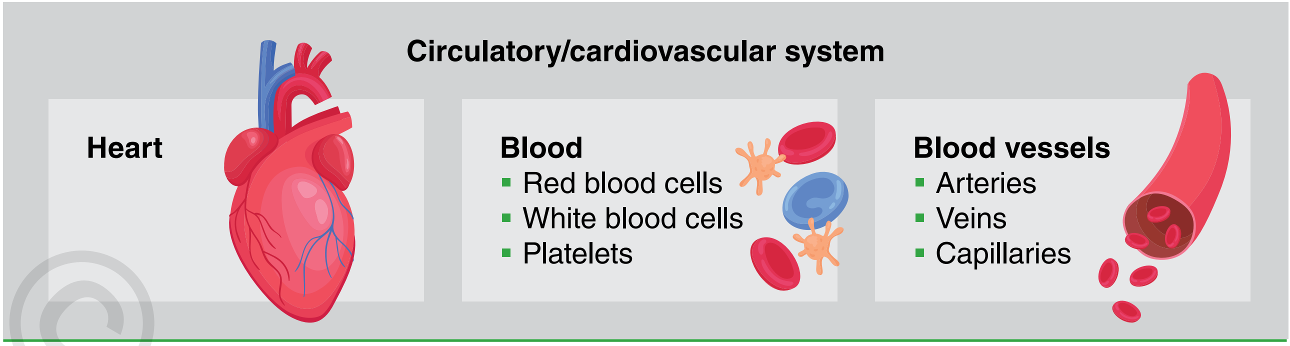

Figure 1.29:
Components of the circulatory system.

Function of the circulatory system

The circulatory system works with other body systems to enable:

- **Respiration** – delivers oxygen to the cells and removes carbon dioxide from them.
- **Nutrient transportation** – carries digested food substances to the cells of the body.
- **Waste removal** – disposal of waste products and poisons that would harm the body if they accumulated.
- **Immunity** – helps protect the body from disease.
- **Cellular communication** – the circulatory system provides a mode of transport for hormones.
- **Thermoregulation** – the circulatory system transports heat (to warm and cool the body).

The heart pumps blood through vessels that travel to every cell in the body. The blood carries oxygen and dissolves nutrients on its way to the cell, and on the return journey it carries carbon dioxide and waste products. The transport of nutrients and wastes is essential for cell function, and the circulatory system plays a significant role in ensuring this occurs.

Also, the distribution of blood flow to various parts of the body changes depending on the current need or circumstance of the body. For example, hypothermia is when the core body temperature drops below 35 °C. In this case, blood flow would focus on vital organs in the centre of the body rather than maintaining the temperature in the body's extremities such as hands and feet. Alternatively, if the body is getting very hot, the blood will be directed to the skin to cool the body through perspiration.

Figure 1.30:
The carotid pulse is one of the easiest waves of blood to locate and feel.

Did you know?

Your heart beats about 100,000 times every day.
If you live for 100 years, that's over 35 million heartbeats!

Production of efficient movement

Ultimately, movement needs to be efficient so the body doesn't fatigue or overload components of body systems unnecessarily. Within the circulatory system, ensuring blood can be pumped to all parts of the body without placing undue stress on the heart is essential. In particular, when exercising, cells within the body produce more carbon dioxide waste and, in turn, need more oxygen. Therefore, the blood needs to quicken its return to the heart and the lungs to continue this transport process. The physiological response of the body is for the heart to beat faster and more strongly. To explain the amount of blood pumped by the heart, the following equation has been developed: **heart rate (HR) × stroke volume (SV) = cardiac output (CO)**.

This formula details the effect heart rate and stroke volume has on cardiac output. Heart rate is the number of beats per minute, stroke volume is the amount of blood pumped out of the left ventricle per beat (measured in millilitres) and cardiac output is the amount of blood pumped per minute (measured in litres).

Figure 1.31: Athletes may use smart watches to monitor and record their heart rate throughout their event.

The more times the heat beats per minute, the more blood that will be pumped out. However, the strength of the single beat influences and helps determine how much blood is pumped.

For example, an elite athlete would have a lower heart rate and a higher stroke volume compared to a sedentary person, who would have a higher heart rate and a lower stroke volume. This is due to the athlete having stronger, more conditioned cardiac muscles, resulting in more blood being pumped out per contraction, therefore requiring the heart to beat less often at rest. Contrastingly, a sedentary person would have a lower stroke volume, requiring the heart to beat more frequently to pump the required blood out to the body. However, at rest, the elite athlete and the sedentary person would have very similar cardiac outputs, as the higher and lower heart rates and stroke volumes counteract each other.

For efficiency, having a lower heart rate and a higher stroke volume is better for the circulatory system. With cardiac muscles being stronger to create a higher stroke volume, during exercise the heart rate can remain relatively low but still supply the blood flow the body needs. Therefore, muscle fatigue is delayed, and the person can participate in the demands of exercise for longer and still accommodate for the body's needs, effectively producing more efficient movement.

Internet activity

Log on to TitanOnline and complete Activity 1.3 – listening to the audio file on the circulatory system.

Learning activity

1. Explain why the blood flowing to the surface of the skin will aid the body in cooling down.
2. Identify the four chambers of the heart.
3. Identify the vessels in which blood is supplied to the heart.
4. Identify the vessels in which blood is removed from the heart.
5. Identify and describe the factors that affect a person's pulse rate.
6. Explain the physiological changes that occur in the body as the pulse rate increases.
7. Calculate your maximum heart rate using the following formula:
   220 – your age = [your maximum rate].
8. Write down your resting heart rate. Then run continuously for two minutes and write down your heart rate again. Draw the results on a line graph.

The respiratory system

Structure of the respiratory system

A constant flow of oxygen is critical in keeping the body's cells working. Just as importantly, wastes such as carbon dioxide, which can be lethal if allowed to accumulate, need to be removed. These two functions are achieved through breathing; that is, through the respiratory system's structure by which oxygen is consumed and carbon dioxide is expelled.

The three major parts of the respiratory system are the airway, the lungs and the muscles of respiration. The airway, which includes the nose, mouth, pharynx, larynx, trachea, bronchi and bronchioles, carries air down to the lungs, through the support of the muscles of respiration like the diaphragm, and is diffused into the bloodstream to be transported to cells. In the reverse action, carbon dioxide is transferred from the bloodstream and sent back through the airways into the atmosphere.

The functions of the human respiratory system are to transport air into the lungs, to facilitate diffusion of oxygen into the bloodstream, to receive the waste product carbon dioxide from the blood, and to exhale the carbon dioxide.

Did you know?

If you were to spread out an adult's alveoli, they would cover a tennis court!

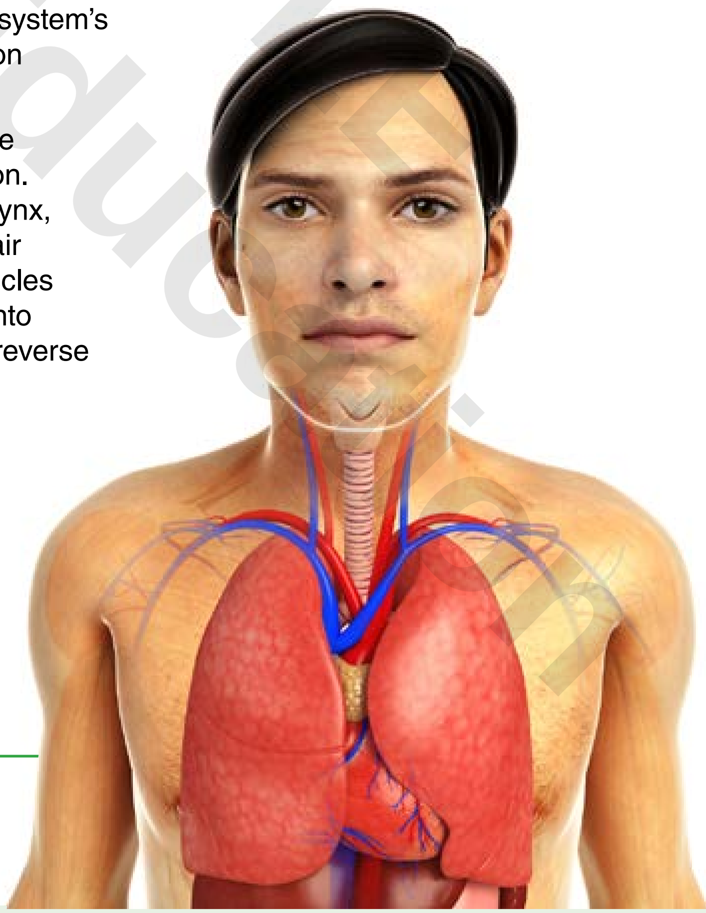

Figure 1.32:
The respiratory system.

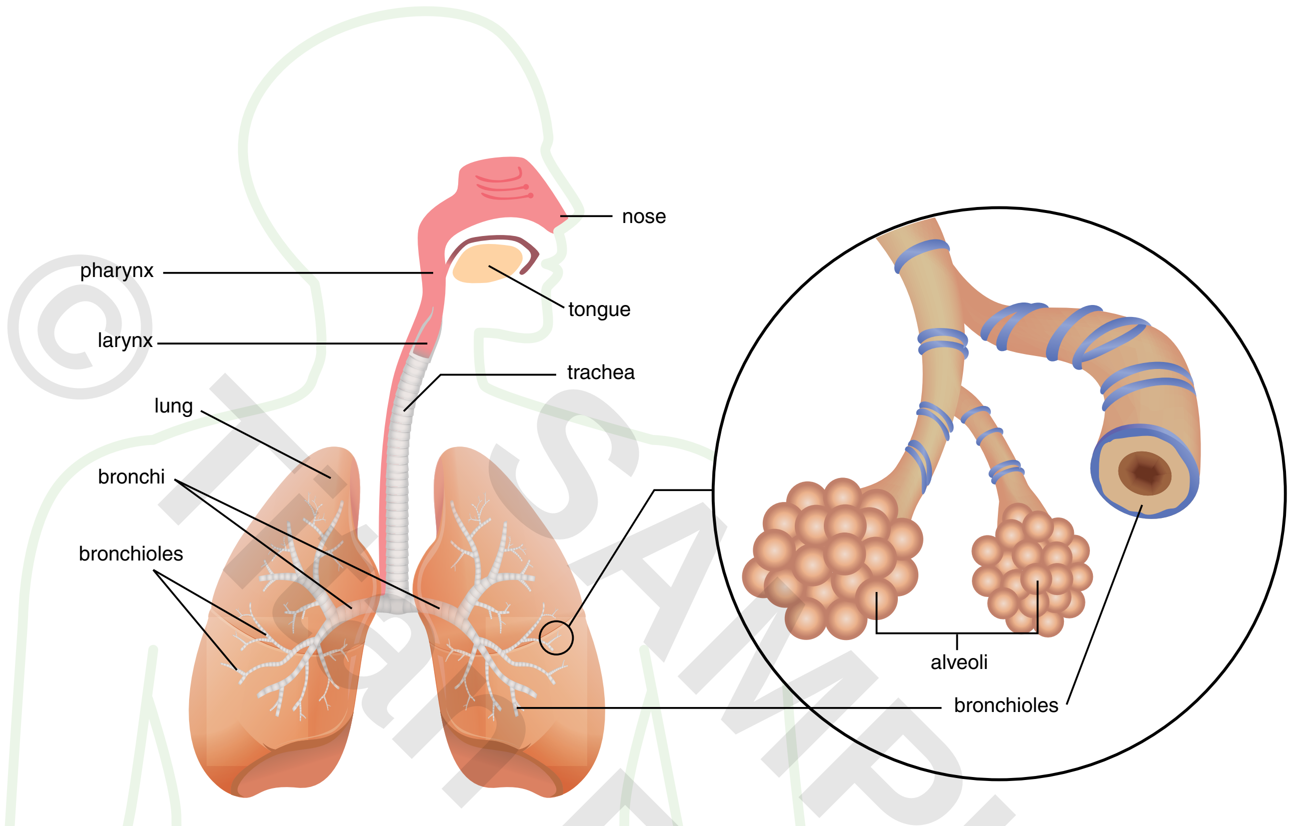

Figure 1.33:
Components of the respiratory system.

Major components of the respiratory system

The major components of the respiratory system are labelled on the diagram in Figure 1.33. The respiratory system relies on the skeletal and muscular systems to perform the function of breathing. The lungs are attached to the ribs by way of suction. The sequence of events is set out in the flowchart in Figure 1.34.

The diaphragm has a vital role in the function of breathing. It is a round sheet of muscle that encloses the bottom of the rib cage. When the diaphragm receives an impulse, it contracts and flattens, and the size of the lungs increases. Both events are contributory factors in the function of breathing in, which is known as inspiration.

Impulse is sent from the brain → Impulse received by muscles of the ribs and chest → Muscles of the ribs and chest contract → Ribs are pulled upwards and outwards → Air rushes into the lungs

Figure 1.34:
How the respiratory system works.

The function of breathing out, or expiration, is a result of the relaxation of the diaphragm and the muscles of the ribs. The relaxation causes the ribs to lower and the diaphragm to return to its dome shape. The air inside the lungs is squeezed out through the nose and mouth, in the same way that air is squeezed out of a deflating balloon.

The breathing rate changes when exercising. When the body is at rest, an individual will breathe about 12 times per minute and take in about half a litre of air. The following equation highlights how much air is ventilated (breathed in and out) in one minute: **12 breaths per minute × 0.5 litre = 6 litres ventilated per minute**.

During exercise, the rate and the depth of breathing increase significantly.

Learning activity

1. Explain the terms 'inspiration' and 'expiration'.
2. Draw a flow diagram of the sequence of events that occurs during expiration.
3. Draw and label the major components of the respiratory system.
4. Explain the effect that the size of the lungs has on the movement of air into and out of the lungs.

When air enters the lungs, it travels down the bronchus, which divides, like a tree, into tiny branches, or bronchioles, which get smaller and smaller. At the end of each bronchiole is a structure called an alveolus, which is like a little balloon or air sac.

Alveoli are full of oxygen-rich air that has been drawn into the lungs during inspiration. The oxygen has to get into the blood so that the cardiovascular system can perform its function of transporting the oxygen to the working cells. This movement of oxygen occurs in the alveoli, where a capillary can always be found close by, and the oxygen can move from one place to the other, that is, from the lungs into the blood.

The capillary that is close to the alveoli is carrying blood that has been pumped from the body via the heart. It is carrying a lot of carbon dioxide. The carbon dioxide moves from the blood into the alveoli at the same time that the oxygen is moving in the other direction, in a process known as gaseous exchange.

The movement of oxygen from the alveoli to the blood can be less efficient if people are suffering from a respiratory disease and have mucus built up in their lungs.

Figure 1.35:
Conditions such as asthma may interfere with the normal function of the respiratory system.

Function of the respiratory system

The respiratory system works with the cardiovascular system to transport oxygen to every cell of the body and to remove carbon dioxide. For these functions to be performed, the body must take air in from the environment.

Air enters the respiratory system through the nose and mouth and then passes down the windpipe, or trachea, into the lungs. On the way to the lungs, the air is warmed, filtered and moistened. The trachea splits into two bronchi, which carry the air into the lungs. In the lungs, gases are exchanged, whereby oxygen can enter the bloodstream and waste products can leave the bloodstream.

Production of efficient movement

The partnership of the circulatory and respiratory systems is essential in efficiently delivering oxygen around the body. It is critical especially during physical activity to keep the body functioning and muscles working efficiently. Enduring the demands of exercise and minimising the physiological effects, including muscle fatigue and lactic acid build-up, is an essential role of the respiratory system.

Figure 1.36:
Without oxygen, the body cannot sustain effort in long-distance events like cross-country skiing.

Oxygen enables cell function that ultimately generates energy for muscles to contract. However, when energy is created in these cells, wastes such as carbon dioxide are also created. The wastes need to be expired from the body through the respiratory system.

Without oxygen, the body cannot sustain effort in long-distance events like a marathon or cross-country skiing. For endurance events, if wastes are not removed from the cells, and oxygen is not frequently delivered, cells tire and muscles fatigue and no longer produce efficient movement. Despite being able to do explosive events like shot put or long jump without initially using oxygen, it is still required for the muscles to recover to their pre-exercise state.

Efficient movement in sport performance is facilitated by the respiratory system in the way oxygen is utilised within the body during exercise demands. For endurance athletes, the more oxygen the body can consume and uptake, the greater the increase in energy production and improved performance. Endurance performance ultimately depends on the body's ability to take in oxygen, transport it to the working muscles, use it at the working muscles, and remove carbon dioxide.

The ability to use oxygen efficiently is known and measured as maximal oxygen uptake: VO_2 max. To get an accurate measurement of VO_2 max, specialised equipment is required for gas analysis. However, there are several tests that can be used to estimate VO_2 max; for example, the multistage fitness test, the '12-minute run' test, the cycle test and the step test.

Internet activity

Log on to TitanOnline and complete Activity 1.4 – follow the instructions to make a working model of the lungs.

Practical activity

The practical experiment detailed as follows is designed for investigating the changes that are observed in the cardiovascular and respiratory systems during rest and during varying intensities of exercise. Working in pairs, one person is the subject and the other person records the results.

Read through the instructions before you start the investigation. Design a table to record the results. Practise taking your partner's pulse before you start.

1. Record your partner's pulse rate over one minute when they are sitting.
2. Count the number of normal breaths your partner takes per minute.
3. Time your partner while he or she is briskly walking for five minutes.
4. Record your partner's pulse rate for the first 15 seconds after the activity ceases. Multiply the figure by four to work out the number of beats per minute.
5. Ask your partner to count his or her breaths for the minute immediately following the activity.
6. Repeat steps 4 and 5 after two minutes.
7. Supervise your partner jogging for five minutes.
8. Record your partner's pulse rate for the first 15 seconds after the activity ceases. Multiply the figure by four to work out the number of beats per minute.
9. Ask your partner to count his or her breaths for the minute immediately following the activity.
10. Repeat steps 8 and 9 after two minutes.
11. Swap roles, and repeat steps 1 to 10.

Learning activity

1. Describe how the circulatory and respiratory systems contribute to efficient movement.
2. Identify the structures that oxygen passes on its route from the atmosphere to the alveoli. Present your answer as a flow diagram.
3. Describe what VO_2 max is and why it is a good indicator of aerobic fitness.
4. Explain the respiratory system's response to exercise.
5. Explain the respiratory system's adaptation to exercise.
6. Explain the function of the:
   a. pharynx
   b. larynx
   c. trachea
   d. alveoli
   e. bronchi
   f. bronchioles
   g. nose.

Figure 1.37:
Road cyclists have high levels of aerobic fitness.

Interrelationships between the body systems

Each of the four body systems – skeletal, muscular, respiratory and cardiovascular – work together to produce efficient movement. During physical activity, these body systems support each other in the demands of exercise to create efficient energy production and effective movement.

It is the individual structure and function of each body system, and each system's interaction with other body systems, that effectively produces movement. For instance, energy needed for muscle contraction and movement cannot be generated without the delivery of oxygen to cells through the bloodstream.

Each body system significantly contributes to movement, including consumption and transportation of oxygen, muscle contraction, and providing a structure to support muscles. During physical activity, for example when running, the body's increased heart rate and ventilation rate is a sign of muscles being under stress. They need an increasing amount of oxygen to continue working efficiently.

Energy production and hydration during physical activity

Various forms of energy exist in the environment. Energy cannot be created or destroyed but it can change from one form to another.

When exercising, the body is constantly working to supply muscles with enough energy to keep contracting, but the way energy is made available to the muscles changes depending on the specific intensity and duration of the exercise.

There are three energy systems the body can utilise and each requires an energy source for muscle contraction to occur. The energy produced in the body is provided by the food an individual eats.

Water is necessary for all cell functions, temperature regulation, and transportation of nutrients and waste. Water is lost as sweat, during its evaporation from the lungs and by way of excretion. In the body, a lack of water is known as dehydration, and can be life threatening because so many of the body's vital processes need water. The recommended daily fluid intake varies depending on age, the temperature and levels of exercise, but two litres of fluid, preferably water, is suggested for adults.

Figure 1.38:
Lack of fluid intake can lead to dehydration and poor performance.

Energy production

Role of food as a fuel

Chemical energy is taken into the body in three forms of food: carbohydrate, fat and protein.

Carbohydrate

All carbohydrates are broken down into glucose, which is the body's primary energy source. This includes starch, dietary fibre and sugar.

Simple carbohydrates

Simple carbohydrates have a quick digestion time, providing a quick source of energy. They are refined sugars and are the source of extra nutrients such as fibre and vitamins.

Complex carbohydrates

Complex carbohydrates take longer to break down so provide a more sustained source of energy. They are found in bread, grain, cereal and vegetables, and include starch and fibre – more filling sources of food. Food is still broken down into glucose molecules during digestion.

Figure 1.39:
Energy is provided by the food we eat.

Fat

Fats and oils belong to the chemical family known as lipids and are an important source of energy. Despite only needing a small amount of fat in the diet, all types of fats are a source of essential fatty acids, protect vital organs, and insulate the body against extreme temperatures.

Saturated fats

Saturated fats are in animal products such as cheese. They are linked to an increase in cholesterol and a higher risk of heart disease so it is important to eat these sparingly.

Monounsaturated fats

Monounsaturated fats are in avocado, nuts, olives, oils (canola and olive oils) and chicken.

Polyunsaturated fats

Polyunsaturated fats are in fish, nuts, soybeans and polyunsaturated margarine.

According to scientific evidence, monounsaturated and polyunsaturated fats are an aid to lowering the body's level of cholesterol.

Figure 1.40:
Monounsaturated and polyunsaturated fats are an important source of energy.

Protein

Protein is necessary for growth, healing, and fighting disease and infection. It is an aid to development of antibodies and provision of energy. Examples of animal-derived sources of protein are meat, fish, chicken and eggs, and examples of plant-derived sources are nuts, kidney beans, lentils and textured vegetable protein.

Each form of energy comes from different foods, has different uses in the body, and fuels different types of activity, as outlined in Table 1.2.

Table 1.2: Food as an energy source.

Food type	Example	Use in the body	Type of activity
Carbohydrate	Bread, pasta, potato, banana	Primary energy source	Simple – short and high-intensity activities. Complex – long and low-intensity activities
Fat	Cheese, nuts, oils	Energy source used after carbohydrate sources are exhausted	Low-intensity aerobic activities like jogging
Protein	Meat, eggs and nuts	Final source of energy (rarely used)	Low-intensity activities of very long duration

Energy that is taken into the body in the form of food is measured in kilojoules. The amount of energy that is required, or the number of kilojoules that are required, depends on the person's size, body composition, metabolic rate and exercise level.

Energy input versus energy output

Food, or chemical energy, is taken into the body and is transformed into mechanical and heat energy.

- If the amount of energy entering the body equals the amount being converted to movement and heat, the individual's weight will remain stable.
- If the amount of energy entering the body exceeds the amount being used, the excess will be stored as fat and the individual will gain weight.
- If the amount of energy entering the body is less than the amount being used, the individual will lose weight.

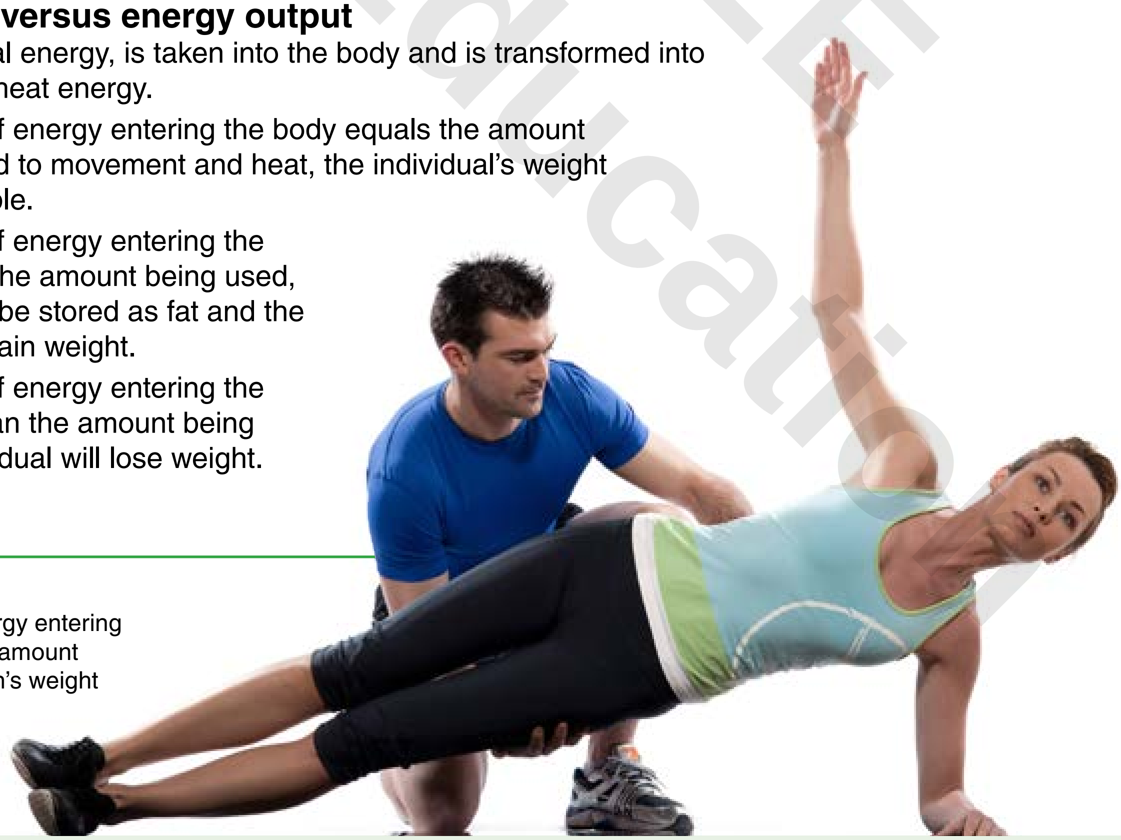

Figure 1.41:
If the amount of energy entering the body equals the amount being used, a person's weight will remain stable.

Aerobic and anaerobic energy production

The aerobic and anaerobic energy systems are pathways for energy production for efficient movement. This energy production is enabled through the molecule ATP, which utilises foods to create chemical energy. This molecule converts carbohydrates, fats and proteins into energy to generate movement.

ATP stands for 'adenosine tri-phosphate', and consists of one molecule of adenosine and three phosphate molecules. The body's muscles have limited ATP stores. When energy is needed to cause muscle contraction, ATP breaks down into ADP, which stands for 'adenosine di-phosphate' and consists of one molecule of adenosine and two molecules of phosphate. In this way, energy is produced for muscular contraction, and the body continues this process to keep moving.

Figure 1.42:
Complex carbohydrates help you feel fuller for longer.

The aerobic energy system

The slow production of energy is provided by way of the aerobic energy system, in which oxygen, along with stored carbohydrates and fats, is used to resynthesise ATP. The oxygen in the cell breaks down carbohydrates and fats to form a source of fuel: ATP. This system of energy production can go on for an extended period of time, for example a 10-kilometre run, as long as the activity level is low.

Internet activity

Log on to TitanOnline and complete Activity 1.5 by investigating the energy systems that are mainly used in a range of sports.

The two anaerobic energy systems

Energy is also provided by way of the following two anaerobic energy systems.

ATP–PC system

In the ATP–PC system, another chemical that is stored in the muscles, phosphocreatine, or PC, is used to resynthesise ATP. Because phosphocreatine exists in the muscle, it is immediately available to rebuild ATP, and can do so very rapidly. This system can therefore be a source of maximum energy, but for only about 10 seconds, because the limited phosphocreatine stores are rapidly depleted. For example, the ATP–PC energy system can adequately fuel activities like throwing a javelin and 50-metre sprint.

Lactic acid system

In the lactic acid system, carbohydrate is broken down into glucose to provide the energy for resynthesising ATP. The breakdown of glucose to form ATP leads to the formation of lactic acid, a waste product produced in the working muscles. The build-up of lactic acid leads to muscle fatigue and exhaustion, therefore limiting the energy system's effectiveness to medium-high intensity activities with a duration of about two to three minutes.

The following is a summary of the energy systems.

Fuel

- **ATP–PC system:** phosphocreatine is used.
- **Lactic acid system:** carbohydrate is broken down into muscle glycogen and is the only fuel source.
- **Aerobic system:** carbohydrates are the main fuel source. Fats and, to a limited extent, protein can also be used.

The amount of energy supplied

- **ATP–PC system:** a very limited amount of energy is supplied.
- **Lactic acid system:** a limited amount of energy is supplied.
- **Aerobic system:** an unlimited amount of energy is supplied at low intensity.

Duration

- **ATP–PC system:** at between 95 per cent and 100 per cent of maximum effort, the system will last for between only 10 and 12 seconds.
- **Lactic acid system:** depending on the level of intensity, the system will last for between 30 seconds and two to three minutes. At between 90 per cent and 95 per cent of maximum effort, the system will last for about 30 seconds.
- **Aerobic system:** at low intensity, the system will last for a virtually unlimited length of time.

Causes of fatigue

- **ATP–PC system:** phosphocreatine is exhausted after about 10 to 12 seconds.
- **Lactic acid system:** lactic acid, which is a waste product, builds up in the muscles, leading to fatigue and exhaustion.
- **Aerobic system:** this system will continue until the body has used muscle glycogen or stored energy in the form of carbohydrate, fats and protein.

Figure 1.43:
A build-up of lactic acid may cause muscle cramps.

Waste products

- **ATP–PC system:** no waste products are produced.
- **Lactic acid system:** lactic acid is produced.
- **Aerobic system:** carbon dioxide and water are produced.

Recovery time

- **ATP–PC system:** recovery time is between 30 seconds and two minutes.
- **Lactic acid system:** recovery time is between 20 minutes and two hours, depending on the exercise's intensity and duration.
- **Aerobic system:** sufficient time – up to 24 hours – is required so that diminished fuel supplies can be replaced.

Sports in which each energy system is mainly used

- **ATP–PC system:** 100-metre sprint, javelin, long jump and weightlifting.
- **Lactic acid system:** 100-metre swimming, 400-metre running and the 'cycling 1 kilometre' time trial.
- **Aerobic system:** triathlon, marathon running, 1500-metre swimming and the cycling road race.

The three energy systems rarely work alone; and considerable overlap occurs between them. Generally, all three systems are contributory factors in production of energy in all activities, to varying extents.

Learning activity

1. Analyse how the interrelationship between the body systems is important during physical activity.
2. Outline the role of food as a fuel source for a range of physical activities.
3. Explain how ATP is re-synthesised.
4. Outline the influence of energy production on performance.
5. Explain how lactic acid is removed from the body.
6. Identify how quickly lactic acid is removed from the body.
7. Describe the types of activity in which the aerobic system is mainly used.
8. Identify three sporting performances in which the ATP–PC system is mainly used.
9. Identify two track events in which the lactic acid system is mainly used.
10. For each of the following activities, determine which energy system would mainly be used:
    a. A 100-metre sprint.
    b. A 5000-metre running race.
    c. A hockey game.
    d. Batting during a cricket game.
    e. A marathon.
    f. An 800-metre running race.
    g. Javelin.
    h. A dance routine.
    i. Lifting weights.
    j. A 1000-metre cycling time trial.
11. Label the three energy systems on the following graph.

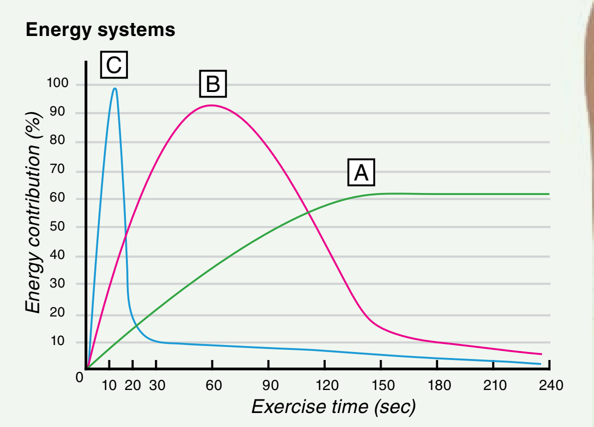

Figure 1.44:
The ATP–PC energy system can adequately fuel activities like throwing a discus.