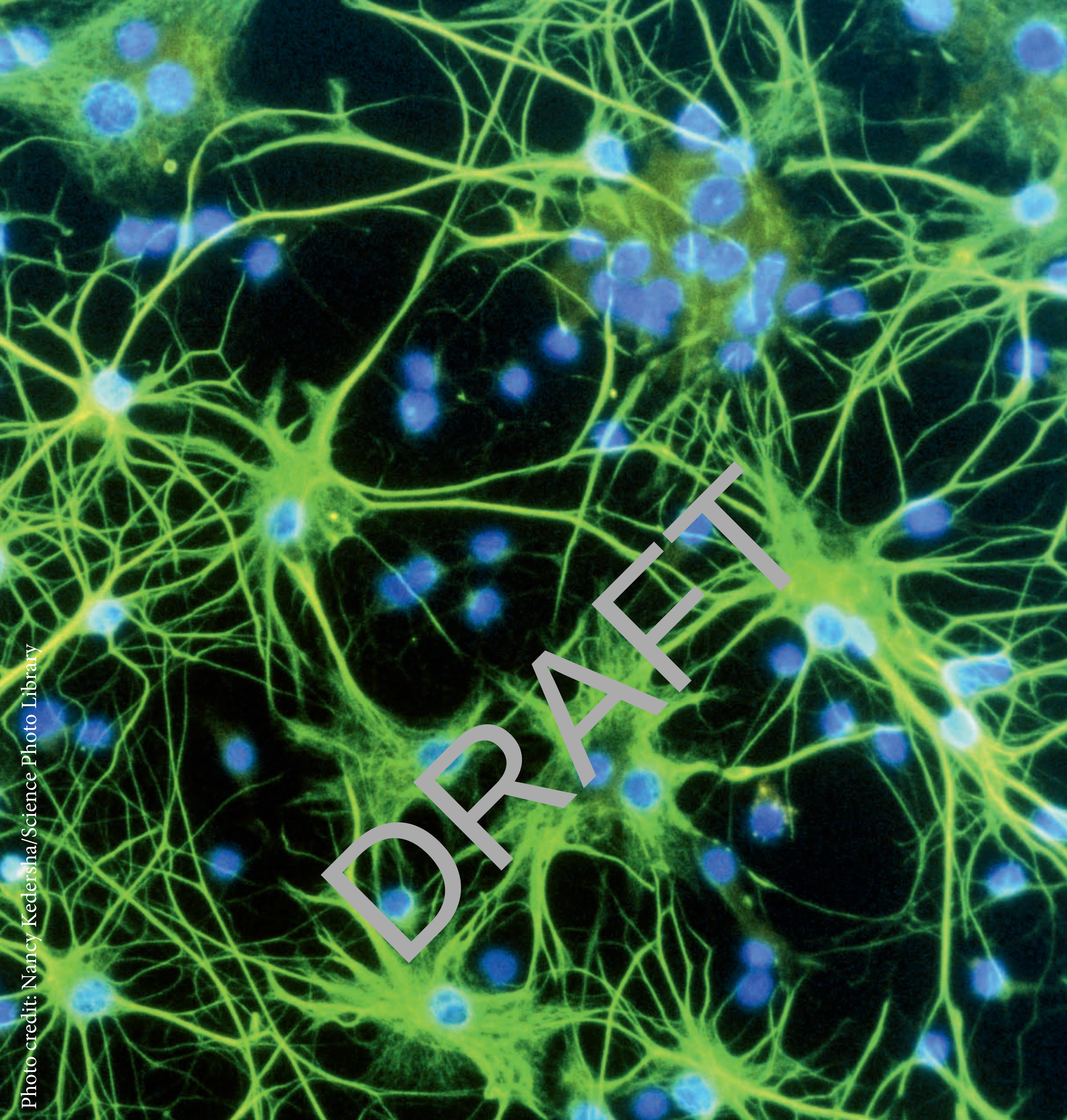

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Human Regulation and Reproduction 9

Getting to know your unit

Assessment

You will be assessed by a series of assignments set by your tutor.

Regulation

The human body is a complex organisation of systems that each need to be controlled in different ways. This unit will help you understand how the human body keeps its internal conditions in a steady state.

Reproduction

There have been many advances in human fertility in recent years. In this unit you will be able to consider these and the hormonal control of the reproductive system. You will also look at fertility treatments.

How you will be assessed

This unit will be assessed by a series of internally assessed tasks set by your tutor. Throughout this unit you will find assessment activity activities that will help you work towards your assessment. Completing these activities will not mean that you have achieved a particular grade, but you will have carried out useful research or preparation that will be relevant when it comes to your final assignment.

In order for you to achieve the tasks in your assignment, it is important to check that you have met all of the Pass grading criteria. You can do this as you work your way through the assignment.

If you are hoping to gain a Merit or Distinction, you should also make sure that you present the information in your assignment in the style that is required by the relevant assessment criterion. For example, Merit criteria require you to analyse and explain, and Distinction criteria require you to assess, analyse and evaluate.

The assignment set by your tutor will consist of a number of tasks designed to meet the criteria in the table. This is likely to consist of a written assignment but may also include activities such as:

- creating a fact sheet about how a body system is controlled
- analysing tables and graphs of data relating to physiological measurements
- analysing case studies or observations from practical activities.

Assessment criteria

This table shows what you must do in order to achieve a **Pass**, **Merit** or **Distinction** grade, and where you can find activities to help you.

Pass	Merit	Distinction
Learning aim A: Understand the interrelationship and nervous control of the cardiovascular and respiratory systems		
A.P1 Describe the organisation and function of the nervous system in relation to cardiovascular and respiratory requirements **Assessment practice 9.1**	**A.M1** Explain how nervous impulses are initiated, transmitted and coordinated in the control of the cardiovascular and respiratory systems **Assessment practice 9.1**	**A.D1** Assess the role of the nervous system in coordinating the cardiovascular and respiratory systems **Assessment practice 9.1**
Learning aim B: Understand the homeostatic mechanisms used by the human body		
B.P2 Describe how homeostatic mechanisms maintain normal function **Assessment practice 9.2**	**B.M2** Explain the role of hormones in homeostatic mechanisms **Assessment practice 9.2**	**B.D2** Analyse the impact of homeostatic dysfunction on the human body **Assessment practice 9.2**
Learning aim C: Understand the role of hormones in the regulation and control of the reproductive system		
C.P3 Describe the structure and function of reproductive anatomy **Assessment practice 9.3**	**C.M23** Explain how the regulation of male and female reproductive systems can affect human reproductive health **Assessment practice 9.3**	**C.D3** Evaluate how conception may be prevented and promoted **Assessment practice 9.3**
C.P4 Describe how hormones are involved in gamete development and conception **Assessment practice 9.3**		

Getting started

The systems inside your body interact to respond to changes on the outside and the inside. On a large sheet of paper, draw a spider diagram to show all of the body systems and what they do. When you have completed this unit, add the interrelationships between the systems and the mechanisms by which the systems communicate with each other.

A Understand the interrelationship and nervous control of the cardiovascular and respiratory systems

The human body is able to control the activities of its different tissues and organs through detecting stimuli and generating appropriate responses. This is done through hormones, nerve impulses or a combination of these.

Key terms

Receptor – a specialised cell or group of cells that respond to changes in the surrounding environment.

Effector – a muscle, organ or gland that is capable of responding to a nerve impulse.

Somatic nervous system – the part of the nervous system that brings about the voluntary movements of muscles as well involuntary movements such as reflex actions.

Autonomic nervous system – the part of the nervous system that controls bodily functions which are not consciously controlled such as the heart beat and breathing.

The need to respond to changes

The ability to respond to internal and external changes, and so avoid harmful situations, increases the chances of survival. In the human body, some nerve cells have become highly sensitive to particular stimuli. These are called **receptor** cells. Responses are brought about by body structures called **effectors**, usually muscles or glands.

Nervous system organisation

The nervous system consists of the brain, spinal cord and a network of neurons. It sends, receives and processes information from all parts of the body. The central nervous system has two main organs: the brain and the spinal cord. The peripheral nervous system has sensory nervous cells that send information to the central nervous system from external stimuli or internal organs, and motor nervous system cells that carry information to organs, muscles and glands from the central nervous system.

The nervous system can be divided into the **somatic nervous system** and **autonomic nervous system**. The somatic nervous system is sometimes referred to as the voluntary nervous system because many of its actions are under conscious control. The somatic nervous system includes sensory neurones which transmit impulses to the central nervous system from receptors all over the body and motor neurons which transmit impulses to the muscles.

The autonomic nervous system is often referred to as the involuntary nervous system because it enables the functioning of internal organs without conscious control. The autonomic nervous system controls involuntary responses but it is possible to gain some voluntary control over these responses. Emptying the bladder and opening the anal sphincter are examples of activities that are controlled by the autonomic nervous system but can be brought under voluntary control through a process of learning called conditioning.

The autonomic system has two distinct parts:

- the parasympathetic nervous system, which maintains the body's functions on a day-to-day basis
- the sympathetic nervous system, which prepares the body to react in emergency situations.

These two systems act antagonistically. Some actions are shown in Table 9.1.

Table 9.1: Actions of the sympathetic and parasympathetic on body structures

	Sympathetic	Parasympathetic
Eyes	Dilates pupil	Constricts pupil
Salivary glands	Inhibits flow of saliva	Stimulates flow of saliva
Lacrimal glands	–	Stimulates flow of tears
Lungs	Dilates bronchi	Constricts bronchi
Heart	Accelerates heartbeat	Slows heartbeat
Liver	Stimulates conversion of glycogen to glucose	Stimulates release of bile
Stomach	Inhibits peristalsis and secretion	Stimulates peristalsis and secretion
Adrenal glands	Stimulates secretion of adrenaline and noradrenaline	–
Intestines	Inhibits peristalsis and anal sphincter contraction	Stimulates peristalsis and contraction of the anal sphincter
Bladder	Inhibits bladder contraction	Stimulates bladder contraction

Nerve cells

What are nerve cells like?

The nervous system is made up of two types of cells. **Neurons** are cells that transmit electrical impulses to and from the brain and nervous system. There are two types of neuron-myelinated and unmyelinated. Myelinated neurons conduct electrical impulses much faster than unmyelinated neurons. Myelinated neurons are found in the peripheral nervous system. They carry impulses from sensory receptors to the central nervous system, or from the central nervous system to the effectors. **Glial cells** provide support for the neuron by carrying out processes such as the digestion of dead neurons and manufacture of the components of neurons.

Neurons are the basic functional unit of the nervous system. They are highly specialised cells and can transmit impulses around the body at up to 200 mph. There are different types of neuron, motor and sensory, but their basic structure is the same. Figure 9.1 shows a motor neuron and a sensory neuron.

Key terms

Neuron – a cell that transmits electrical impulses and is located in the nervous system.

Glial cells – cells that provide support for neurons by carrying out process such as manufacturing neuron cell components and digesting dead neurons.

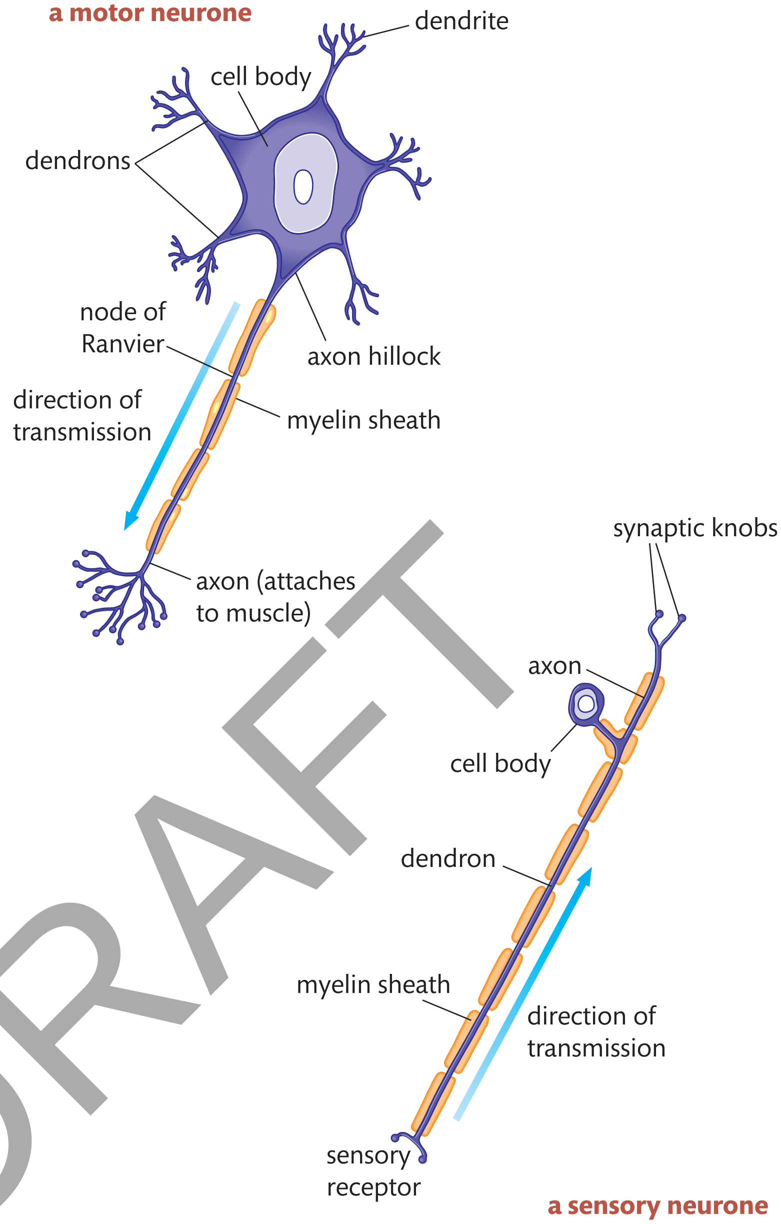


Figure 9.1: The structure of a motor neuron and a sensory neuron

Table 9.2: The structures of neurons and their functions

Structure	Function
Cell body	• Contains the cell nucleus and other organelles, such as the mitochondria and ribosomes.
Dendrites	• Very thin extensions of the cytoplasmic membrane that conduct impulses to the cell body and link with surrounding neurons.
Axon	• Long process that extends from the cell body to transmit impulses away from the cell body to form connections with a muscle or a gland. Axons and dendrites are collectively referred to as nerve fibres.
Myelin	• An insulating material that prevents loss of electrical impulse and rapid transmission in some types of neuron. (Unmyelinated neurons do not have this.)

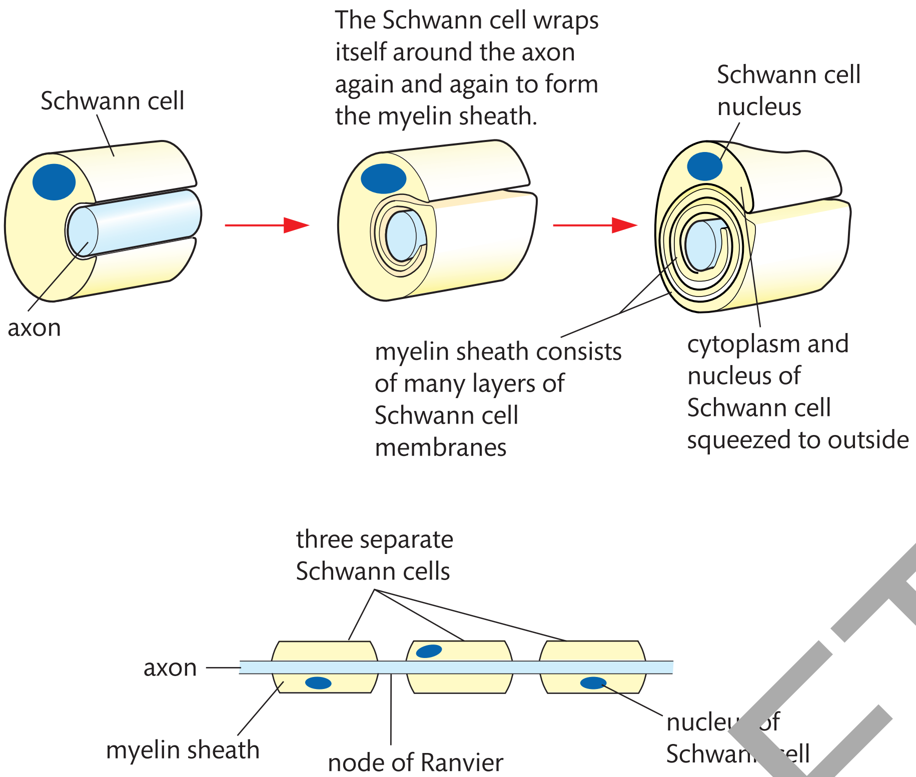


Figure 9.2: The myelin sheath, an insulating layer, is created when Schwann cells grow around the axon

Figure 9.2 shows a Schwann cell, which is a type of glial cell. It produces the insulating myelin layer that can be seen on the axons of some neurons. (Several unmyelinated neurons may be surrounded by just the Schwann cell.)

PAUSE POINT Can you describe the structure of motor neuron and a sensory neuron?

Hint Draw a diagram of each type of neuron and label the structures.

Extend Squids can escape quickly from danger because they have nerve fibres with a very large diameter. How can a larger nerve fibre enable faster movement than a small one?

How are impulses generated?

The body is able to produce electrical impulses by the movement of positively charged metal ions (Sodium, Na^+, and Potassium, K^+) in and out of nerve cells in a controlled manner. By moving certain ions into a cell, it is possible to change the potential difference (voltage) and cause an impulse to be transmitted.

Research

Most of our knowledge of nervous impulse transmission comes from the work of two scientists, Alan Hodgkin and Andrew Huxley, who conducted experiments on axons from the squid. Squids possess exceptionally large axons, termed giant axons, measuring a millimetre in diameter which were big enough to work on.

Find out more about their experiments.

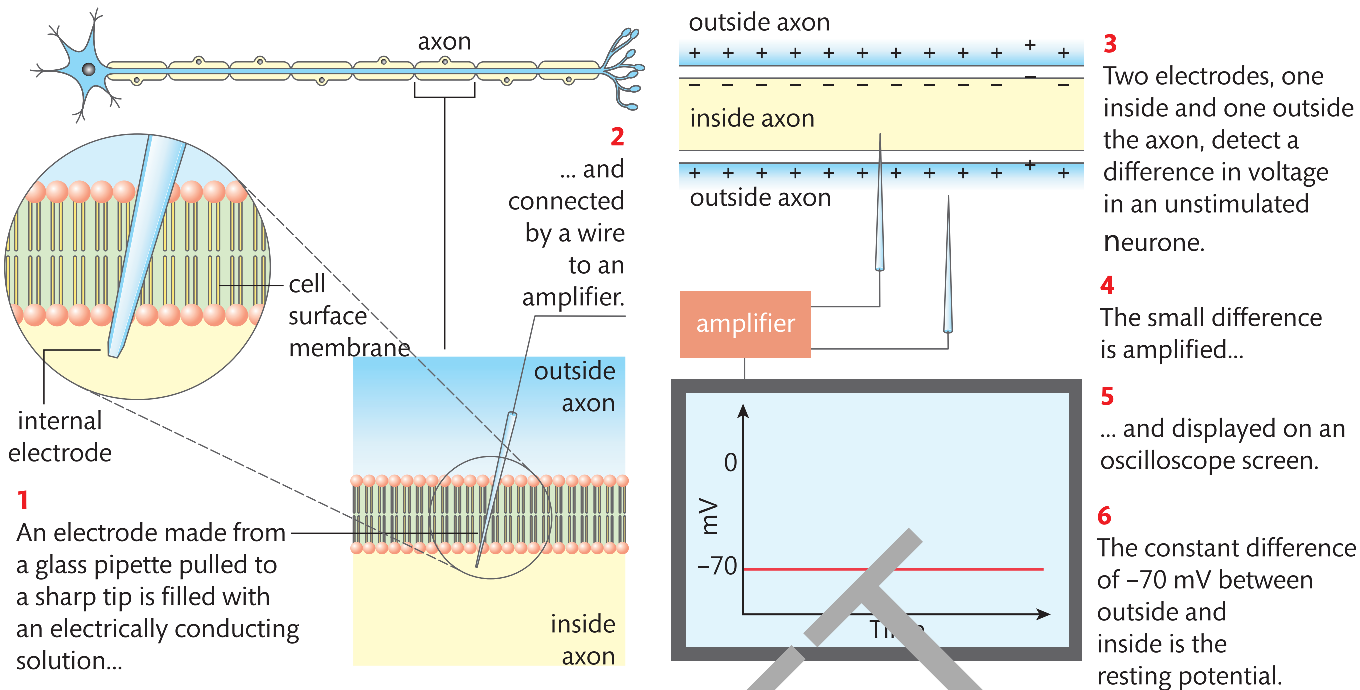


Figure 9.3: This apparatus, with an internal and external electrode, is used to investigate how neurons work. Here you can see the resting potential of a neurone being measured. The resting potential is the potential difference across the membrane in millivolts.

Resting potential

When the neuron is resting (that is, between impulses), proteins in the axon cell membrane, called carrier proteins, pick up sodium ions and transport them out of the cell. This is known as the sodium pump. At the same time, potassium ions are actively transported into the axon cell cytoplasm. This is referred to as the potassium pump.

As approximately three sodium ions are carried out of the cell for every potassium ion that is brought in, the net result is that the outside of the axon membrane is positively charged compared to the inside. When in this resting state, the axon is said to be polarised. Figure 9.4 shows how the resting potential is maintained by the sodium pump.

We call the difference between the inside and outside potentials the resting potential and it is approximately −70 mV. This means that the electrical potential inside the axon is 70 mV lower than the outside when the axon is resting.

Action potential

A nerve impulse is initiated when a neuron is stimulated. In everyday situations, the stimulus can be chemical, mechanical, thermal or electrical. When scientists experiment on nerve impulses they use electrical impulses.

An impulse will travel along the axon when the neuron is stimulated. In experiments, the stimulus is an electrical current because scientists can control its strength, duration and frequency. This prevents the axon from being damaged.

When an electrical current is applied to the axon, there is a brief change in the potential from −70 mV to +35 mV. This means that the inside of the axon becomes positively charged relative to the outside. This change in potential is called the **action potential** and lasts about three milliseconds.

Key term

Action potential – a sudden and rapid increase in the positive charge of a neuron caused when sodium and potassium ions move across the cell membrane.

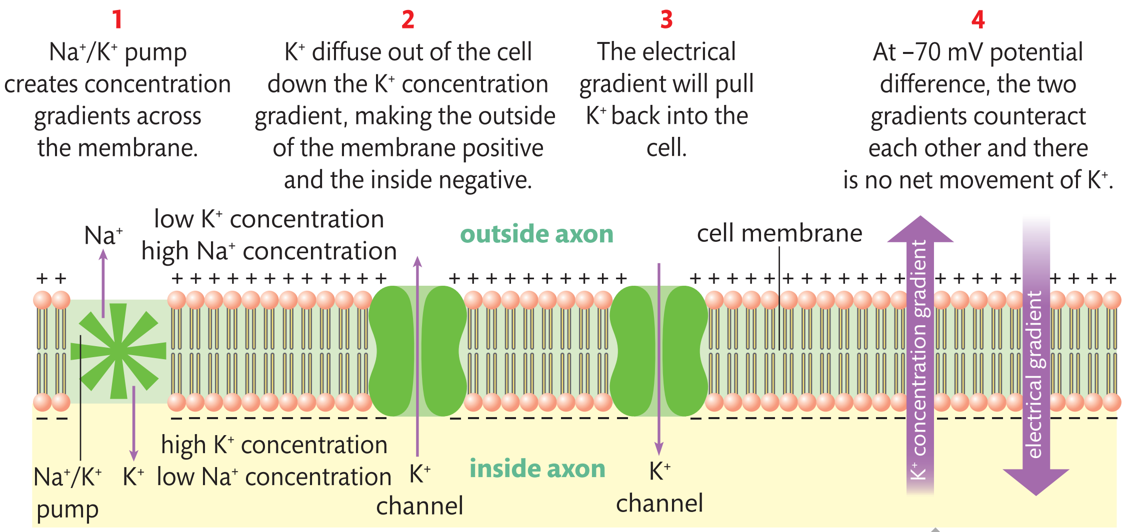


Figure 9.4: The resting potential of the axon is maintained by the sodium pump, the relative permeability of the membrane and the movement of potassium ions along concentration and electrochemical gradients.

During the action potential, the axon is **depolarised**. If the electrodes are connected to a cathode ray oscilloscope, the action potential shows as a peak on the trace. Figure 9.5 shows the changes in sodium ions and potassium ions during the excitation of an axon in an action potential.

Key term

Depolarisation – when the axon is stimulated, channels in the axon membrane open. This allows sodium ions to diffuse into the axon. This creates a positive charge in the axon and causes the action potential.

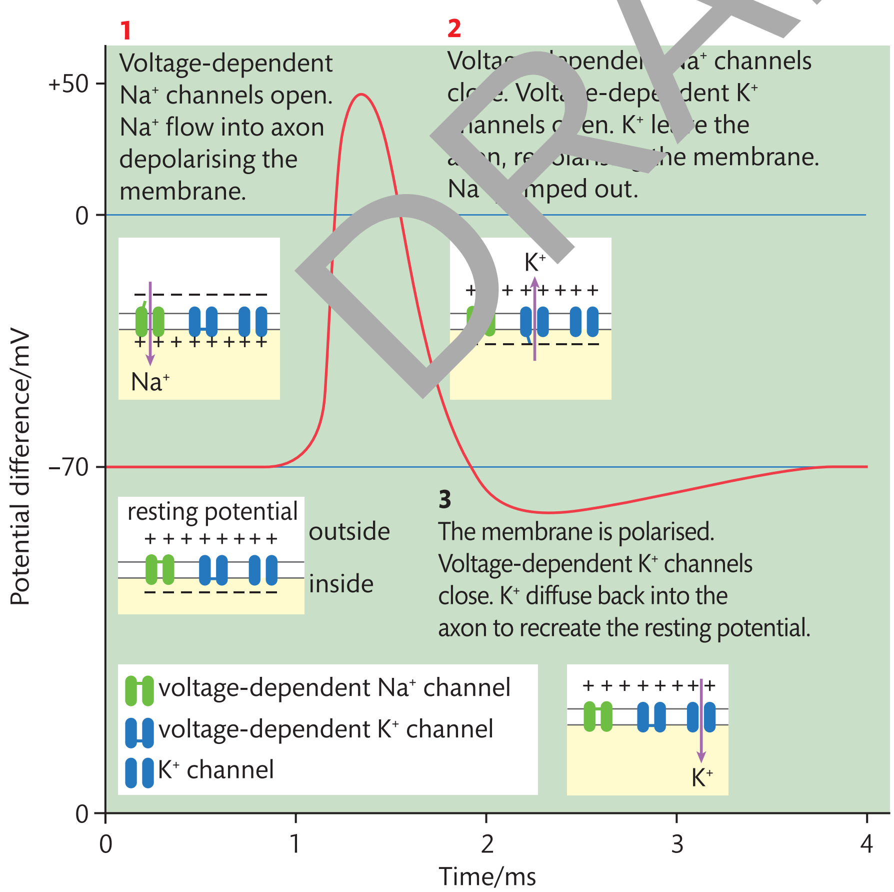


Figure 9.5: The ionic changes during excitation of an axon result in an action potential.

Key term

Diffuse – move from a region of high concentration to a region of low concentration.

Depolarisation

When the axon is stimulated, channels in the axon membrane open. This allows sodium ions to **diffuse** into the axon. This creates a positive charge in the axon and causes the action potential. Channels then open in the membrane to allow potassium ions to diffuse out of the axon.

Repolarisation

Sodium channels close. This prevents any further movement of sodium ions into the axon. This re-establishes the resting potential and the axon membrane is said to be repolarised.

The diffusion of potassium ions is so rapid that, for a brief period, the potential difference drops below that of the resting potential. This is termed an overshoot or hyperpolarisation, which helps to ensure that the action potential travels in one direction along the neuron. This recovering region of the axon membrane would require greater depolarisation than the 'downstream' region to initiate an action potential.

The potassium channels close and the **sodium-potassium pump** begins. The normal concentration of sodium and potassium ions is restored and the resting potential is re-established.

How does an impulse travel along a neuron?

Once an action potential is set up in response to a stimulus, it will travel the entire length of that nerve fibre. The length of a nerve fibre can range from a distance of a few millimetres to a metre or more.

The movement of the nerve impulse along the fibre is the result of local currents set up by the movements of sodium and potassium ions at the action potential. These ion movements occur both in front of and behind the action potential.

The effect is that the membrane in front of the action potential is depolarised sufficiently to cause the sodium ion channels to open. The sodium ion channels behind the action potential cannot open due to the **refractory period** of the membrane behind the spike. In this way the impulse is can only travel in one direction along the axon of the neuron.

Figure [illegible].6 shows how changes in ions set up small local currents enabling the impulse to travel in one direction along the axon.

Key terms

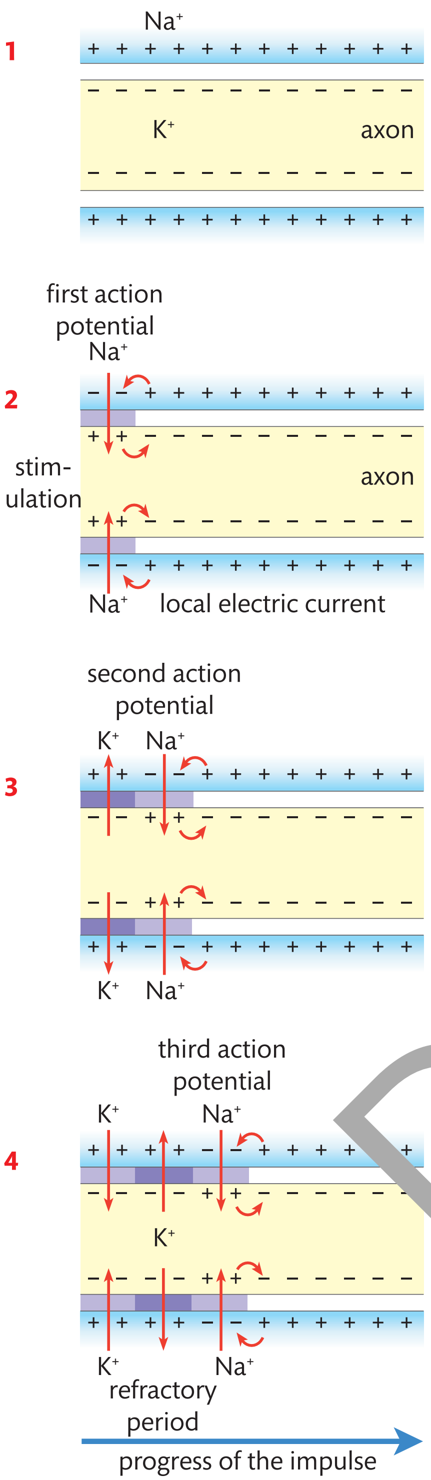
Sodium-potassium pump – carrier proteins in the cell membrane that transport sodium ions and potassium ions in opposite directions across the cell membrane.

Refractory period – the brief period following an impulse before another impulse can be generated.

The all-or-nothing principle

Action potentials obey the all or nothing principle. This means that the size of the action potential is always the same despite the strength of the stimulus.

Information about the strength of the stimulus is carried along the neuron as changes in the frequency of the impulses. A stronger stimulus will result in a greater frequency of impulses being transmitted along the neuron.



At resting potential there is positive charge on the outside of the membrane and negative charge on the inside, with high sodium ion concentration outside and high potasssium ion concentration inside.

When stimulated, voltage-dependent sodium ion channels open, and sodium ions flow into the axon, depolarising the membrane. Localised electric currents are generated in the membrane.

The potential difference in the membrane adjacent to the first action potential changes. A second action potential is initiated. At the site of the first action potential the voltage-dependent sodium ion channels close and voltage-dependent potassium ion channels open. Potassium ions leave the axon, repolarising the membrane. The membrane becomes hyperpolarised.

A third action potential is initiated by the second. In this way local electric currents cause the nerve impulse to move along the axon. At the site of the first action potential, potassium ions diffuse back into the axon, restoring the resting potential.

Figure 9.6: The transmission of an impulse along a neuron

PAUSE POINT What are the main mechanisms that maintain the resting potential of a neuron?

Hint Draw diagrams to show how a resting potential is maintained and how an action potential is initiated.

Extend What will happen to the frequency of the action potential when a stimulus is increased above the threshold level?

Saltatory conduction

In neurons that are insulated by myelin, the ions can only pass in and out of the axon freely at the nodes of Ranvier, which are about 1 mm apart. This means that action potentials can only occur at the nodes and so they appear to jump from one to the next. This is shown in Figure 9.7.

As the movement of ions associated with the action potential occur much less frequently, the process takes less time. The effect is the increased speed of the impulse.

> **Key term**
>
> **Saltatory conduction** – (from the Latin verb *saltus*, which means *to leap*) in myelinated neurons the impulse appears to jump along the axon between nodes. The action potentials are propogated from one node of Ranvier to the next node, which increases the conduction velocity of action potentials.

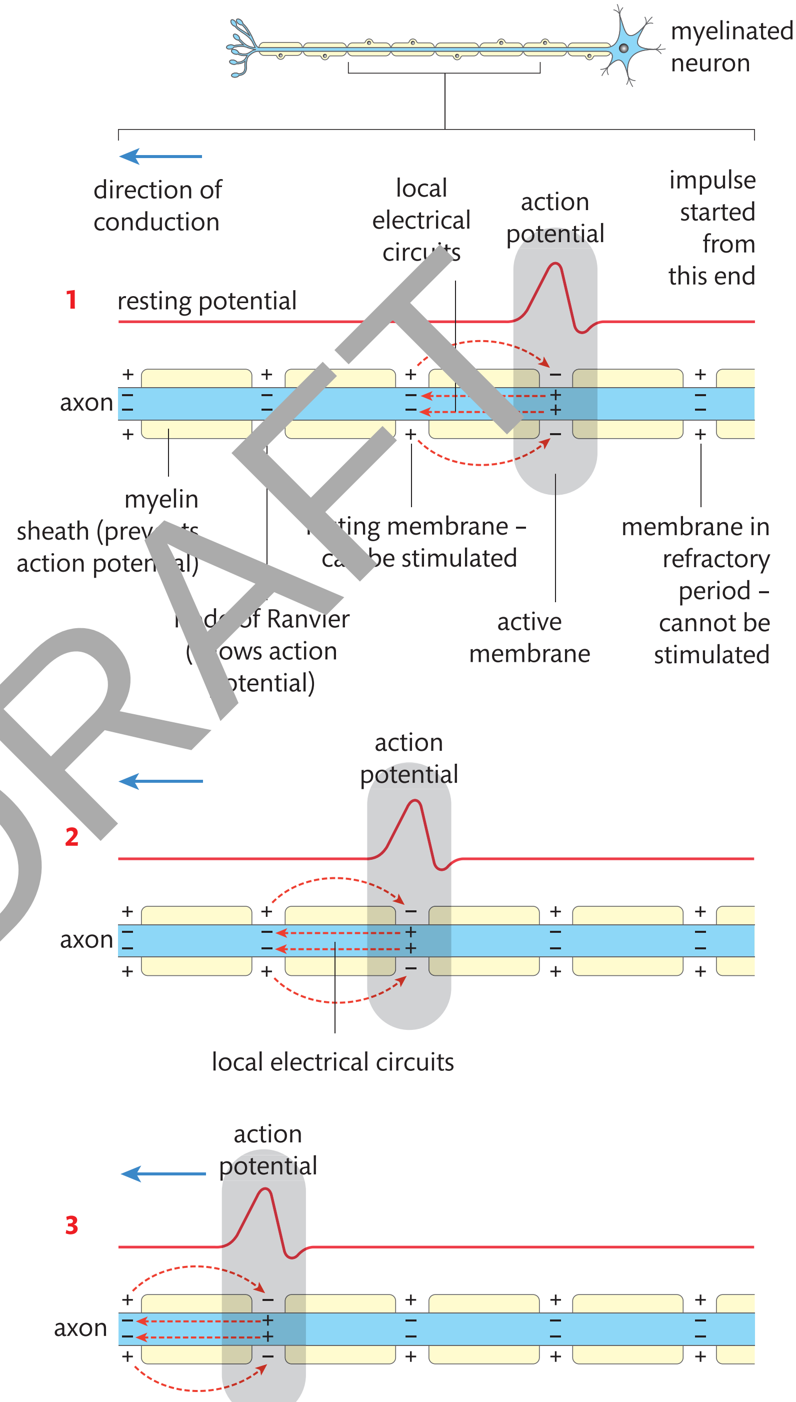


Figure 9.7: Saltatory conduction. By 'jumping' from node to node along a myelinated nerve fibre, the nerve impulses in vertebrate neurones can travel very rapidly along very narrow nerve fibres. This allows for the development of complex, but compact, nervous systems.

▶ **Figure 9.8:** The structure of the synapse

Neurotransmitters

Different neurons release different neurotransmitters, which diffuse across the synaptic cleft to trigger an action potential in the postsynaptic neuron.

Neurons that produce neurotransmitters which decrease the potential of the **postsynaptic membrane** and make it more likely to produce an impulse are termed excitatory presynaptic cells. Inhibitory presynaptic cells release neurotransmitters which increase the postsynaptic membrane potential and make it less likely to produce an impulse.

The minimum level of neurotransmitter required to produce a postsynaptic action potential is called the **threshold level**.

Key terms

Postsynaptic membrane – the membrane of the cell body or dendrite of the neuron carrying the impulse away from the synapse. It contains a number of channels to allow ions to flow through, and protein molecules which act as receptors for the neurotransmitter.

Threshold level – the point at which increasing stimuli trigger the generation of an electrical impulse.

Research

Drugs that affect the nervous system do so by speeding up and slowing down the transmission of nerve impulses across the synapse. They are classified as excitatory or inhibitory drugs.

Research examples of excitatory and inhibitory drugs. Find out how they act on the synapse. Find examples of these drugs that have been misused by sports-people to enhance their performance. How do they improve performance and what are the side effects on health?

Synaptic transmission

Acetylcholine and dopamine are examples of neurotransmitters released by excitatory presynaptic cells.

When the action potential arrives at the **axon terminal**, it causes calcium channels in the **presynaptic membrane** to open. As the concentration of calcium ions is greater in the synaptic cleft than the axon terminal, they diffuse into the axon terminal.

The increased presence of calcium ions in the axon terminal causes the synaptic vesicles to move towards the presynaptic membrane. The vesicles fuse with the membrane and release the neurotransmitter, acetylcholine, into the synaptic cleft.

Acetylcholine diffuses across the synaptic cleft and attaches to the receptor site on the postsynaptic membrane. The binding of the neurotransmitter to the receptors causes sodium channels to open in the postsynaptic membrane. As synaptic vesicles are only present in the axon terminal of the presynaptic neuron, impulses can only travel in one direction.

Sodium ions diffuse into the postsynaptic cell, causing depolarisation and an action potential to be set up. Enzymes split acetylcholine into acetate and choline so that it is removed from the receptor sites. The sodium channels close so that further action potentials stop.

The presynaptic cell takes up the choline by active transport using energy from ATP, where it is combined with acetyl coenzyme A to reform acetylcholine inside the axon terminal.

Key term

Axon terminal – the axon of a neuron ends in a swelling called the axon terminal. It contains mitochondria which provide energy for active transport, and synaptic vesicles which release the neurotransmitter into the synaptic cleft.

Presynaptic membrane – the axon terminal membrane of the neuron carrying the impulse to the synapse.

PAUSE POINT What are the processes that take place at a synapse?

Hint Draw an annotated diagram of a synapse to explain the function of each structure.

Extend Why does the synapse have a high concentration of mitochondria?

Responding to a stimulus

Being able to respond to changes in our environment is essential to our safety and survival. It is the function of the nervous system to enable us to detect changes and coordinate actions in response to these changes.

The nervous system enables us to respond to changes by:

- detecting changes (stimuli) inside the body and in the external environment
- interpreting the change and deciding how to respond to it
- coordinating actions or behaviours that bring about a response to the change, such as moving away from something dangerous.

Figure 9.9 shows the sequence of events that occur in a **voluntary response**.

Key term

Voluntary response – a conscious action taken in response to a stimulus (change in the environment).

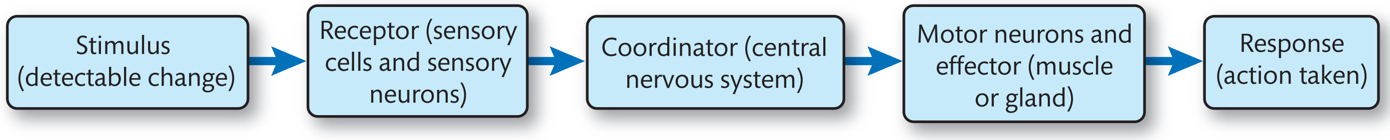


Figure 9.9: The stages of a voluntary response

A reflex action is a rapid and unconscious response brought about by the nervous system. Many reflex actions are protective actions and occur in response to harmful stimuli but many of the actions that your body performs without you thinking about them, such as coughing and swallowing, are also reflex actions.

The neurons involved in a reflex make up a reflex arc. Figure 9.10 shows the reflex arc involved in removing your hand away from a hot object.

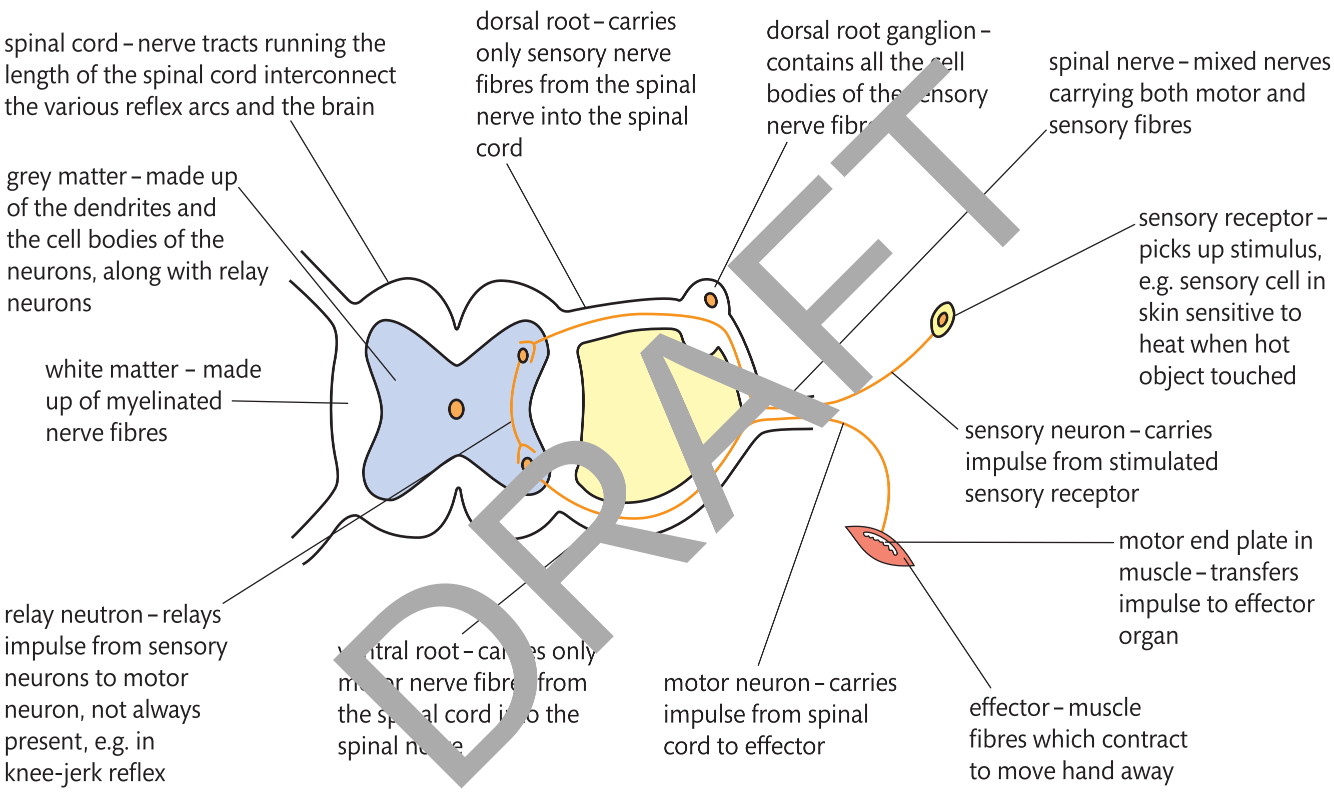


Figure 9.10: The reflex arc showing the structures and sequence of events involved in a reflex action

As you can see in the diagram, the brain is not involved in the reflex arc. This is why the response is unconscious. Instead, the sensory neuron forms a synapse with an **interneuron** (or relay neuron) which forms a synapse with the motor neuron. Figure 9.11 shows the structure of an interneuron.

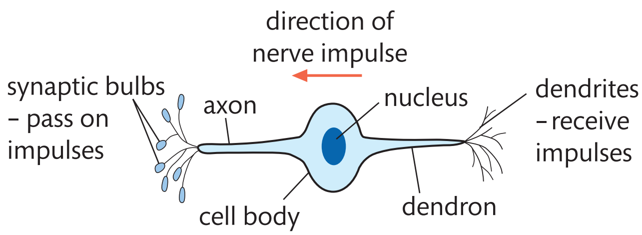


Figure 9.11: The structure of an interneuron. Interneurons are found in the spinal cord.

Key term

Interneuron – a type of nerve cell found inside the central nervous system that acts as a link between sensory neurons and motor neurons.

Key terms

Afferent pathway – the route taken by impulses that travel away from a stimulus to the spinal cord.

Efferent pathway – the route taken by impulses that travel away from the spinal cord to the effectors (muscles or glands).

Discussion

Sometimes you can override a reflex or learn to ignore it. People wearing contact lenses have to overcome the blinking reflex. Can you think of any other examples of overriding a reflex?

Impulses will travel along the spinal cord to the brain. This is why you become aware of the reflex action shortly after it happens.

The receptor in the reflex shown in Figure 9.10 are thermoreceptors in the dermis of the finger, which generates the sense of pain. The effectors are muscle fibres in the hand.

The thermoreceptors initiate nerve impulses that travel along the **afferent pathway**, which is along the sensory neuron to the spinal cord. The sensory neuron enters the spinal cord and forms a synapse with an interneuron located in the grey matter of the spinal cord.

The interneuron forms a synapse with a motor neuron. The impulse leaves the spinal cord via the **efferent pathway**, which is along the motor neuron to the effector, the muscles of the hand and arm. The muscles contract to move the finger away from the hot surface.

The neuromuscular junction

A neuromuscular junction is a synapse between a motor neuron and a muscle. The structure and function is similar to that of a synapse between two neurons.

When the axon reaches a muscle, it forms branches and loses its myelin sheath. The axon branches to make contact with different fibres in the muscle in a plate-like structure called the neuromuscular junction or motor end plate.

The motor end plates consist of folds of the muscle fibre surface and are located opposite the axon terminal knob. There is a small gap between the membrane of the neuron and the muscle fibre called the synaptic cleft.

A neuromuscular junction functions in a similar way to the synapse between two neurons. The following is a summary of transmission at the neuromuscular junction.

- The action potential arrives at the neuromuscular junction.
- Calcium ion channel proteins open and calcium ions diffuse into the synaptic cleft.
- The diffusion of calcium ions causes the synaptic vesicles to move to the junction membrane.
- The vesicles fuse with the junction membrane and release acetylcholine (neurotransmitter) into the synaptic cleft.
- Acetylcholine diffuses across the cleft and attaches to the receptor molecules on the muscle fibre.
- Sodium ion channels open in the muscle fibre membrane.
- The movement of sodium into the cytoplasm of the muscle fibre causes depolarisation.
- An action potential is generated across the muscle fibre.
- The muscle contracts.

A neuroglandular junction is where a neuron and a gland interact.

PAUSE POINT Can you explain how an impulse is generated and transmitted from neuron to neuron and at a neuromuscular junction?

Hint Close the book and draw a flow diagram to show the stages involved for each type of synaptic transmission.

Extend Some poisons have an antagonistic effect on synaptic transmission. Find out how curare, hemlock and botulin act on the synapse and their resulting effects on the nervous system and the human body.

Stimuli detection by receptor cells and sense organs

The human body needs to detect and respond to changes in its surroundings. Sense organs are specialised organs, such as the eye, ear and skin, where sensory neurons are concentrated to form receptors. Receptors detect specific changes in the environment, which are called stimuli.

Receptor cells act by converting stimuli into electrical responses in neurons. The process of converting one type of energy into the electrochemical energy of an action impulse is called **transduction** (or signal transduction).

Receptors are only able to respond to specific stimuli. A summary is shown in Table 9.3.

Table 9.3: Examples of receptors in the human body and their stimuli

Receptor	Stimuli detected	Examples
Chemoreceptors	Chemical stimuli	Nose and mouth
Photoreceptors	Light energy	Eyes
Thermoreceptors	Temperature changes	Skin
Mechanoreceptors	Changes in movement, pressure or vibrations	Pacinian receptors in the dermis
Electroreceptors	Electrical fields	Mainly found in fish

Receptor cells act as transducers. This means they convert the energy of the stimulus into the electrical energy of a nerve impulse which is transmitted along a sensory neuron to the **central nervous system**.

The frequency of the impulse sends messages to the brain about the strength of the stimulus, which enables the body to respond in an appropriate way. Receptor cells can act individually or in a group in a sense organ.

Key terms

Transduction – the conversion of a signal from outside the cell to a functional change within the cell, e.g. odour to electrochemical signals.

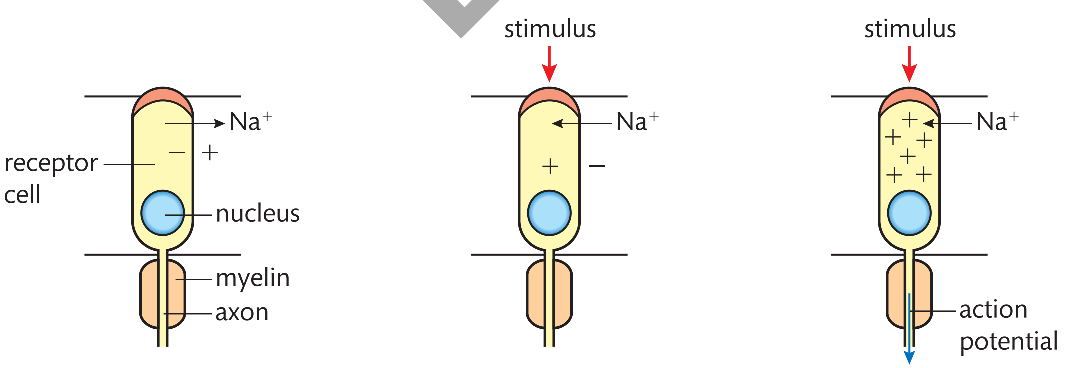
Central nervous system – (CNS) consists of the brain and spinal cord.

What do receptor cells do?

A receptor cell responds to a specific stimulus by initiating an action potential in a sensory neuron, which carries an impulse to the central nervous system where it is interpreted and a response is coordinated.

When a receptor cell is stimulated, sodium ions move across the cell membrane in a similar way to that which takes place when an action potential is generated in a neuron.

Figure 9.12 shows how the generator potential is developed in the receptor cell.



At rest the sensory cell inside is negative relative to the outside

The stimulus causes sodium ions to enter the cell. The cell inside becomes less negative. The generator potential is initiated.

The generator potential builds up and initiates an action potential.

Figure 9.12: These diagrams show in a simplified way how a generator potential and action potential are developed by a receptor cell.

As Figure 9.12 shows, the function of the receptor cell is to produce a generator potential which initiates an action potential. The way that this happens is specific to the type of receptor. In mechanoreceptors, receptors that detect movement or changes in pressure, it is physical changes to the cell caused by pressure or movement of a tiny hair that causes the sodium channels in the cell membrane to open up and cause depolarisation of the cell membrane.

In other receptors, stimuli may cause a series of chemical reactions to take place which then lead to the sodium channels in the cell membrane opening and causing depolarisation.

Neurological disorders

Motor neurone disease

The 2014 film, *The Theory of Everything*, was a biographical account of the life of the world-famous physicist, Stephen Hawking, who developed motor neurone disease (MND) as a university student. MND is a fatal disease, which arises from the degeneration of motor neurons in the spinal cord.

MND is characterised by:

- impairment of the use of the limbs
- twitching and cramping of muscles in the hands and feet
- difficulty in speaking and projecting the voice
- difficulty in breathing and swallowing.

Parkinson's disease

Key term

Peripheral nervous system – consists of nerve cells linking the CNS with receptors and effectors.

Parkinson's disease develops as a result of a deficiency of the neurotransmitter, dopamine. It is caused by a loss of nerve cells in part of the brain called the substantia nigra. Nerve cells in this part of the brain produce dopamine, which acts as a messenger between the brain and **peripheral nervous system** to control and coordinate body movements. Loss of the nerve cells is a slow process. The symptoms of Parkinson's disease only start to develop when 80% of the nerve cells in the substantia nigra have been lost.

Stephen Hawking developed Motor Neurone Disease when he was a university student.

The symptoms of Parkinson's disease are:

- involuntary shaking
- slow movement
- stiff and inflexible muscles.

Multiple sclerosis

Multiple sclerosis (MS) is an autoimmune condition. This means that the body's immune system has begun to attack body tissues. In MS, the immune system mistakes the myelin for a foreign substance and starts to attack it. This disrupts the impulses travelling along the neurons causing the impulses to be slowed, jumbled and sent down another neuron or stopped altogether.

There are many different symptoms of MS. The most common ones are:

- fatigue
- numbness and tingling in the limbs
- blurring of the vision
- mobility difficulties
- problems with balance
- muscle weakness.

PAUSE POINT Can you explain how the three neurological disorders are caused? Cover the section about the nervous system disorders and write a summary of each of the three diseases discussed in this section.

Hint Produce a large diagram to show the main structures of the nervous system. Annotate the diagram to show the structures and functions of the nervous system that are affected by each disease, and why each symptom occurs.

Extend Mercury poisoning was common among hat makers in the 1800s, when a mercury solution would be applied to animal fur to make felt. Research how mercury affects the nervous system and produce a poster to show your findings.

Cardiovascular system regulation and control

Receptors in the cardiovascular system

The **cardiovascular system** is controlled by a number of reflex actions which are initiated by receptors that detect changes in blood pressure and blood pH levels.

Key term

Cardiovascular system – the heart and blood vessels.

Chemoreceptors in the cardiovascular system

If you have felt short of breath, it's because chemoreceptors in your cardiovascular system have detected that your blood oxygen levels are low or that your blood carbon dioxide levels are too high. These chemoreceptors are located in the walls of the aorta and carotid arteries, as shown in Figure 9.13.

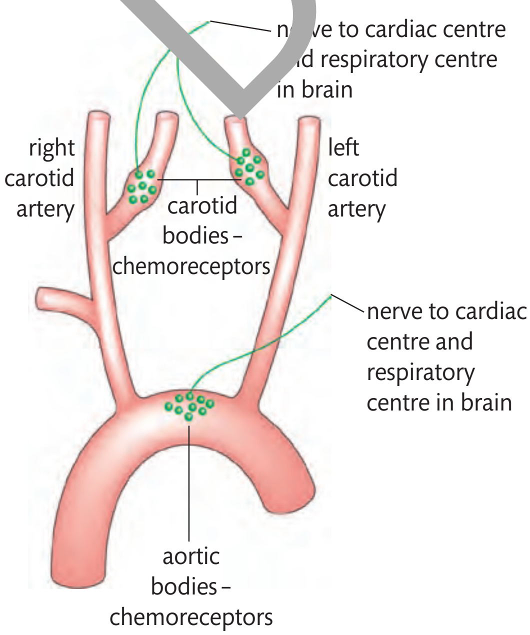


Figure 9.13: Chemoreceptors in the walls of aorta and carotid arteries

These receptors are sensitive to the levels of carbon dioxide in the blood. As carbon dioxide levels rise, the pH of the blood decreases (the blood becomes more acidic) and this is detected by the aortic and carotid chemoreceptors.

When a chemoreceptor detects a fall in the blood pH, a small depolarisation occurs in its cell membrane and an action potential is produced. This generates an electrical impulse.

The impulse travels along sensory neurones to the cardiac control centre in the medulla of the brain. This increases the impulses travelling down the sympathetic nerve to the heart. As a result, the heart rate increases, and there is an increased blood flow to the lungs. The effect of this increased blood flow is that carbon dioxide is removed from the blood.

As blood carbon dioxide levels fall, the blood pH rises. The chemoreceptors respond to this by reducing the number of impulses to the cardiac centre. This reduces the number of impulses in the sympathetic nerve to the heart and reduces the acceleration of the heart rate, so it returns to the intrinsic rhythm.

The chemoreceptors are also involved in the control of the breathing rate.

Baroreceptors in the cardiovascular system

Baroreceptors are pressure receptors located in the walls of the aorta and carotid artery. Their function is to detect changes in blood pressure and send this information to the cardiovascular centre of the brain. It is important that the blood pressure remains at an adequate level so that blood can reach all of the tissues and organs.

If the blood pressure drops too low, then blood will not reach all of the tissues. If the blood pressure rises too high, then it may cause damage to the blood vessels and eventually lead to heart disease or stroke.

If the blood pressure rises, the walls of the blood vessels will stretch more. This stimulates the baroreceptors in the blood vessel walls. The baroreceptors generate a greater number of action potentials to the cardiovascular centre which then initiates responses to cause a decrease in blood pressure.

If blood pressure falls, there will be a decrease in the number of action potentials sent from the baroreceptors to the cardiovascular centre, which initiates responses to increase blood pressure.

[redacted]

Gas exchange

In order to stay healthy all of the cells in your body require a constant supply of energy. Energy is provided by **respiration**, which is a series of oxidation reactions that occur within the cells. Respiration therefore requires a supply of oxygen, which is brought to the cell by the blood. It also requires a supply of glucose.

Respiration produces energy as a useful product and waste products, carbon dioxide and water.

As respiration is a constant process in the body's cells, there is a constant need for oxygen to be brought to the cells and for carbon dioxide to be removed.

Gas exchange is the process where oxygen is supplied to the cells and carbon dioxide is removed.

The control of gas exchange

Oxygen is constantly taken up by cells and carbon dioxide is constantly released. This is called gas exchange and occurs by diffusion.

As organisms increase in size, their surface area to volume ratio decreases and diffusion alone is an insufficient mechanism for efficient gas exchange. A large fluctuation of respiratory gases can have harmful effects on the body.

A deficiency of oxygen (hypoxia) deprives cells of the vital requirement of **metabolism**. A build-up of carbon dioxide in the tissues leads to increased acidity of the blood and tissues, which inhibits enzymes, stops metabolism and would quickly prove fatal.

In the human body, breathing enables a constant supply of oxygen and constant removal of carbon dioxide. The cardiovascular system provides a transport mechanism to carry oxygen, nutrients, carbon dioxide, hormones and waste products to and from exchange surfaces.

The lungs and breathing

Figure 9.14: The lungs and associated structures of the thoracic cavity

The human lung is an efficient structure which enables maximum gas exchange to take place with minimum heat loss. The structure of the lungs are shown in Figure 9.14.

The regular breathing pattern is an automatic action controlled by nerve impulses from the **ventilation centre** in the brain. However, as impulses are also received from higher centres in the brain, the breathing rate can be brought under voluntary control. This allows a person to hold their breath while diving, for example.

Breathing in (inhalation)

- The diaphragm muscles contract.
- The diaphragm flattens.
- The intercostal muscles between the ribs contract lifting the rib cage upwards and outwards.

- The volume of the thoracic cavity increases.
- The air pressure inside the thorax becomes lower than the external environment.
- Air moves down the concentration gradient into the lungs and into the alveoli where gas exchange takes place.

Breathing out (exhalation)

- The rib cage drops downwards and inwards.
- The diaphragm relaxes and domes upwards.
- The volume of the thoracic cavity decreases.
- The elasticity of the lung tissues means the lungs recoil to their original size.
- Air pressure inside the thorax becomes greater than the external environment and the air moves out of the lungs.

PAUSE POINT What is gas exchange, where does it occur and why is it necessary?

Hint Explain how oxygen moves from the lungs to a muscle cell and how carbon dioxide moves from the same cell to the lungs.

Extend Find out about Fick's Law. How do the lungs follow this law?

Case study

The Hering-Breuer reflex

In 1868, two scientists, Josef Breuer and Ewald Hering discovered a reflex action that prevents over inflation of the lungs. They discovered that stretch receptors in the smooth muscle of the airways respond to excessive stretching of the lung during large inhalations.

As the lungs inflate, the frequency of nerve impulses from stretch receptors in the bronchi to the ventilation centre increases until a point is reached where inhalation is inhibited. Tissues that were stretched during inhalation recoil and air is forced out of the lungs, the Hering-Breuer reflex.

When someone is placed on a ventilator because he or she is having problems breathing, care must be taken by hospital staff to avoid over-inflating the lungs. As the ventilator is doing the breathing for the patient, his/her Hering-Breuer reflex cannot initiate to regulate the size of their breaths.

The ventilator has to be programmed to adjust the volume of air pushed into the patient's lungs and the frequency of breaths. This ensures that the patient receives the right amount of oxygen and the lungs are not damaged.

Check your knowledge

1 Try taking a deep breath. Why can you only breathe in a limited amount of air before you have to breathe it out again?

2 Why is it important for anaesthetists to understand the Hering-Breuer reflex in order to do their job safely?


Photo credit: Yon Marsh/Alamy Stock Photo

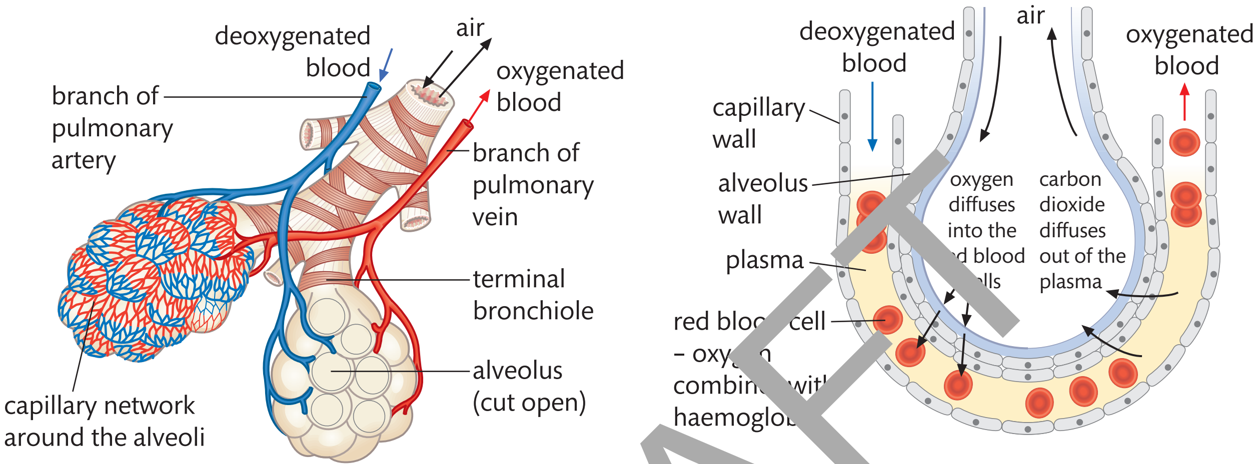
▶ **When a** patient is connected to a ventilator, hospital staff need to ensure that the lungs are not over-inflated.

The ventilation centre sends nerve impulses to the intercostal muscles and the diaphragm.

When the intercostal muscles and the diaphragm contract, the space inside the thorax increases. This causes a decrease in the air pressure relative to the external environment. The result is that air moves into the lungs and you experience this as breathing in, inhalation.

Exhalation occurs because the intercostal muscles and the diaphragm relax. This causes the volume of the thoracic cavity to decrease and the air pressure inside to increase relative to the external environment.

Gaseous exchange in the alveoli



▶ **Figure 9.15:** Gaseous exchange in the alveoli

The lungs have a number of adaptations which make them highly efficient in the process of gas exchange.

- They contain millions of air sacs (alveoli) which creates a large surface area to enable rapid diffusion of oxygen and carbon dioxide.
- The alveoli have walls that are one cell thick creating a short diffusion pathway.
- The lungs have a rich blood supply enabling each alveolus to be close to a capillary. Capillary walls are one cell thick which allows gases to pass rapidly from the alveolus into the blood and vice versa.
- The flow of blood through the capillaries means that a steep concentration gradient is maintained, which ensures rapid diffusion of gases (as described in the section below).

Diffusion of oxygen

The air in the alveolus is rich in oxygen. Blood arriving from the body in the capillaries of the alveoli is low in oxygen. Oxygen diffuses down the concentration gradient from the alveolus to the capillary where it combines with haemoglobin in the red blood cells and is transported to the rest of the body.

Diffusion of carbon dioxide

Carbon dioxide from cellular respiration in the body is transported in the blood to the lungs. Blood arriving at the alveolus is high in carbon dioxide and the air in the alveolus is low in carbon dioxide. Carbon dioxide diffuses down the concentration gradient into the alveolus, where it is exhaled into the external environment.

The constant pumping of blood through the capillary and ventilation of the lungs ensures that a steep concentration gradient is maintained which, when combined with short diffusion pathway, ensures that a rapid rate of diffusion is maintained.

Chemoreceptors

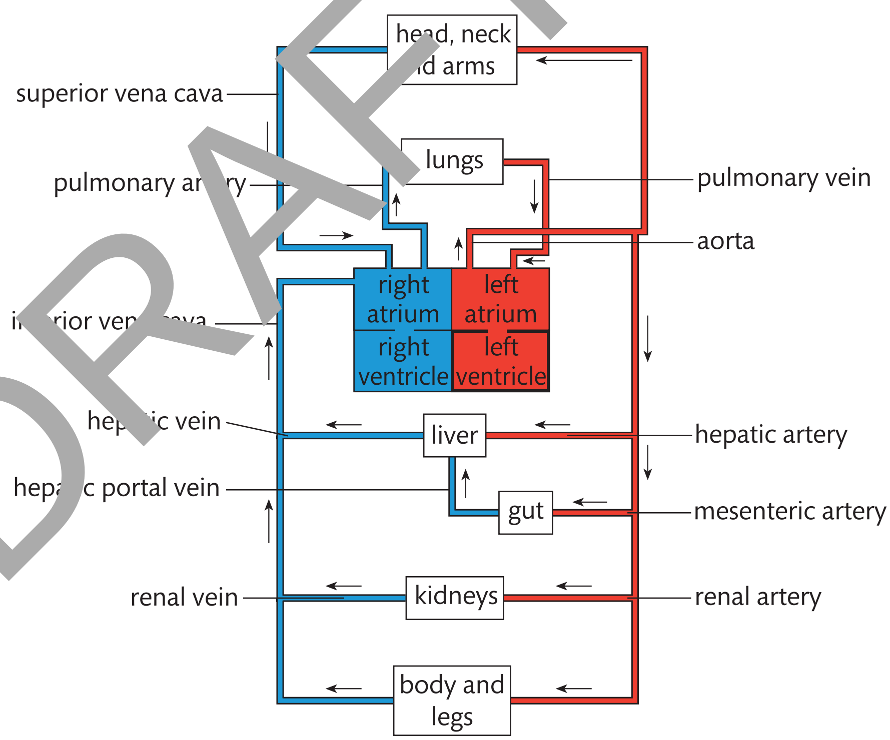
During exercise, carbon dioxide levels in the blood increase due to increased levels of respiration taking place in body cells. Carbon dioxide in the blood forms carbonic acid, which leads to a fall in blood pH levels.

When the pH of the blood decreases, chemoreceptors in the carotid artery and aorta are stimulated and send impulses to the ventilation centre. The ventilation centre responds by sending impulses to the external intercostal muscles and the diaphragm to increase the breathing rate. This is a function of the sympathetic nervous system.

Circulation of the blood

Figure 9.16 shows the general layout of the cardiovascular system and the direction the blood flows around it.

The cardiovascular system comprises of a muscular pump, the heart, which pumps blood into a system of blood vessels. Blood is first pumped into arteries which divide into smaller vessels called arterioles. Arterioles divide into networks of tiny blood vessels in the tissues called capillaries, where exchange of materials between the tissues and blood takes place. From the capillaries the blood is carried into larger vessels called venules, which join to form veins, larger vessels that carry the blood back to the heart.



▶ **Figure 9.16:** The main blood vessels and direction of blood flow around the cardiovascular system

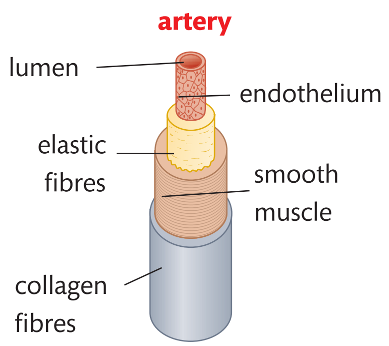
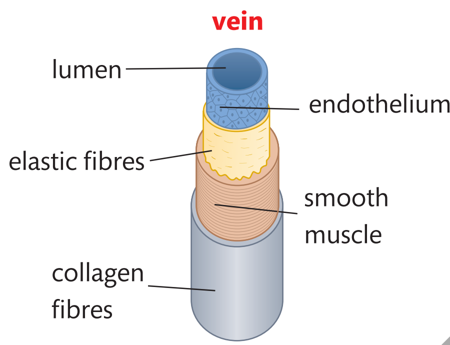
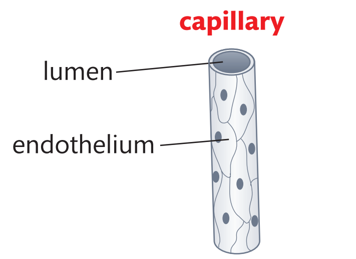
The structure and function of blood vessels

A closed circulation

Blood vessels form a closed system that begins and ends with the heart. The blood is always enclosed by arteries, arterioles, capillaries, venules or veins, which vary in diameter, shown in Table 9.4.

Arteries carry blood away from the heart and divide to form smaller arteries and arterioles. Arterioles subdivide to form capillaries which form networks of tiny blood vessels in the tissues. Capillaries join up to form venules, which join up to form veins. Veins carry blood back to the heart.

Table 9.4: Structure and function of arteries, veins and capillaries

Arteries	Veins	Capillaries
		
• Carry blood away from the heart • Thick muscular walls • Large amount of elastin in walls • Small lumen (inner open space within the vessel) • High blood pressure • Rapid blood flow • Pulse • No valves	• Carry blood back to the heart • Thin muscular walls • Small amount of elastin in walls • Large lumen • Low pressure • Slow blood flow • No pulse • Valves to prevent backflow of blood	• Form networks in the tissues of the body • Link arterioles and venules • Walls are made up of a single layer of endothelium cells • No elastin fibres or muscle • Small lumen, just enough to allow blood cell to pass through • Little pressure • Slow blood flow • No pulse • No valves
Function Carry fast flowing blood under high pressure away from the heart. Elastic walls enable the vessel to stretch and recoil to keep the blood flowing.	**Function** Carry slow flowing blood under low pressure back to the heart. There is sufficient pressure to force valves in the veins to open, and backflow of blood causes the valves to close therefore keeping blood flow in one direction.	**Function** Networks of tiny, thin blood vessels in the tissues of the body that supply blood to all tissues and cells of the body. Thin walls create a short diffusion pathway to enable rapid diffusion of substances between the tissues and the blood.

The structure of the heart

The human heart is made up of cardiac muscle. The cells in the muscle fibres of cardiac muscle are interconnected which enables impulses to spread rapidly from muscle cell to muscle cell.

Heart muscle is myogenic, meaning it can contract and relax rhythmically without fatigue and of its own accord.

Figure 9.17 shows the external and internal structure of the heart. The heart is a double pump, which means it comprises of two pumps side by side. The right side of the heart pumps blood to the lungs and the left side of the heart pumps blood to the rest of the body. Each side of the heart is separated from the other so that oxygenated and deoxygenated blood are kept separate.

Each side of the heart is comprised of two chambers: the atrium (upper chamber) and the ventricle (lower chamber). These are separated by a valve, which ensures that blood flows in only one direction through the heart.

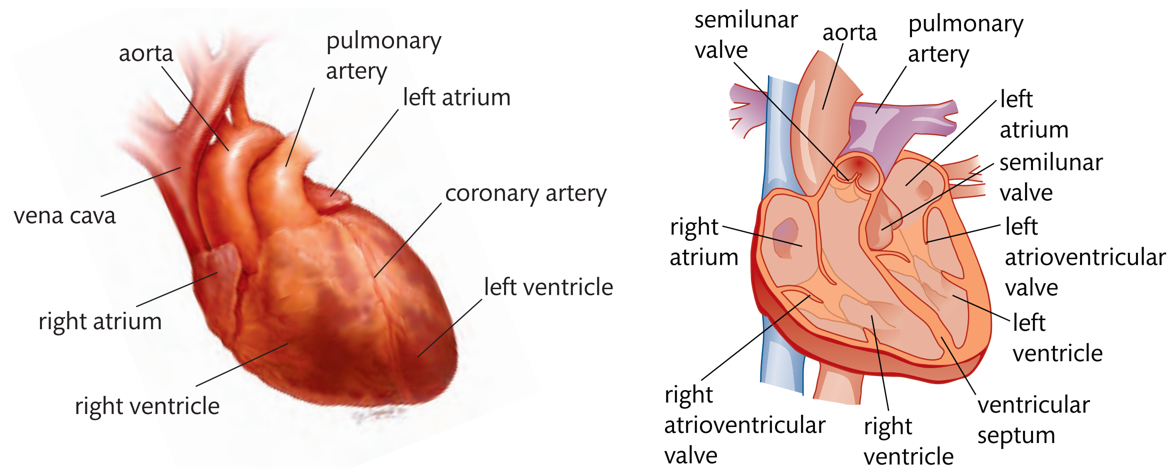


Figure 9.17: External and internal structure of the heart

Step-by-step: Dissection of a mammalian heart

6 Steps

1 Place the heart on the dissection board and locate the tip of the heart or apex. Only the left ventricle extends all the way to the apex.

2 Turn the heart around so that the front of the heart, or ventral side, is facing you. You can recognise the ventral side because it has a groove that extends from the right side at the broad end of the heart diagonally to a point to the left and above the apex.

4 Using scissors, cut through the side of the pulmonary artery (curves out of the right ventricle) and continue cutting down the wall of the right ventricle. Take care to only cut deep enough to go through the wall of the heart chamber.

5 With your fingers, push open the heart at the cut so that you can see the internal structure. Locate the ventricles, the atria, the septum and the valves (tough, stringy structures). Look at the blood vessels and note the differences between them.

3 Locate the upper chambers, the atria, and the lower chambers, the ventricles, and the blood vessels. The arteries have thick, rubbery walls and the veins have thinner walls.

6 Using scissors, make a further cut from the outside of the left atrium downwards through the left ventricle to the apex. Push open the heart with your fingers and locate the ventricles, atria and valves. Note the differences in thickness of the two sides of the heart. Clear away following the instructions of your tutor and wash your hands thoroughly when you have finished.

The cardiac cycle

The cardiac cycle describes the sequence of events in one complete heartbeat.

1. Both atria relax and fill with blood from the vena cava or pulmonary vein.
2. The atria contract and force open the atrioventricular (AV) valves.
3. Blood flows into the ventricles.
4. The pressure of the blood filling the ventricles makes the AV valves close.
5. The ventricle walls contract causing increased pressure inside the ventricles.
6. When the pressures inside the ventricles exceed the pressure in the adjoining blood vessels, the semi-lunar valves are forced open.
7. Blood enters the pulmonary artery or the aorta.
8. The semi-lunar valves close and prevent the back flow of blood into the ventricles.

Control of the cardiac cycle

The heart does not need impulses from the nervous system in order to contract and relax. Each cardiac cycle is started by specialised muscle cells in the right atrium called the **sinoatrial node** (SAN).

The SAN sends electrical impulses to the atria walls. This causes depolarisation to take place. The effect is that the electrical impulses spread across both atria as a wave and both atria contract at the same time.

Collagen fibres between the atria and ventricles prevent the impulse wave spreading to the ventricles. This is important as it ensures that the ventricles do not contract until the atria have finished contracting.

When the wave meets the junction between the atria and the ventricles, it causes the **atrioventricular node** (AVN) to generate its own electrical impulse. The AVN transmits an impulse down strands of fibres lying between the ventricles called the Bundle of His.

Key term

Sinoatrial node (SAN) – specialised muscle cells in the right atrium that start the cardiac cycle by sending impulses across the atria walls. This is often called the heart's pacemaker as these cells control the speed of the cardiac cycle.

Key term

Atrioventricular node (AVN) – specialised muscle cells in the junction of the atria and ventricles that receive impulses from the SAN and send impulses across the ventricle walls.

The Bundle of His breaks up into a series of fibres called Purkinje tissue which transmit the impulse to the apex of the ventricles. This causes the ventricles to contract from the base of the heart upwards.

Blood is then forced out of the ventricles into the aorta or pulmonary artery.

The changes in electrical activity of the heart can be detected using an electrocardiogram (ECG) where electrodes are attached to the chest and connected to a monitor which displays the electrical changes as a trace.

PAUSE POINT What is the cardiac cycle and how is it controlled?

Hint Draw a diagram of a heart that shows the pathways of the impulses during the cardiac cycle.

Extend Find out how an artificial pacemaker works. What sort of heart conditions can be improved using a pacemaker?

Taking measurements of heart function

Health professionals use a stethoscope to listen to the sounds of the heart and can detect if the patient has a faulty valve. A microphone placed over the heart will also detect damaged or stiffened valves.

Electrocardiograms (ECGs) measure the electrical activity of the heart. Figure 9.18 shows a sample of the traces that can be obtained from an electrocardiogram.

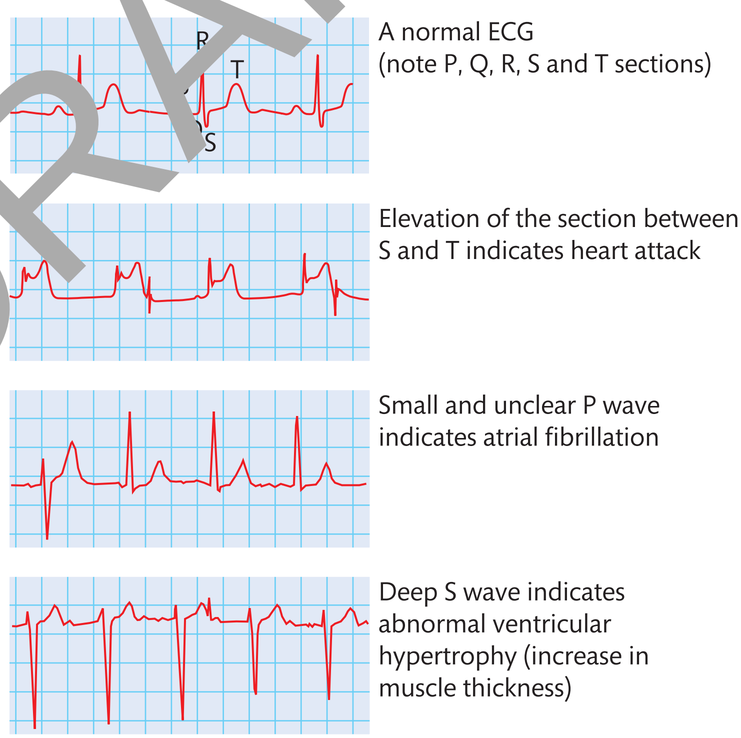


Figure 9.18: A normal ECG trace (top) compared with others that indicate heart problems

The P-wave shows the depolarisation of the atria, which is the conduction of an impulse through the atria. The QRS-wave represents depolarisation of the ventricles, the conduction of an impulse through the ventricles. The T-wave shows ventricular repolarisation.

ECGs record the electrical activity of the heart and do not show the heart's contractions. The atria start to contract part way through the P-wave and the ventricles contract during the QRS-wave.

Nervous control of the heart

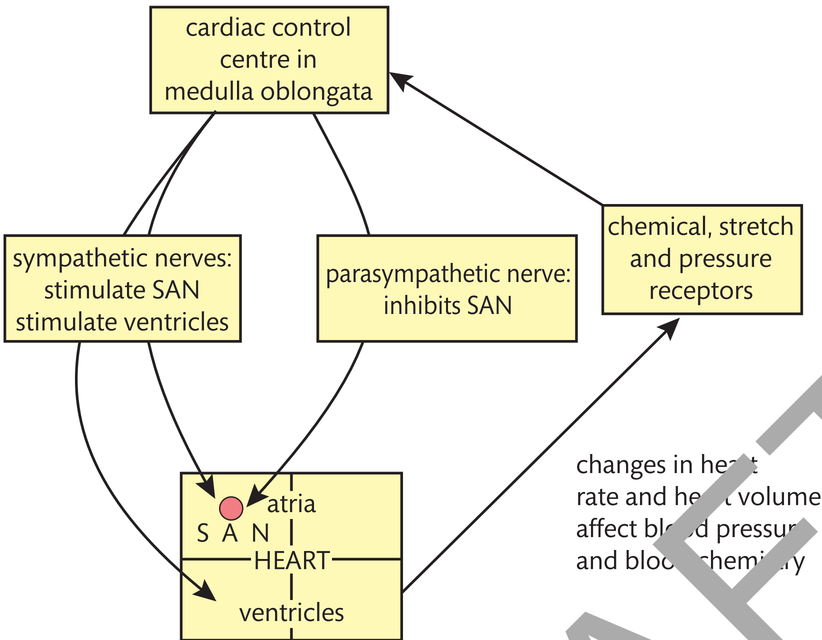


Figure 9.19: The cardiac centre in the medulla oblongata controls the heart rate via parasympathetic and sympathetic nerve stimulation.

Although the SAN initiates the rhythm of the heartbeat, there are situations when we need the output of the heart to increase, for example, during exercise.

Changes to **cardiac output** are regulated by the autonomic nervous system. The cardiac control centre, which is situated in the medulla oblongata of the brain, controls changes in the heart rate and the volume of blood pumped with each heartbeat in response to changes in the internal environment. Figure 9.19 shows how the cardiac centre in the medulla oblongata controls the heart rate via parasympathetic and sympathetic nerve stimulation.

Key term

Cardiac output – heart beat rate multiplied by the stroke volume.

Chemical, stretch and baroreceptors in the lining of the blood vessels and the chambers of the heart send nerve impulses to the cardiac centre.

The cardiac centre responds by sending impulses to the heart along parasympathetic and sympathetic nerves. Nerve impulses travelling down the sympathetic nerve from the cardiac centre in the brain to the heart release noradrenaline to stimulate the SAN. Figure 9.20 shows how a negative feedback system controls the heart output through baroreceptors.

This increases the frequency of the signals from the pacemaker region, so that the heart beats more quickly. Branches of this sympathetic nerve also pass into the ventricles, so they also increase the force of contraction.

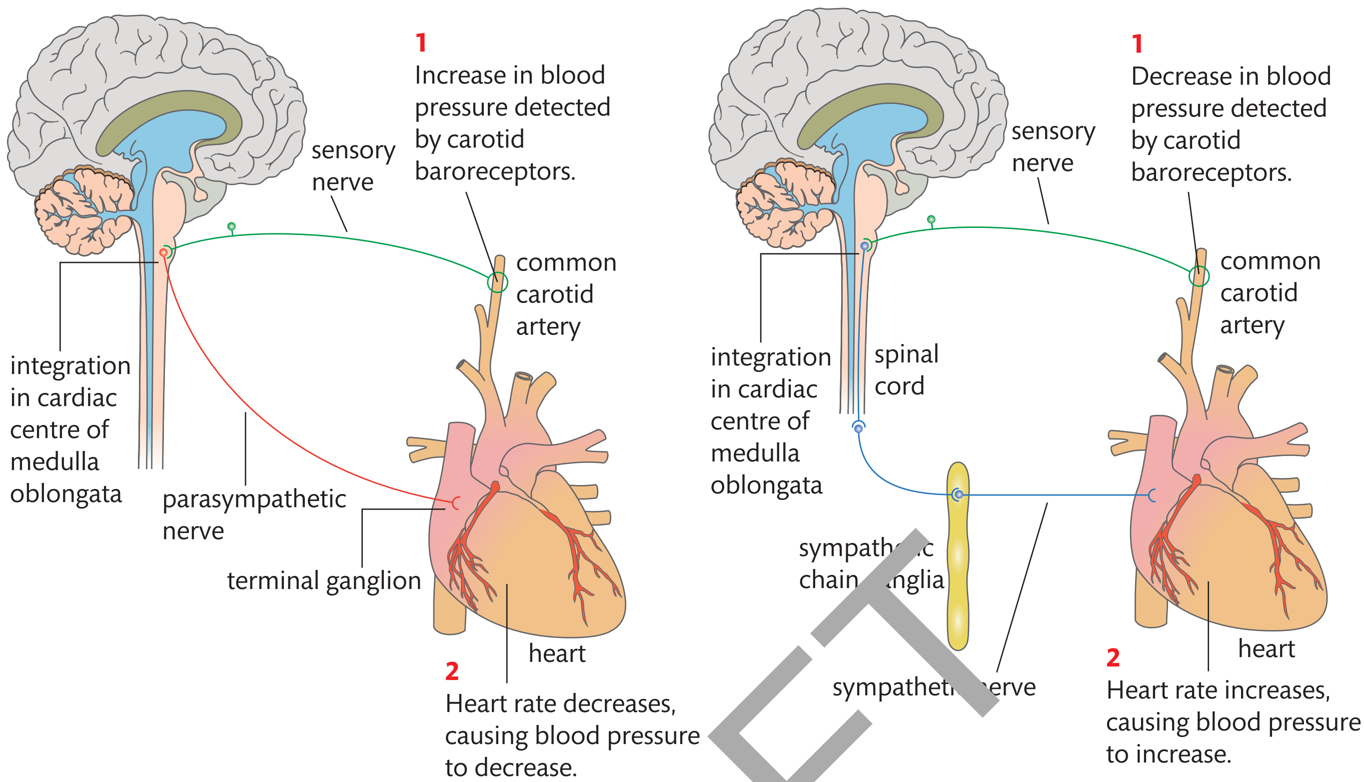


Figure 9.20: A negative feedback system for controlling the heart through the baroreceptors – one of the complex interactions that enable the output of the heart to match the demands of the body.

Key term

Stroke volume –the volume of blood pumped out of the heart with each contraction.

Nerve impulses in the parasympathetic nerve release acetylcholine, which inhibits the SAN and slows the heart down.

Worked Example

1 Alan has a resting heart rate of 60 beats per minute. His cardiac output is 4.2 dm^3/min. What is his resting **stroke volume**?

Cardiac output (CO) = stroke volume (SV) ´ heart beat (resting) HBR

Therefore SV = CO/HBR

Convert 4.2 dm^3 to cm^3 = 4200 cm^3

SV = 4200 cm^3/60 = 70 cm^3

2 What would you expect to happen to Alan's heart rate, stroke volume and cardiac output when he is running?

The heart rate will increase. The stroke volume will also increase. Therefore the cardiac output will increase. All of these will ensure that more blood is pumped each minute to supply the contracting muscles with more oxygen for the increased levels of respiration needed to make more ATP for muscle contraction.

3 Fatima has a resting cardiac output of 6.3 dm^3/min and her heart rate is 79 beats per minute. Calculate her resting stroke volume.

4 A female heart has to beat more times per minute than a male heart in order to pump the same volume of blood. Use your knowledge of the heart to explain why.

Assessment practice 9.1

A.P1 A.M1 A.D1

The following questions will help prepare you for your assessment.

1 Draw diagrams of a motor neuron and a sensory neuron and label the main structures.
2 Describe how an electrical impulse travels along a neuron.
3 Draw and label a diagram of a synapse. Produce a flow chart to summarise the sequence of processes that enable an impulse to pass from one neuron to the next one.
4 Describe how the cardiac cycle is controlled by electrical impulses.
5 Explain how a nervous impulse is initiated and transmitted along a motor neuron.
6 How does the nervous system coordinate the cardiovascular and respiratory systems?

Plan

- I know what the task is and what I am being asked to do.
- I know how confident I am in my abilities to complete the task. I know any areas I might struggle with.

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain what the task was and how I approached the task.
- I can explain how I would approach the hard elements differently next time (i.e. what I would do differently).

B Understand the homeostatic mechanisms used by the human body

In order to survive, your body needs to keep its internal environment within certain levels. Keeping internal conditions such as pH, temperature and salt concentration in a steady state is called **homeostasis**.

Key term

Homeostasis – the maintenance of a constant internal environment within an organism.

Feedback and control

Homeostasis requires a high level of monitoring and control. Hormones and the nervous system interact to detect and respond to stimuli in order to bring about changes that will bring conditions back to the correct level. The body uses systems of feedback to monitor and regulate conditions within the body.

Feedback

A thermostat is an example of a feedback mechanism. Household central heating systems make use of a thermostat to maintain the temperature of the room. If the temperature of the room falls, then the thermostat detects the change and switches the radiator on so that temperature of the room increases.

When the room gets too warm, the thermostat detects the increase in temperature and switches the radiator off to allow the room temperature to fall. The radiators are switched on or off depending on the temperature of the room detected by the thermostat.

Negative feedback

Figure 9.21 shows how the temperature of a room is controlled by a thermostat. In the example of the room thermostat, the change in temperature causes the radiators to produce the opposite effect to the change in temperature, so when the room cools, the radiators switch on to heat it up. This is called negative feedback.

Negative feedback is the means by which homeostasis is achieved. A change in one condition inside the body causes effectors to restore the condition to its original level.

All negative feedback systems have similar components. There is:

- an output (the factor that needs to be controlled such as blood pH)
- a set point, which is the norm for the factor (in the case of blood pH, the set point is 7.35–7.45).

Detectors (sensory receptors) monitor the output and coordinators (sometimes called regulators) compare the actual output with the set point and send out an error signal when the output falls outside the set point range.

Corrective mechanisms then restore the conditions to the set point.

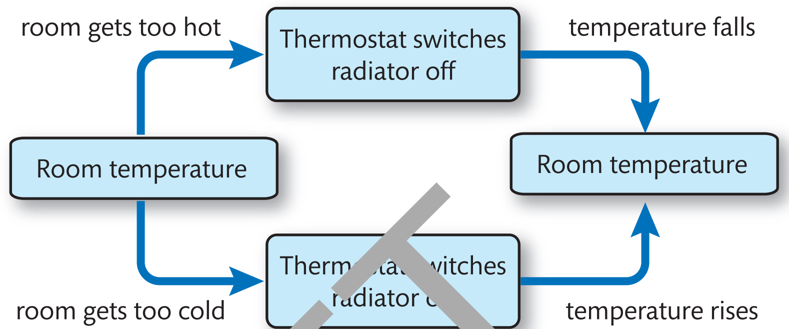


Figure 9.21: Negative feedback in a central heating system

Positive feedback

In a positive feedback system, the effectors work to amplify an effect brought about by a change, as a small change in the output causes a further change in the same direction.

This system can be harmful because it can create unstable conditions. However, in some circumstances positive feedback is useful. Figure 9.22 shows an example of positive feedback in the human body.

An example of the use of positive feedback is the contractions of the uterus during labour. The pressure of the baby's head on the cervix causes the release of hormones that increase the contraction of the uterus, so the head is then pushed down even harder on the cervix.

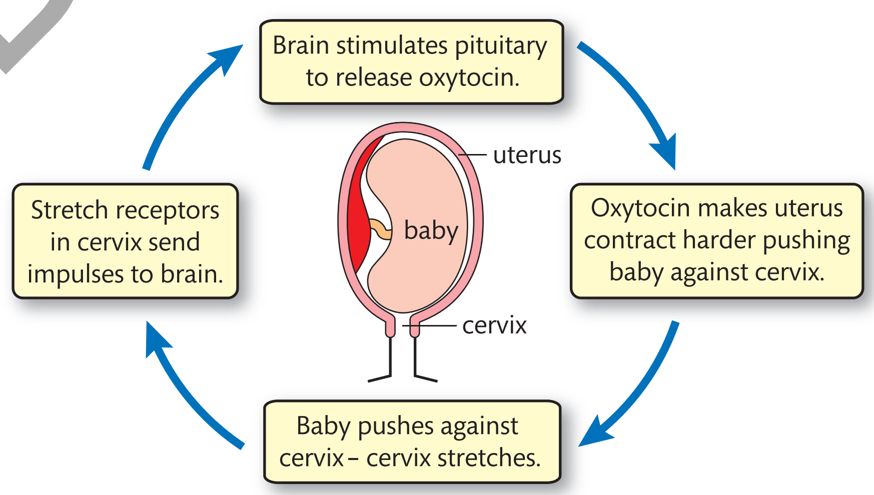


Figure 9.22: Positive feedback during labour. The pressure of the baby's head on the cervix causes the release of hormones to increase contractions and the baby is pushed harder through the birth canal.

Glands and organs

Glands and hormones

The human body is able to send messages through the body in two ways. Rapid messages can be sent by a system of electrical impulses carried by the nervous system. Slower messages can be sent through the blood by chemicals called hormones, which are secreted by glands. Hormones enable more than one tissue to be targeted because hormones are carried around the body in the blood. Hormones also enable long term changes to tissues to be brought about. An example is changes to the body during puberty. Glands that secrete hormones into the blood are called endocrine glands. These glands make up the endocrine system. Figure 9.23 shows the location of the main endocrine glands in the human body.

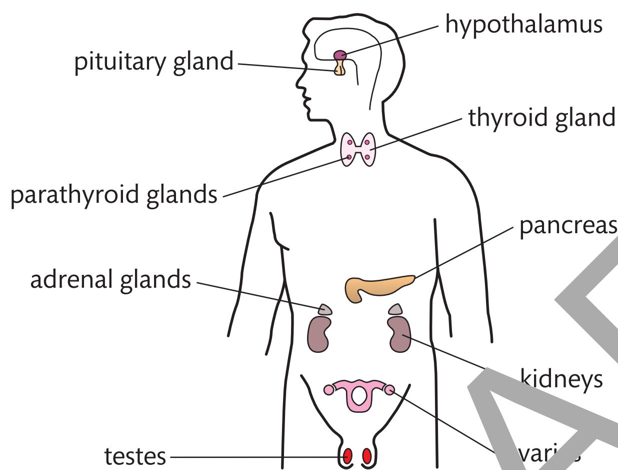


Figure 9.23 The main endocrine glands in the human body

Figure 9.24 shows how hormones are transported from the endocrine gland to the target organ. Once a hormone enters the bloodstream it is carried around in the blood until it reaches the target organ or organs. The cells of the target organs have specific receptor molecules on the surface of their membranes that bind to the hormone molecules. This brings about a change in the membrane and produces a response.

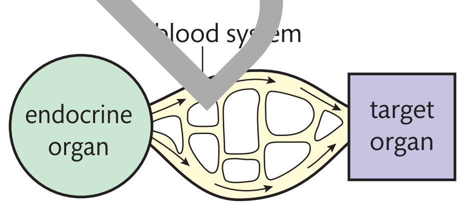


Figure 9.24: The pathway of a hormone from the endocrine gland, where it is produced, to the cells of the target organ

Exocrine, endocrine or both?

Exocrine glands contain ducts that transport secretions from the gland to its surface. An example is the salivary glands which secrete saliva into the mouth when you eat.

Endocrine glands pass secretions directly into the bloodstream rather than flowing along a duct. Endocrine glands secrete hormones into the bloodstream.

Some glands have an endocrine and exocrine function. A summary is shown in Table 9.5. The pancreas is an exocrine and an endocrine gland. Its exocrine function is to secrete digestive enzymes and its endocrine function is to secrete insulin and glucagon to regulate blood sugar levels.

Table 9.5: Functions of some glands of the human body

	Gland	Location	Secretion	Main function
Exocrine	Sweat gland	Dermis layer of the skin	Sweat	Lower body temperature
	Brunner's glands	Duodenum	Alkaline mucus	Neutralises acid from the stomach
Endocrine	Thyroid	Below the larynx in the neck	Thyroxine	Regulation of metabolic rate
	Parathyroid	Behind the thyroid gland in the neck	Parathyroid hormone	Regulation of calcium levels
	Pituitary	Base of brain	Thyroid-stimulating hormone Growth hormone Prolactin Adrenocorticotropic hormone (ACTH) Antidiuretic hormone (ADH)	Controls several other glands – adrenals, thyroid
Exocrine and endocrine	Pancreas	Abdomen	Alkaline mucus (exocrine)	Neutralise stomach contents as they enter the duodenum
			Insulin and glucagon (endocrine)	Blood glucose regulation
	Liver	Abdomen	Bile (exocrine)	Emulsification of fats
			Angiotensinogen, thrombopoietin, insulin-like growth factor (endocrine)	Regulation of blood pressure, platelet formation, cell growth and development

Homeostatic mechanisms: osmoregulation

Osmoregulation is the homeostatic control of body water and is an example of a negative feedback mechanism. We gain water from our food and drink but also lose it through urine, sweat and breathing. This needs to be balanced.

The kidneys

The kidneys are a pair of organs located in the urinary system. This system is shown in Figure 9.25.

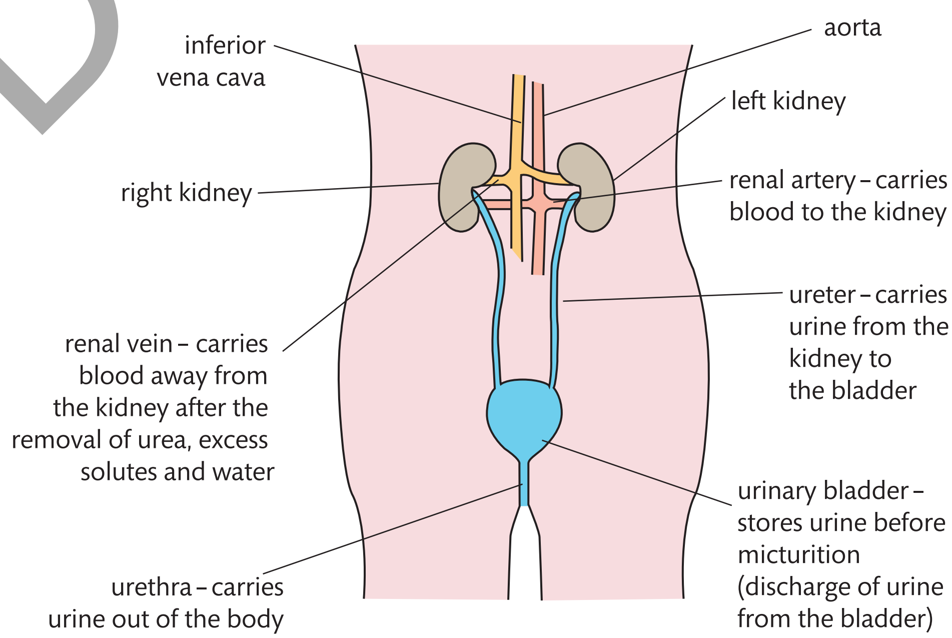


Figure 9.25: The human urinary system

Kidney structure

Figure 9.26 shows the structure of the kidney. The outside of the kidney is surrounded by a layer of fat and connective tissue. These layers protect the kidney from damage and hold it in place inside the body.

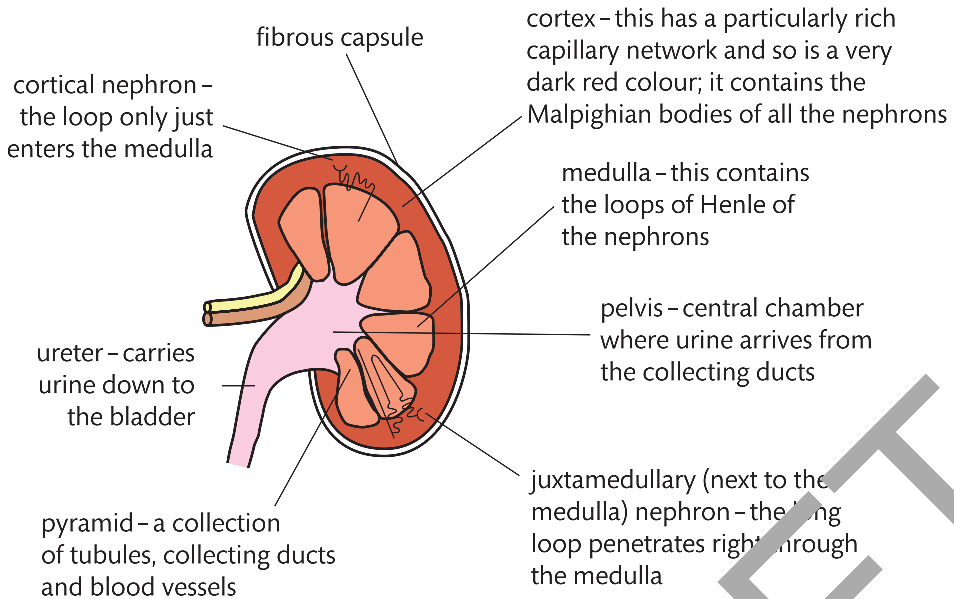


Figure 9.26: The gross structure of the kidney seen with the naked eye. The two main types of tubules have been superimposed.

The function of the kidneys is to filter waste products, such as urea out of the blood. The kidneys also have a homeostatic role as they help to regulate the pH and water content of the blood.

The nephron

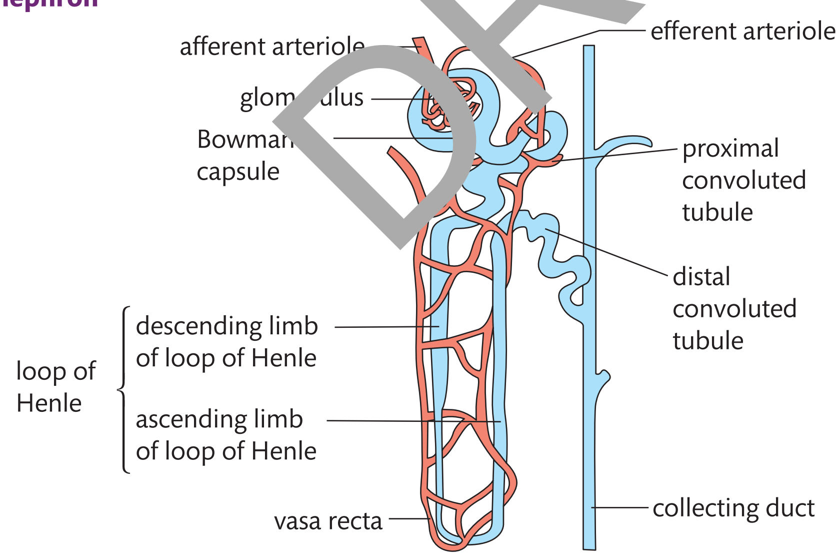


Figure 9.27: The structure and function of the nephron.

Figure 9.27 shows the nephron, which is the filtering unit of the kidney. There are thousands of nephrons in each of your kidneys. One end of the nephron is cup-shaped, the Bowman's capsule, and lies in the cortex, shown in Figure 9.28. Below the capsule is a twisted section of the nephron, called the proximal convoluted tubule, which leads to a long, hair-pin like structure called the Loop of Henle.

The Loop of Henle runs down through the medulla and then back up to the cortex, where it forms another twisted tubule called the distal convoluted tubule. This links to the collecting duct which carries urine from the medulla to the kidney pelvis.

The Bowman's capsule

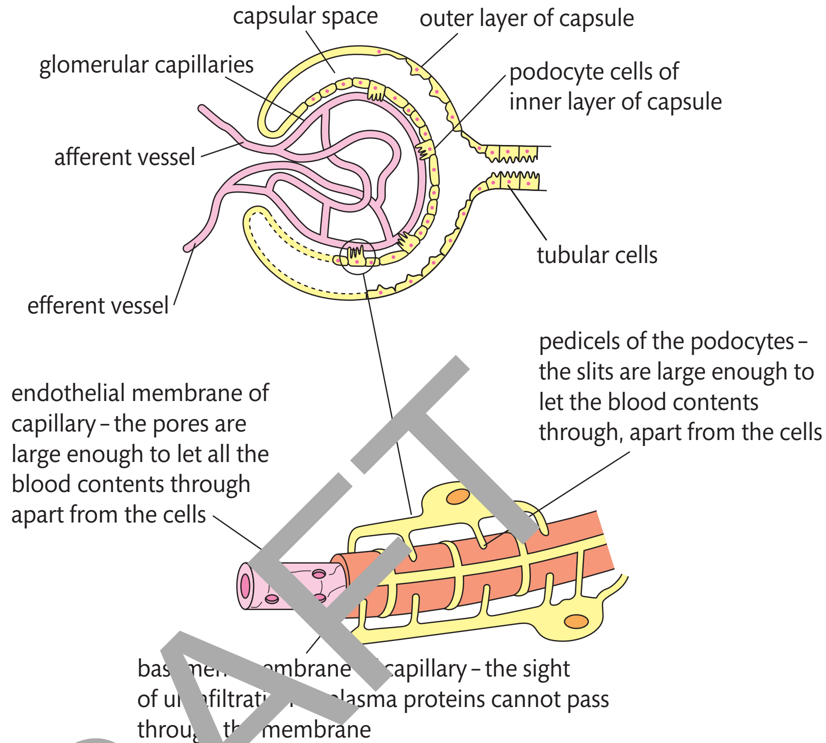


Figure [illegible].28: The main structure of the Bowman's capsule

Blood is supplied to the kidney by the renal artery, which branches to form arterioles. Each Bowman's capsule receives blood from an arteriole, called the afferent arteriole. The arteriole branches into a dense capillary network inside the Bowman's capsule called a glomerulus. These capillaries join up to form the efferent arteriole which takes the blood away from the capsule.

The afferent arteriole is wider than the efferent arteriole, which means that more blood is brought to the Bowman's capsule than is transported away from it. This is necessary to create the pressure required to filter the blood.

Ultrafiltration

Ultrafiltration is the process by which small molecules are filtered out of the blood under pressure in the Bowman's capsule.

Blood entering the Bowman's capsule is contained by two layers of cells and a basement membrane. The first layer of cells is the capillary endothelium, which is one cell thick and contains numerous gaps between the cells. The second layer of cells is the wall of the Bowman's capsule.

Cells in this layer are called podocytes as they have foot-like processes. These cells also have numerous gaps in between them. Separating the walls of the capillary and Bowman's capsule is a membrane called the basement membrane. This is made up of collagen and glycoprotein.

The effect of these three layers is a mesh-like structure which acts as a filter. The high blood pressure in the glomerulus forces substances across the basement membrane and into the Bowman's capsule. Only small soluble molecules can pass through the filter layers, whereas blood cells and also large molecules such as proteins cannot.

The Loop of Henle

The Loop of Henle is a long hairpin-shaped loop that runs through the medulla and back up into the cortex. Its function is to create an area of high solute concentration in the medulla through which the nephron collecting duct flows. This enables a large amount of water to be reabsorbed from the collecting ducts by osmosis.

The first part of the loop is called the descending limb and the second part is the ascending limb. The ascending limb is more permeable to salts and less permeable to water.

As the filtrate passes along the loop, sodium and chloride ions move out by diffusion at first and then by active transport from the ascending limb into the surrounding tissue.

The filtrate therefore becomes more concentrated as it moves along the loop. This means that the solute concentration at any point in the loop is lower in the ascending limb than in the descending limb. This mechanism is called a **counter-current multiplier** mechanism.

The collecting duct passes through the medulla to the pelvis, passing through the region of high solute concentration and water is drawn out by osmosis and reabsorbed into the bloodstream. This results in the formation of concentrated urine. This process is summarised in Figure 9.29. As water is reabsorbed into the bloodstream and therefore retained in the body, dehydration is prevented.

> **Key term**
>
> **Counter-current multiplier** – a counter-current system (a system that maintains a concentration gradient along its length) that uses energy to actively transport substances across a membrane to create a diffusion gradient.

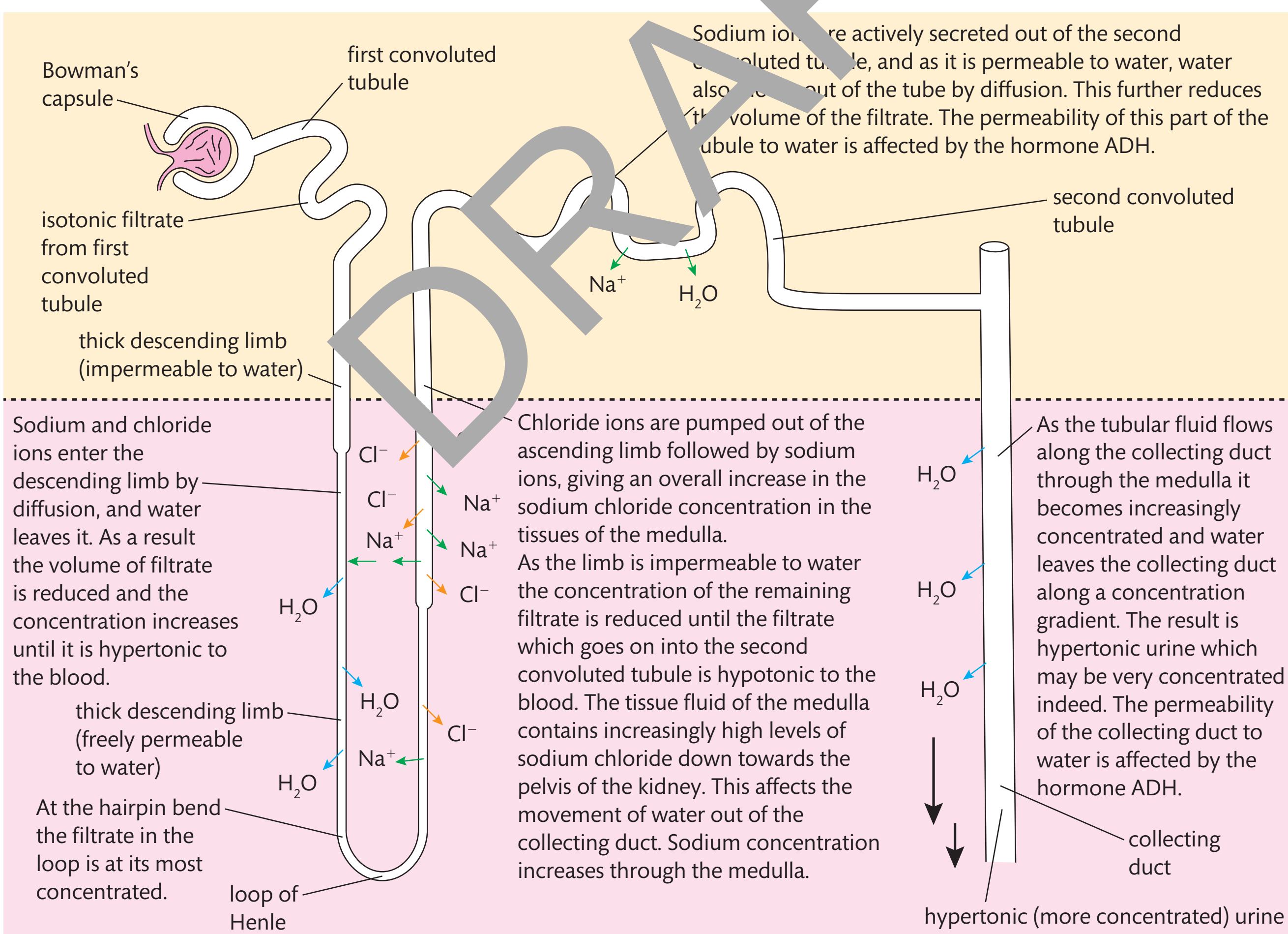


Figure 9.29: A model of the role of the Loop of Henle in the reabsorption of water and the production of concentrated urine in the kidney.

Ultrafiltration in the Bowman's capsule is so efficient that it removes useful substances like amino acids and glucose from the blood. Useful substances are absorbed back into the blood by selective reabsorption.

Glucose, amino acids, vitamins and mineral ions are actively transported out of the proximal convoluted tubule and back into the blood.

Cells lining the tubule have finger-like projections called microvilli to create a large surface area and mitochondria to supply the energy required to actively transport substances across the membrane.

Step-by-step: Dissecting a kidney

4 Steps

1 Examine the external structure of the kidney. Locate the ureter, renal artery and renal vein.

2 Lie the kidney flat on the dissection board and cut around the side so that you cut the kidney in half sideways.

3 With your fingers, open up the two sides of the kidney so that you can see the internal structures.

4 Locate the renal cortex, medulla, renal pyramids and renal pelvis. Look carefully at their structure and draw annotated diagrams of what you can see. Clear away carefully ensuring that you follow the tutor's instructions. Wash your hand thoroughly when you have finished.

The control of ions by osmoregulation

As well as controlling the amount of water in the urine and preventing dehydration, osmoregulation regulates the concentration of ions. Controlling the concentration of ions in the body is essential as cells can only function efficiently if tissue fluids contain the correct levels of ions.

Hormones control the levels of ions in the blood by causing changes to the following:

- the uptake of ions into the blood from the gut
- removal of ions from the blood by the kidneys and excretion in the urine
- release of ions into the blood from organs.

The role of hormones in osmoregulation

The concentration of sodium ions is controlled by a hormone, aldosterone. Aldosterone is secreted by the adrenal glands and it increases the uptake of sodium ions from the gut into the bloodstream and their reabsorption in the kidney.

The control of this process is negative feedback. If the sodium ion concentration is too high, less aldosterone is produced and sodium uptake is decreased. When sodium ions concentration decreases, more aldosterone is produced and uptake of sodium is increased.

When sodium ion concentration decreases, blood volume and blood pressure will also fall because water is lost with the sodium ions. The fall in blood pressure is detected by baroreceptors which send impulses to the cardiovascular centre in the brain. This stimulates the liver to produce angiotensinogen, which then stimulates the production of aldosterone. The resulting uptake of sodium ions and water will lead to an increase in blood volume and blood pressure.

Potassium ion concentration is affected by changes in sodium ion concentration. This is because of the sodium-potassium pump which moves the two ions in opposite directions across cell membranes. This means that the hormones that control sodium ion concentrations will also control the levels of potassium ions. This is called the sodium-potassium balance.

Atrial natriuretic peptide (ANP) is released by muscle cells in the atria of the heart when blood volume increases. ANP acts in the opposite way to aldosterone to increase sodium and also water loss, therefore reducing blood volume.

PAUSE POINT Can you explain how the kidney filters waste products from the blood?

Hint Read back through the unit and produce a poster to summarise the roles of the nephron, Bowman's capsule and Loop of Henle in filtration and reabsorption.

Extend The medulla of the kangaroo rat's kidney is approximately seven times thicker than that of the beaver and approximately double the thickness of a human medulla. How does this adaptation enable the kangaroo rat to survive in dry conditions?

The kangaroo rat lives in desert conditions.

The role of the kidney in osmoregulation

Osmoregulation is the homeostatic control of body water and is an example of a negative feedback mechanism. We gain water from our food and drink but also lose it through urine, sweat and breathing. This needs to be balanced.

Osmoreceptors in the hypothalamus detect changes in blood solute concentration. If you have not had a drink for a while, your blood will become more concentrated (less water).

The osmoreceptors detect the change and stimulate the pituitary gland to produce anti-diuretic hormone (ADH). ADH is released into the blood stream and makes the distal convoluted tubule more permeable to water. This allows more water to be reabsorbed from the distal convoluted tubule and the collecting duct. Less water is passed into the urine and a more concentrated urine is produced.

Discussion

Kidney transplants are now a common surgical procedure. However, in the UK there are twice the number of people waiting for a suitable donor than the ones who receive a transplant. In what ways could this situation be resolved?

If you drink lots of fluids, your blood becomes more dilute. Osmoreceptors detect the change. This leads to a reduction in the production of ADH. The distal convoluted tubule becomes less permeable to water. Less water is reabsorbed and a larger quantity of dilute urine is produced.

The hypothalamus is also connected to the thirst centre in the brain making you feel thirsty when blood water levels decrease so that you drink and take in fluids. The stomach filling with water switches off the thirst centre.

Homeostatic mechanisms: control of blood glucose levels

The role of the pancreas in blood glucose regulation

The pancreas is an exocrine and endocrine gland. Its exocrine function is to secrete pancreatic juice into the duodenum during digestion. Its endocrine function is the regulation of blood glucose.

The pancreas contains groups of cells called the Islets of Langerhans. There are two types of these cells:

- alpha cells secrete the hormone, glucagon, and are sensitive to low blood glucose levels in the blood
- beta cells secrete the hormone insulin and are sensitive to increased blood glucose levels.

Glucagon and insulin have antagonistic actions in order to maintain a constant blood glucose level.

Figure 9.30 shows how the body regulates blood glucose levels. Blood glucose levels can rise for a number of reasons.

- Absorption of carbohydrates after a meal. Carbohydrates are sugars and starchy foods. They are quickly broken down into glucose and absorbed into the blood causing blood sugar levels to rise.
- Conversion of glycogen to glucose by a process called glycogenesis. Glycogen is an emergency store of energy stored in the liver and muscles. It can be quickly converted to glucose to meet the body's requirements.
- Conversion of amino acids to glycerol and glucose in a process called gluconeogenesis. When amino acids are absorbed in excess, they are broken down by a process in the liver called deamination. The amino part of the molecule is excreted and the rest of the molecule is converted into glucose.

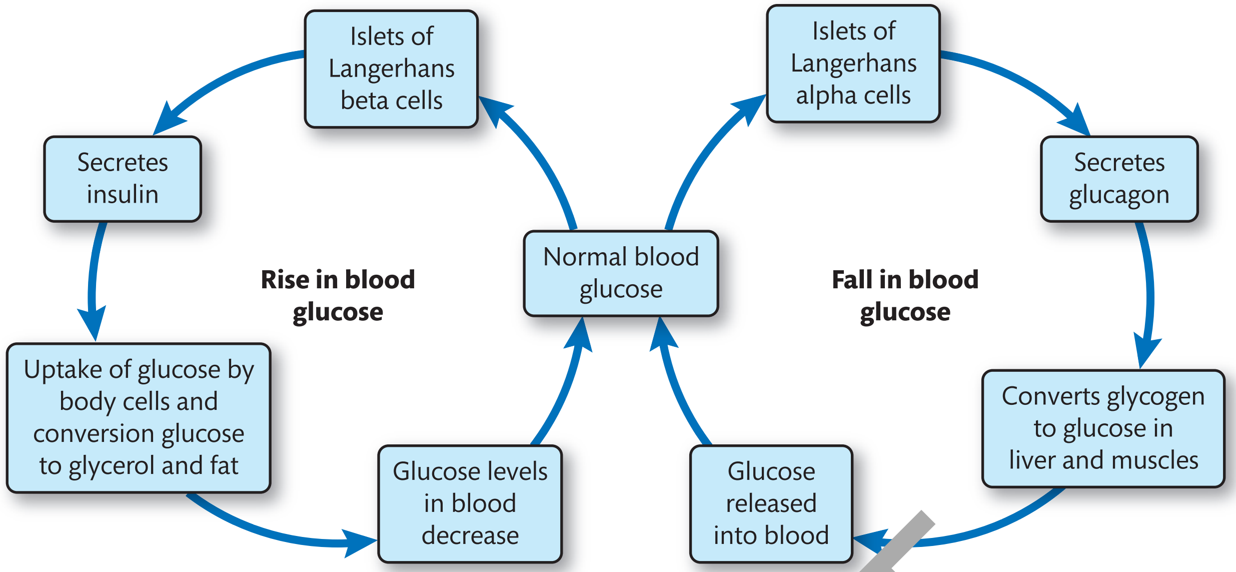


Figure 9.30: The regulation of blood glucose levels

Glucagon

If blood glucose levels fall too low, the alpha cells of the pancreas will detect the decrease and secrete glucagon. This hormone acts on the membranes of the liver cells and activates enzymes in the liver cells to convert glycogen to glucose and increase the rate of gluconeogenesis. The effect is that blood glucose levels rise.

Insulin

If blood glucose levels increase, the beta cells of the pancreas detect the change and secrete insulin. Insulin is transported in the bloodstream to the muscles, liver and adipose cells, where it attaches to the cell membranes. It changes the permeability of the cell membranes and increases the rate at which glucose is transported across the membrane into the cells. This:

- increases the rate of respiration due to the increased level of glucose present in the cell
- increases the rate of conversion of glucose to glycogen
- increases the rate of conversion of glucose to fat which is stored in the adipose cells
- reduces blood glucose levels.

Homeostatic mechanisms: thermoregulation

Your core body temperature remains at 37°C whether you are standing in the snow or lying in your bed, unless you have a fever. Homeostasis uses negative feedback to ensure that body temperature remains constant. A summary of this process is shown in Figure 9.31.

The hypothalamus in the brain monitors the temperature of the blood passing through it and acts as the body's thermostat. It also receives information from temperature receptors in the skin.

If the blood temperature is too high, the hypothalamus sends out nerve impulses that will switch on cooling mechanisms such as sweating.

If the temperature is too cold, the hypothalamus will send out nerve impulses to switch on warming mechanisms such as shivering.

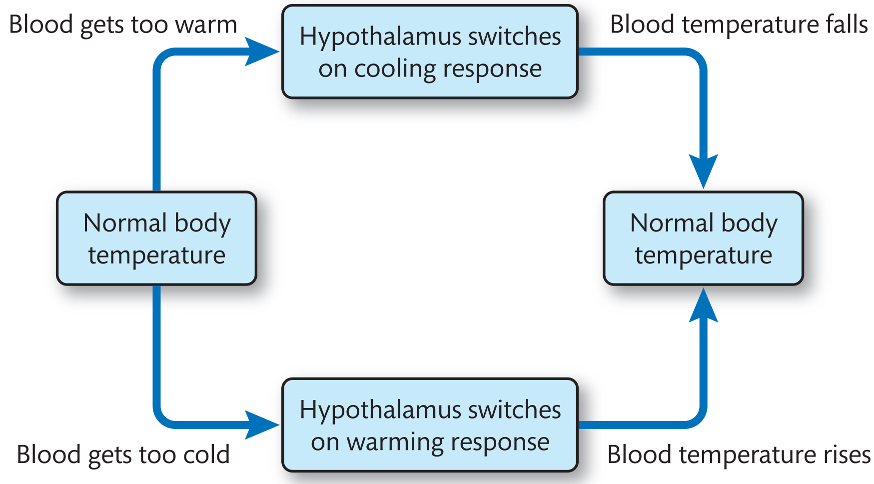


Figure 9.31: Negative feedback control of body temperature

The role of the skin in thermoregulation

The dermis layer of the skin contains a number of structures that are involved in the regulation of body temperature. These are shown in Figure 9.32.

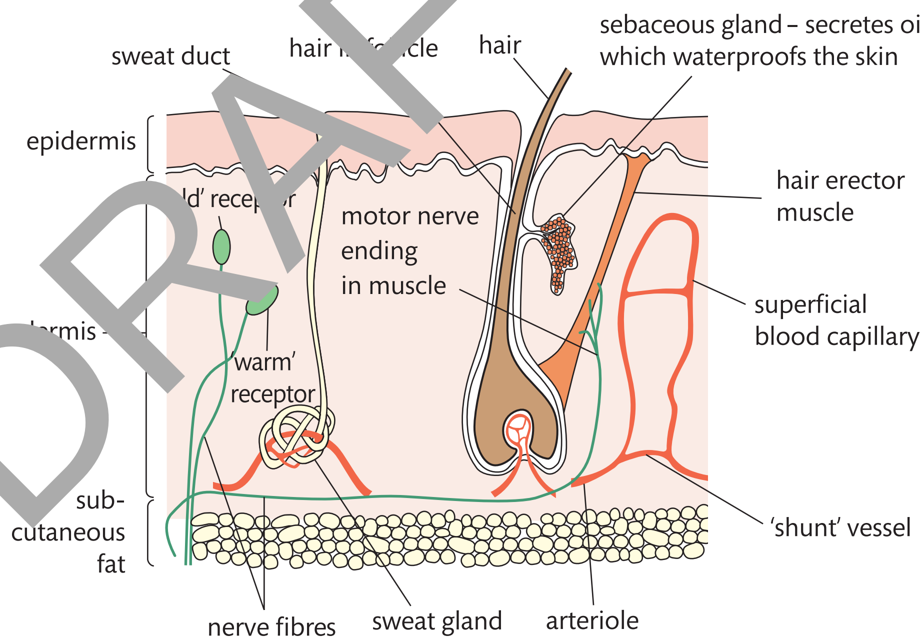


Figure 9.32: The human skin showing the structures involved in thermoregulation

Capillaries in the skin are involved in heat regulation as well as bringing nutrients and oxygen to the skin. Arterioles that bring blood to the skin capillaries contain muscle in their walls. When skin temperature rises, the muscles in the arteriole walls relax. This causes the arteriole to dilate which allows more blood to flow to the capillaries in the skin surface. This is called vasodilation. Heat is then lost to the surroundings.

When skin temperature falls, the arteriole muscles contract. Less blood flows to the capillaries. Blood is diverted along a shunt vessel to prevent blood entering the capillary network and less heat is transferred to the surroundings. This is called vasoconstriction. Figure 9.33 shows what happens to structures in the dermis to enable vasodilation and vasoconstriction.

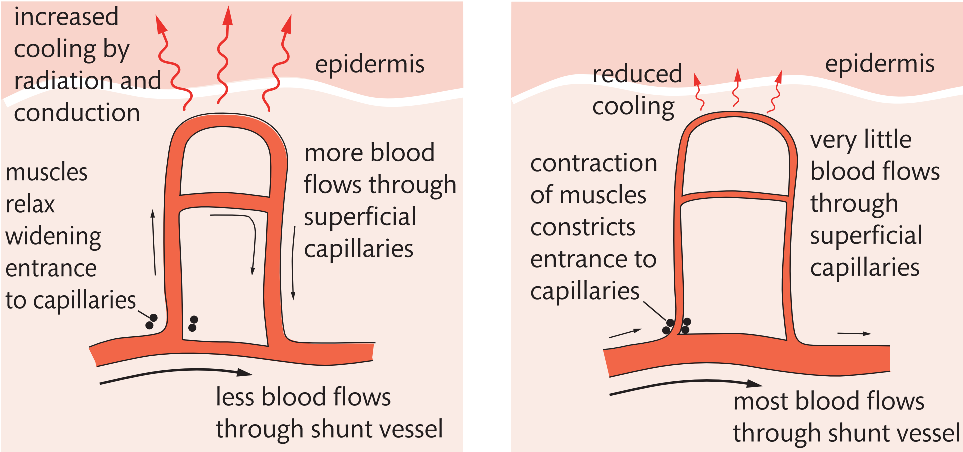


Figure 9.33: The role of blood vessels in thermoregulation

Sweat glands have their own capillary blood supply. When the temperature rises sweat glands produce a salty solution called sweat which flows to the skin surface through sweat ducts and out of the pores. When evaporating, water from the sweat takes heat from the skin which causes a cooling effect.

Each hair follicle in the skin is connected to an erector muscle. In low temperatures the muscle contracts and pulls the hair upright. A layer of air is trapped around the skin, which has an insulating effect. This causes goose pimples.

Impact of an imbalance of homeostatic mechanisms

Diabetes

Diabetes is a condition where the body is unable to regulate its blood glucose levels. Table 9.6 summarises the symptoms and their causes.

Table 9.6: The symptoms of diabetes and their underlying causes

Symptom	Cause
Weight loss	There is insufficient insulin to increase the permeability of the cell membranes to glucose. The cells are therefore starved of fuel and have to respire using fats and proteins instead. Insulin also acts as an anabolic (body building) hormone and lack of it leads to muscle wasting.
Thirst	High levels of glucose in the blood cause a decrease in water potential in the blood.
Lack of energy and tiredness and craving sweet foods	Cells are starved of the glucose they require for respiration to release energy.
Presence of glucose in the urine (glycosuria)	The kidneys are unable to reabsorb the high levels of glucose filtered into the tubules.

The severity of diabetes varies from person to person. There are two types of diabetes.

Type 1 diabetes

Type 1 diabetes, known as insulin dependent diabetes or juvenile onset diabetes, usually occurs in childhood. It is caused when cells of the immune system attack beta cells in the Islets of Langerhans, so destroying a person's ability to produce insulin.

Type 1 diabetes is treated with insulin injections and careful management of the diet and exercise.

People with diabetes have to monitor their blood glucose levels and take care to inject the right amount of insulin. An overdose of insulin will result in too much sugar being removed from the blood leading to a condition called hypoglycaemia. Brain cells require glucose for fuel and a lack of glucose can lead to unconsciousness, coma and death. A person with diabetes who is found unconscious should be given sugar.

Type 2 diabetes

Type 2 diabetes, known as insulin independent or late onset diabetes, usually occurs later in the life cycle. It is caused when cells gradually lose their response to insulin or an insulin deficiency.

Type 2 diabetics can control their blood glucose levels by regulating their diet and exercise, but some require insulin injections. Type 2 diabetes has been linked to high fat diets and obesity.

Hyperglycaemia

Hyperglycaemia is the medical term for high blood glucose levels and is often caused by insufficient insulin due to diabetes. The main symptoms of hyperglycaemia are increased thirst and the need to urinate frequently. Other symptoms that can occur are headaches, tiredness, blurred vision, hunger and difficulty concentrating or thinking. Very high levels of blood glucose can cause coma and even death. Long term damage from hyperglycaemia can be damage to the organs and tissues, often resulting in amputation of extremities such as toes and fingers. It can also cause damage to the immune system and poor healing of cuts and wounds. Nerve damage and loss of sight are also caused by long term hyperglycaemia.

PAUSE POINT What effect does eating a high carbohydrate meal have on blood glucose levels?

Hint How do insulin and glucagon interact to regulate blood glucose levels?

Extend What type of diet is most likely to lead to the development of Type 2 diabetes? Explain why.

Hyperthermia

Hyperthermia is a condition where the body temperature is higher than normal and the body's usual cooling mechanisms cannot cool the body down. It is often caused when people over-exert themselves in hot weather and results in dizziness, itchy and irritated skin, cramps, swelling of the ankles and feet and heat exhaustion. The most severe effect of hyperthermia is heat stroke which causes fainting, confusion and irregular heart beat. Death can result from severe hyperthermia.

Hypothermia

Hypothermia results when the body temperature falls too low and the warming mechanisms cannot warm the body up sufficiently. Mild hypothermia causes constant shivering, tiredness, confusion, fast breathing and cold, pale skin whereas severe hypothermia may cause unconsciousness, a weak and irregular heart beat or death.

SIADH (syndrome of inappropriate anti-diuretic hormone secretion)

SIADH makes it difficult for the body to get rid of excess water. This causes fluids to build up in the body and sodium levels to drop. It can cause cramps, nausea, vomiting, confusion, hallucinations, seizures and coma.

Assessment practice 9.2

B.P2 B.M2 B.D2

You are a trainee nurse working on the renal ward of the local hospital. You have been asked to design and produce a display board for a visitors' area.

The subject of the display is homeostasis and its importance in the body. It also needs to contain materials that cover homeostatic dysfunctions and their impact on the body.

Produce a range of materials suitable for the display board that explain the function and importance of homeostatic mechanisms and the role of hormones on the control of these mechanisms.

Plan

- I know what the task is and what I am being asked to do.
- I know how confident I am in my abilities to complete the task. I know any areas I might struggle with.

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain what the task was and how I approached the task.
- I can explain how I would approach the hard elements differently next time (i.e. what I would do differently).

C Understand the role of hormones in the regulation and control of the reproductive system

Structure and function of reproductive anatomy

The female reproductive system

The basic structure of both male and female reproductive systems consists of a genital tract, a tube that runs from the gonads (organs that produce **gametes**) to the external environment. Figure 9.34 shows the anterior view of the female reproductive system and a side view is shown in Figure 9.35.

Figure 9.34: The female reproductive system (anterior view)

The ovaries lie inside the abdominal cavity and are held in place by ligaments. The ovary surface is covered with germinal epithelium which is made up of **oogonia**, cells which divide by mitosis to produce **primary oocytes**, and also divide to produce follicle cells.

Close to the ovary lies the funnel of the Fallopian tube. The funnel is lined with finger-like structures called fimbrae. The fimbrae are lined with cilia and their function is to collect the **secondary oocyte** as it leaves the ovary during ovulation.

Key terms

Gamete – sex cells e.g. sperm and ovum.

Oogonia – ovum producing cells in the germinal epithelium of the ovary.

Primary oocyte – diploid cell formed by cell division in the oogonia. The primary oocyte starts to divide by **meiosis** but stops at prophase I.

Secondary oocyte – cell formed when the primary oocyte completes the first meiotic division. The second meiotic division takes place after fertilisation.

Meiosis – a type of cell division by which the amount of genetic material is precisely halved to produce a haploid gamete.

[redacted]

Figure 9.35: The female reproductive system (side view)

The Fallopian tubes are muscular tubes which are lined with cilia. The secondary oocyte is swept along the Fallopian tube by a combination of cilia motion and muscular contractions.

The Fallopian tubes lead to the uterus, which is a pear shaped muscular organ. The Fallopian tubes join the uterus at a point called the uterine horn.

The uterus wall consists of smooth muscle called the myometrium. The uterus is lined with the endometrium, a tissue rich in blood supply, into which the blastocyst will implant.

The lower end of the uterus comprises of a muscular opening called the cervix. The cervix leads to the vagina which is a muscular tube linking the cervix to the external environment through the vulva.

The vulva consists of a number of folds of skin, the labia. There are two inner folds called the labia minora and two outer folds called the labia majora.

There is a small body of erectile tissue, the clitoris, enclosed within the labia. The clitoris is highly sensitive and swells with blood during sexual stimulation.

Discussion

Humans and primates are the only mammals that have a pear shaped uterus. Most mammals have a Y-shaped uterus. How might the shape of the uterus link to the number of offspring usually produced?

The male reproductive system

Figure 9.36 shows the anterior and side views of the male reproductive system.

There are three important glands which have ducts joining the urethra.

These are the seminal vesicles, prostate gland and the Cowper's gland. These secrete fluids which nourish the sperm and make it alkaline. The purpose of increasing the pH is to neutralise the acidic conditions in the urethra and acidic conditions in the vagina which will be hostile to the sperm.

Each testis is divided up into a series of compartments called lobules, which contain a number of tightly coiled tubes called the seminiferous tubules.

The seminiferous tubules are lined with a layer of cells called the germinal epithelium, which contain cells called **spermatogonia**. The spermatogonia cells undergo mitosis to produce **primary spermatocytes**.

Key terms

Spermatogonia – sperm producing cells in the germinal epithelium of the seminiferous tubules.

Primary spermatocyte – diploid cell formed by cell division in the spermatogonia.

Figure 9.36: The male reproductive system

The seminiferous tubules merge to form a network of tubules called the vas efferentia. These merge to form a long tube called the epididymis, which lies just outside the testis.

The epididymis leads to the vas deferens which leaves the scrotal sac and joins the urethra. Sperm are stored in the epididymis and vas deferens until ejaculation occurs.

During ejaculation, a mixture of sperm and fluids from the glands emptying into the urethra are released from the end of the penis in a secretion called semen.

PAUSE POINT Make sure you can summarise the location and functions of the structures in the male and female reproductive systems.

Hint Produce a table to summarise the names and functions of each of the structures in the male and female reproductive systems.

Extend Produce a flow chart to summarise the path of ejaculated sperm from the vagina to the secondary oocyte. Include descriptions of all of the structures in the female reproductive tract that the sperm must swim through before fertilisation.

Key terms

Gametogenesis – the development of gametes (sex cells – sperm and ova) in the gonads (testes and ovaries).

Spermatogenesis – the process of sperm formation in the testes.

Oogenesis – the process in which ova are formed in the ovaries.

Haploid – describes a cell that contains one of each type of chromosomes.

Diploid – describes a cell that contains two sets of chromosomes; usually one set from the mother and the other from the father.

Reproductive processes

Gamete production

The production of gametes in the gonads is known as **gametogenesis**. **Spermatogenesis** is the formation of sperm in the testes and **oogenesis** is the formation of ova in the ovaries.

Gametogenesis involves meiosis to produce gametes that are **haploid**. This is important so that at fertilisation the resulting offspring are **diploid**.

There are three stages of gametogenesis and these are essentially the same in both sexes:

1. multiplication phase, where diploid cells in the germinal epithelium divide many times by mitosis
2. growth phase, where the daughter cells formed in the multiplication phase increase in size
3. maturation phase, the daughter cells divide by meiosis and the resulting haploid cells form gametes.

Spermatogenesis

Spermatogenesis is the process by which sperm are produced in the testes. A diagram of the testis is shown in Figure 9.37.

[redacted]

Figure 9.37: Section of the testis

Key term

Secondary spermatocyte – cell formed when the primary spermatocytes divide by meiosis.

In male humans, spermatogenesis takes place in the seminiferous tubules and begins during puberty. The stages of development are shown in Figure 9.38.

Spermatogonia cells divide many times by mitosis to produce primary spermatocytes. These then grow and divide by meiosis to form **secondary spermatocytes** which develop into spermatids.

The spermatids have the correct number of chromosomes to be gametes but do not have the physical structure of a sperm that will allow them to swim to an ovum and fertilise it.

To enable the spermatids to mature into sperm, there are Sertoli cells in the wall of the seminiferous tubules which secrete a fluid to nourish the spermatids and protect them from destruction by the immune system.

Sertoli cells are stimulated by the hormone testosterone which is released by Leydig cells adjacent to the seminiferous tubules.

[redacted]

▶ **Figure 9.38:** Stages of development of the human sperm

Oogenesis

The production of ova in the ovaries is called oogenesis and begins before birth while the female is a foetus. Oogonia divide to form primary oocytes.

Cells in the germinal epithelium divide to form follicle cells, which surround the primary oocytes to form primary follicles. Meiosis then begins in the primary oocytes but stops at prophase I.

[redacted]

▶ **Figure 9.39:** Development of a follicle in the human ovary

Figure 9.39 shows how follicles develop in the ovary. During puberty, Follicle stimulating hormone (FSH) produced by the pituitary gland stimulates the primary follicles to develop further. Several follicles will start to develop each month but usually only one will mature to form a Graafian Follicle.

Inside the Graafian Follicle the primary oocyte completes the first meiotic division to form a secondary oocyte and a polar body. The follicle cells surrounding the secondary oocyte grow and a series of fluid filled spaces form.

The Graafian follicle matures and moves to the surface of the ovary, where eventually it bursts and releases the secondary oocyte. This process is known as ovulation.

The second meiotic division occurs only when a sperm penetrates the secondary oocyte during fertilisation. Many of the follicle cells remaining in the ovary develop to form the corpus luteum, which is important in the secretion of the hormone progesterone.

PAUSE POINT	What is meant by gametogenesis?
Hint	List the stages of spermatogenesis and the stages of oogenesis.
Extend	An overactive thyroid gland can stop the maturation of spermatocytes. Explain how this will cause a decline in fertility.

Ovulation disorders

Ovulatory disorders are one of the leading causes of infertility. Anovulation (no ovulation) is a disorder in which ova do not develop properly, or are not released from the ovaries. Women who have this disorder may not menstruate for several months. Others may menstruate even though they are not ovulating.

Anovulation may result from:

- hormonal imbalances
- eating disorders
- other medical disorders.

Women athletes who exercise a great deal may also stop ovulating.

Oligo-ovulation is a disorder where ovulation fails to occur on a regular basis. Women suffering from this disorder may often have a menstrual cycle which is longer than the normal cycle of 21 to 35 days.

Infertility may also be caused by abnormalities in oocyte development. The main cause of increased risk for miscarriage in older women is increased rates of chromosomal abnormalities in their ova. Aneuploidy is a condition where there is an abnormal number of chromosomes in the gamete nucleus. Two well-known examples of aneuploidy are:

- Down's syndrome, where an extra chromosome is present (trisomy)
- Turner's syndrome, where a chromosome is missing (monosomy).

Aneuploid eggs and embryos are responsible for most of the decline in fertility with female ageing and the low success rate with in vitro fertilisation (IVF) for women over 40.

Sperm disorders

Sperm morphology is one factor that is examined as part of a semen analysis to evaluate male infertility. Sperm morphology results are reported as the percentage of sperm that appear normal when semen is viewed under a microscope.

Normal sperm have an oval head with a long tail. Abnormal sperm have head or tail defects such as a large or misshapen head or a crooked double tail. These defects can affect the ability of the sperm to reach and penetrate the ovum. A large percentage of misshapen sperm is not uncommon.

Sperm morphology alone is not used as an indicator of fertility. A typical semen analysis will also assess:

- volume of semen
- total sperm number
- sperm concentration
- vitality (percentage of live sperm)
- motility (movement).

Hormonal changes in the menstrual cycle

The menstrual cycle is the period of time from the first day of a woman's period until the day before her next one, which is typically 28 days. The onset of the menstrual cycle begins during puberty from the age of 10 upwards and ends at the menopause, typically when the woman is aged 50–55.

Phases of the menstrual cycle

The menstrual cycle is divided into two phases: a follicular phase during which a Graafian follicle develops and a luteal phase where the corpus luteum develops and then regresses.

During the first 14 days after the beginning of menstruation, a Graafian follicle develops in one of the ovaries. After ovulation (around day 14 of the cycle) the empty follicle undergoes a series of changes. The follicle cells enlarge and a yellow pigment accumulates inside the cavity of the follicle turning it into a solid corpus luteum (yellow body). If fertilisation does not take place, the corpus luteum remains in the ovary for a week to 10 days.

While the Graafian follicle is developing, the wall of the uterus prepares itself for receiving a blastocyst. The endometrium thickens and becomes permeated with blood vessels and glands in readiness for implantation. If fertilisation does not occur, the unfertilised egg degenerates.

The corpus luteum regresses and the endometrium of the uterus breaks down and sloughs off. The discarding of the endometrial tissue along with loss of blood takes place intermittently over a number of days in a process called menstruation.

[redacted]

Figure 9.40: Changes occurring in the body during the menstrual cycle

Hormonal control of the menstrual cycle

The menstrual cycle typically lasts about 28 days and is controlled by hormones (see Figure 9.40). The cycle involves the production and release of an ovum and the preparation of the uterus to receive the ovum in the event of fertilisation. The hormonal control of the cycle can be summarised as follows.

- The anterior pituitary gland secretes Follicle Stimulating Hormone (FSH) which is carried by the blood to the ovary where it stimulates the development of a Graafian follicle.
- The Graafian follicle matures and produces oestrogen which is carried in the blood to the anterior pituitary gland to stop FSH production, and produce another hormone, Luteinising Hormone (LH). Oestrogen also stops further Graafian follicles from developing.
- LH triggers the release of the secondary oocyte from the Graafian follicle (ovulation) on around day 12 of the cycle. LH also stimulates the remaining follicle cells to form the corpus luteum.
- The corpus luteum secretes the hormone progesterone and a small amount of oestrogen. The ovary continues to secrete a reduced amount of oestrogen.
- The presence of progesterone and oestrogen in the blood inhibits the production of FSH and LH and stimulates the endometrium to thicken.
- If pregnancy occurs, hormones produced by the embryo stimulate the corpus luteum to continue to secrete progesterone. High levels of progesterone and oestrogen inhibit FSH and keep the endometrium (the uterus lining) thick.
- If pregnancy does not occur, the corpus luteum degenerates, causing progesterone and oestrogen levels to decrease.
- Falling levels of oestrogen and progesterone mean that FSH production is no longer inhibited and the anterior pituitary gland begins to secrete FSH again.
- The endometrium breaks down, menstruation takes place and the cycle begins again.

Processes leading to conception

Inside the Fallopian tubes

The Fallopian tubes are lined with cilia. After ovulation the wafting motion of the cilia carry the secondary oocyte into the Fallopian tube and along its length to the uterus.

Follicle cells attached to the secondary oocyte provide a large surface area to make contact with the cilia and enable motion to occur. If fertilisation is to occur, it will usually do so about a third of the way along the Fallopian tube.

Once fertilisation takes place, contractions of the smooth muscle in the walls of the Fallopian tube will push the zygote to the uterus, a process that takes about three days.

Fertilisation

Following **ejaculation**, the sperm are deposited at the top of the vagina close to the cervix. They will then swim by use of their tails through the cervix and up through the uterus to the Fallopian tubes.

The semen contains hormones called prostaglandins, which stimulate the muscles of the uterus and Fallopian tubes to contract and assist sperm movement. If ovulation has occurred recently there will be a secondary oocyte in the Fallopian tube.

The secondary oocyte is surrounded by follicle cells and a membrane called the **zona pellucida**. As sperm cells swim along the Fallopian tubes, the **acrosome** releases proteases to digest a way through the follicle cells and zona pellucida.

Key terms

Ejaculation – the release of semen from the body via the urethra in the penis.

Zona pellucida – the membrane that forms around a secondary oocyte as it develops.

Acrosome – a cap-like structure that covers the front section of the head of the sperm. It contains enzymes to break down the follicle cells and zona pellucida surrounding the oocyte.

Despite millions of sperm cells being released in a single ejaculation, usually only one will penetrate the outer membrane of the secondary oocyte. When this occurs the zona pellucida thickens and separates from the surface to form a barrier to other sperm cells.

At the same time, the secondary oocyte undergoes the second meiotic division to form a mature ovum. The sperm nucleus fuses with the ovum nucleus to produce a diploid zygote (fertilised ovum).

Implantation

After fertilisation, the zygote begins to divide by mitosis and forms a ball of cells termed the blastocyst. The outer layer of cells of the blastocyst are called the trophoblast and it is the layer by which the tiny embryo embeds into the endometrium (implantation).

In a human, it takes about one week from the release of a secondary oocyte to the development into a blastocyst and implant. Implantation will usually begin to take place on day 21 of the menstrual cycle and end on around day 28.

The trophoblast develops into two membranes:

- the chorion, which develops finger-like projections called chorionic villi. These provide an increased surface area for the absorption of nutrients and eventually form the placenta. The chorion produces the hormone **hCG**
- the amnion, which forms the amniotic sac, a fluid filled sac that surrounds the developing foetus.

Key terms

hCG – human chorionic gonadotropin, a hormone produced by the chorion. It prevents the breakdown of the corpus luteum. This ensures that progesterone production continues and FSH production is inhibited.

PAUSE POINT Summarise the main events that take place to enable conception to take place.

Hint Describe the journey of a sperm cell from epididymis to fertilisation.

Extend Find out what an ectopic pregnancy is, how it occurs and what the effects on the mother's health are likely to be.

Assisted conception

In the event of fertility problems, a couple may be offered assisted conception techniques to increase the chance of conceiving a child. These include the following three options.

- Option 1: Intrauterine insemination – sperm are inserted directly into the uterus at the time of ovulation (also artificial insemination).
- Option 2: In vitro fertilisation (IVF) – ova are gathered from the ovary and combined with sperm in a petri-dish in the laboratory.
- Option 3: Donated gametes – donor sperm or ova are used in the intrauterine insemination or IVF procedure.

Hormone replacement therapy has been known to cause ovaries to release eggs in rare cases.

Causes of conception problems

Erectile dysfunction

Erectile dysfunction is the inability to get and maintain an erection. This means that the man is unable to have penetrative sex resulting in infertility. It can be caused by narrowing of blood vessels going to the penis, often associated with high blood pressure and diabetes, hormonal problems or injury. It can also have psychological causes such as anxiety and depression.

Anti-sperm antibodies

Usually sperm and blood do not come into contact with each other as the Sertoli cells form a barrier between the blood and the testes. Occasionally, often due to an infection or injury, this barrier can be broken down and the sperm cells can enter the bloodstream. When this happens, white blood cells detect the sperm as invaders and form anti-bodies to destroy the sperm cells in the same way that they would attack and destroy invading bacteria.

Anti-sperm anti-bodies can affect sperm cells in a number of ways that cause infertility. They can cause sperm to stick together, making them unable to swim through the cervix and uterus. They can cause reactions between the sperm membrane and mucus in the cervix, which immobilises the sperm and prevents them swimming further. Antibodies can also make the sperm unable to bind with the zona pellucida, which prevents fertilisation from taking place.

Menopause

As a woman ages, the quantity and quality of ova produced decline making it harder for her to conceive. Age-related changes to the uterus also make it harder for implantation to occur. The result is a decline in fertility as a woman grows older.

Hypo/hyperthyroidism

Hypothyroidism (underactive thyroid gland) and hyperthyroidism (overactive thyroid gland) can cause infertility in males and females..

In women, hypothyroidism increases the levels of a hormone called prolactin which inhibits FSH production. As a result, ovulation cannot be triggered. Hyperthyroidism causes irregular menstrual cycles making it harder to conceive as well as a thinner uterus lining, making implantation less likely and increasing the chance of miscarriage.

In men, both hypothyroidism and hyperthyroidism can cause erectile dysfunction and lower testosterone, which lowers the sex drive.

Contraception methods

Hormones can be used to prevent pregnancy. There are a range of hormonal methods of contraception. The differences between them include:

- the type of hormone used
- the amount of hormone used
- the way the hormone enters the body.

The hormones used in contraception are progesterone or a combination of progesterone and oestrogen. They can be taken orally, implanted into the body tissue, injected, absorbed from a patch on the skin or placed into the vagina.

Progesterone only contraception

Progestin, a synthetic version of progesterone, is used in progesterone only contraception. Like progesterone, progestin acts on the anterior pituitary gland to inhibit the production of FSH and LH. It also thickens the mucus of the cervix, making it difficult for sperm to pass through into the uterus. In addition, progestin makes the endometrium thinner. This makes it less likely that the trophoblast will implant.

Progesterone only methods of contraception include the mini-pill (oral contraception), the implant and the contraceptive injection.

Oestrogen and progesterone combination contraception

Combination hormonal methods work by acting on the anterior pituitary gland to inhibit the production of FSH and LH. This prevents the development of the Graafian follicle so that ovulation does not occur.

Combination methods of contraception include the combination pill (oral contraception), skin patch and the vaginal ring.

Case study

Kelly Shaw: CASH (Contraception and Sexual Health) Nurse

I've been working as a CASH nurse for 5 years now. When I chose to go into this area of work, we were known as Family Planning nurses. I started my career by training as an Adult nurse and then working on the wards in a busy general hospital. I chose to do additional specialist training in Sexual Health and Contraception after 3 years as a general Adult nurse. No two days of my job are ever the same. I meet a wide range of people from a variety of backgrounds. As well as sound medical knowledge, the role needs good interpersonal skills such as being approachable, non-judgemental and supportive.

Today my work has included meeting with people visiting our walk-in session with a range of requirements, from contraception advice to testing for sexually transmitted infections. I also had to work with colleagues to trace and contact previous partners after people who have tested positive for STI's. In the afternoon, I visited the local sixth-form college to deliver a sexual health workshop to Year 12 students.

As a sixth-form student, I studied the Level 3 BTEC Applied Science course which enabled me to go on to university to study for a degree in Adult Nursing. Studying the structure and functions of the reproductive system provides a sound knowledge base for my work; by understanding the structure I can explain to service-users how and why STI's spread and I can explain how different contraception methods work. This ensures that service users receive the correct advice and treatment to understand and manage their condition.

Check your understanding

1. Why does the role require interpersonal skills such as being approachable, non-judgemental and supportive?
2. Choose one method of contraception. Explain how it works.

Assessment practice 9.3

C.P3 C.M4 C.M3 C.D3

Your local NHS trust has just opened a new fertility clinic in the local area. The clinic will serve a wide cross section of the local community.

The waiting room requires a series of leaflets for its service users to read when they visit the clinic.

Subject areas that need to be covered by the leaflets include the structure and functions of the reproductive systems as well as the importance of hormones in gamete development and the regulation of fertility.

The leaflets need to be descriptive and explanatory. To assist service users with difficult decision making processes, there should be evaluations of methods of promoting and preventing conception.

Plan

- I know what the task is and what I am being asked to do.
- I know how confident I am in my abilities to complete the task. I know any areas I might struggle with.

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain what the task was and how I approached the task.
- I can explain how I would approach the hard elements differently next time (i.e. what I would do differently).

Further reading and resources

Parker, S. (2009). *The Concise Human Body Book*. London: Dorling Kindersley.

Websites

NHS: **www.nhs.uk**
Information about health and body dysfunctions.

Diabetes UK: **www.diabetes.org.uk**
Information about diabetes and its treatment.

Chartered Society of Physiotherapists: **www.csp.org.uk**
Information about working in physiotherapy.

THINK FUTURE

Photo credit: sylv1rob1/Shutterstock.com

Karin Dawson

Physiotherapist

I've been working as a physiotherapist for five years now. I started my career working in a busy general infirmary and now I have my own private practice. I love my work as it involves working with people from a wide range of age groups and backgrounds. For example, this morning I was working with an 8-year-old boy who has Perthes disease and helping him to regain full mobility to his hip following damage to his femur. This afternoon I will be working with a well-known local rugby player, helping him to gain full movement in his left shoulder which was damaged in a tackle during a match.

Studying level 3 anatomy and physiology has helped me enormously with my career – we don't just rub muscles! To be an effective physiotherapist, I need a good understanding of how the body works and of dysfunctions that can occur. This means that I can treat the person holistically and understand the impact of my work on their recovery.

Focusing your skills

Communication skills

As well as a good knowledge of health, anatomy and physiology, a health care worker needs to have good communication skills.

- Do not just hear the message, listen to it. Listening means paying attention to the words that are spoken and also the tone of voice and body language of the person speaking. This gives you a clear message about what the person is saying and meaning.
- Make and maintain eye contact with the person to whom you are speaking.
- Empathise with the person. This means trying to see things from the other person's point of view.
- Ask the person what they would like you to call them. This is especially important with older people, as it shows respect.

How do I check someone's pulse?

You can check a person's pulse by placing two fingers on the inside of their wrist.

- Hold the person's arm out straight and turn it so the palm of their hand faces upwards.
- Place your first finger and middle finger on their wrist just below the thumb.
- Press firmly but not too hard; you should be able to feel a gentle beating sensation.
- If you can't feel the pulse, try moving your fingers slightly or press a little harder.
- Using a clock or a watch, count the number of beats in one minute.
- Alternatively you can count the number of beats in 30 seconds and multiply the number by two.

Getting ready for assessment

Scott is working towards a BTEC National in Applied Sciences. He was given an assignment with the following title 'Assess the role of the nervous system in coordinating the cardiovascular and respiratory systems'. He had to produce a booklet suitable for trainee health care assistants to use. He had to ensure that his booklet included:

- information about the structures in the nervous, cardiovascular and respiratory systems
- information about how the nervous system responds to stimuli
- information about the changes that occur in the cardiovascular and respiratory systems and what causes them
- explanations of how the nervous system coordinates the cardiovascular and respiratory systems.

How I got started

First I collected all my notes on this topic and put them together into a folder. I decided to sort my notes into three sections – the nervous system, the cardiovascular system and the respiratory system. I needed to make sure I included enough work in each section to achieve all the criteria.

I then drew a concept map so that I could see clearly the way that each system worked and I could then add how they are linked in to my concept map. I was then able to see clearly the role that the nervous system played in the control of the systems.

I attended a public lecture about the cardiovascular system at my local FE college.

How I brought it all together

I organised my booklet into three chapters to ensure that my work was in a clear coherent order. In each chapter I included:

- an introduction which included the main organs in each system
- clear annotated diagrams to support the explanations
- an assessment of the role of the nervous system in the coordination of the system.

I ended each chapter with a summary and references for further reading.

What I learned from the experience

I learned the importance of planning and being organised. When writing about the body systems, there are a lot of parts to include and a lot of detail about interactions to include, so its vital that you plan how you are going to present your work so that it makes sense to the reader.

Think about it

- Have you written a plan with timings so you can complete your assignment by the agreed submission date?
- Do you have notes for each of the systems mentioned in the assignment title?
- Is your information written in your own words and referenced clearly where you have used diagrams from text books or the internet?