

Figure 8.4.15: A comparison of spermatogenesis and oogenesis.

	Oogenesis	Spermatogenesis
Similarities	Both begin with production of cells by mitosis	
	In both cells grow before maturation	
	In both two divisions of meiosis produce haploid gametes	
Differences	Usually only one secondary oocyte is produced per menstrual cycle	Millions of sperm cells are produced continuously
	Only one large gamete is produced per meiosis	Four small gametes are produced per meiosis

	Occurs in ovaries which tend to alternate oocyte production	Occurs in testes which both produce sperm cells
	Early stages occur during fetal development	Process begins at puberty
	Ova released at ovulation during the menstrual cycle	Sperm cells released at ejaculation
	Ceases at menopause	Continues throughout an adult male's life

Table 8.4.4: Oogenesis and spermatogenesis compared.

8.4.5 Pregnancy and prenatal development

Approximately 24 hours after fertilisation, the zygote begins to divide by mitosis. Mitosis continues and, after about 5 days of division, it produces ball of around 100 cells known as a blastocyst, as shown in Figure 8.4.16. As these divisions are occurring, the ball of cells is moved down the oviduct towards the uterus. After about 7 days it reaches the uterus and settles in the endometrium lining, where it implants itself and continues to divide and develop into an embryo.

Once the blastocyst has become established in the endometrium, it begins to secrete the hormone human chorionic gonadotropin (hCG). hCG travels in the bloodstream to the ovary, where its role is to maintain the corpus luteum, the mass of cells that developed from the empty follicle. The corpus luteum produces progesterone and estrogen, which in a non-pregnant woman maintain the endometrium until the end of the menstrual cycle, when the corpus luteum degenerates. During pregnancy, it is important that the lining remains in place. hCG stimulates the corpus luteum so that it grows and continues to produce its hormones for the first 3 months (the first trimester) of pregnancy. Thereafter, the placenta is fully formed and produces placental progesterone and estrogen, so the corpus luteum degenerates.

The embryo grows and develops. After about 1 month, the embryo is only 5 mm long but has a beating heart and the beginnings of a nervous system. From 2 months onwards it is known as a fetus. The fetus at this stage is 30–40 mm long and has recognisable limbs with developing bones. The uterus lining

provides nourishment for the early embryo but the placenta soon forms from the endometrium and fetal membranes and by about 12 weeks it is fully functioning. The fetus is connected to the placenta by the umbilical cord and is surrounded by a fluid-filled sac called the amnion, which contains amniotic fluid. The fetus is supported in this fluid throughout its development and is protected by it from bumps and knocks, as the fluid is an effective shock absorber. Amniotic fluid also enables the growing fetus to move and develop its muscles and skeleton. A human fetus will grow and develop for 40 weeks, or approximately 9 months, before it is born. This time between conception and birth is known as the gestation period.

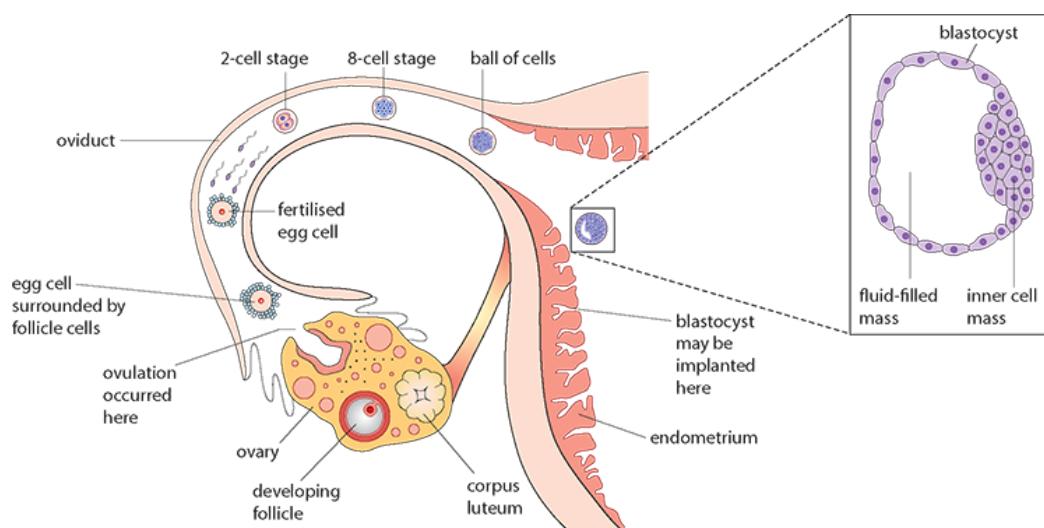
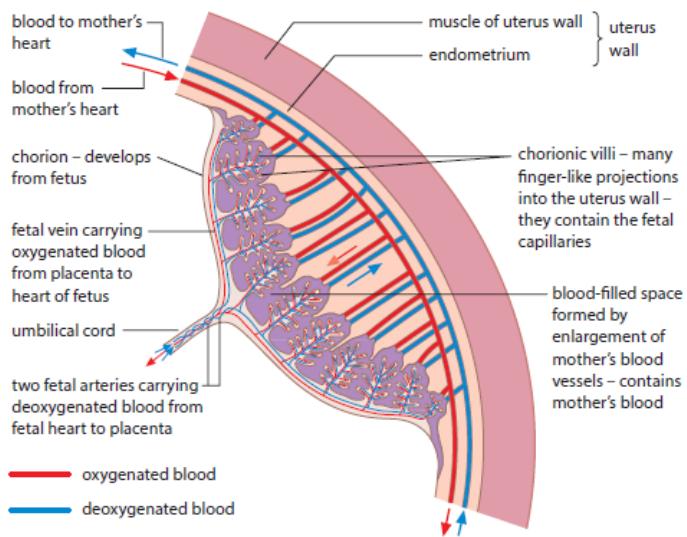
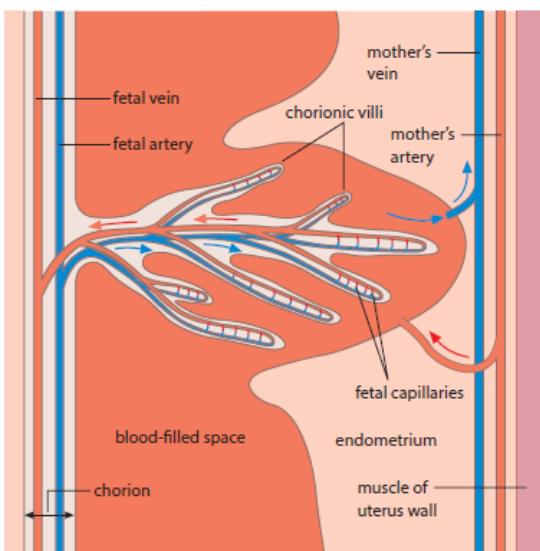


Figure 8.4.16: The blastocyst consists of an outer layer of cells enclosing an inner cell mass and a fluid-filled space. The outer layer forms part of the placenta and the inner cell mass develops to become the body of the embryo.

Placenta, showing chorionic villi and fetal and maternal blood supplies



Detail of chorionic villi showing capillaries



Fetus in the uterus, showing placenta and umbilical cord

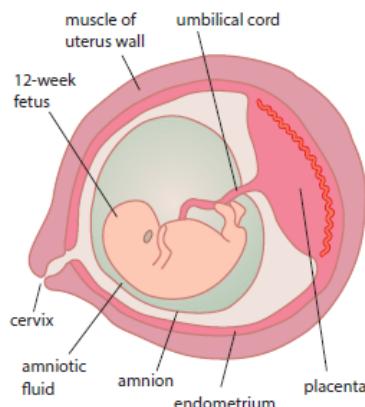


Figure 8.4.17: The position and structure of the placenta.

KEY POINTS

blastocyst ball of approximately 100 cells formed from the fertilised ovum.

fetus an unborn offspring that develops from an embryo; a developing human baby about 2 months after fertilisation.

human chorionic gonadotropin (hCG) hormone secreted by the uterus lining to maintain the early pregnancy.

placenta structure in the uterus formed of maternal and fetal tissue that provides oxygen and nutrients to and removes waste products from a developing fetus.

Pregnancy testing

hCG is excreted in the urine of a pregnant woman and it is this hormone that is detected in a home pregnancy test. Test kits contain monoclonal antibodies that bind to the hCG proteins. Kits produce a result as a colour change or other result that can be seen in just a few minutes.

The placenta

The developing fetus depends on its mother for all its nutrients and oxygen and for the disposal of its waste carbon dioxide and urea. The **placenta** allows these materials to be exchanged between the mother and the fetus and also acts as an endocrine gland, producing estrogen, progesterone and other hormones that maintain the pregnancy.

The placenta is a disc-shaped structure, about 180 mm in diameter and weighing about 1 kg when it is fully developed. It is made up of the maternal endometrium and small projections, or villi, from the outer layers of the **chorion**, which surrounds the embryo. These **chorionic villi**, which are rich in capillaries, grow out into the endometrium to produce a very large surface area for the exchange of gases and other materials (Figure 8.4.17). Fetal blood remains inside these capillaries, which penetrate the endometrium tissue until they are surrounded by maternal blood flowing into blood sinuses (spaces) around them.

In this way, the mother's blood is brought as close as possible to the fetal blood to allow for efficient diffusion without the two ever mixing.

Nutrients and oxygen from the mother's blood diffuse into the fetal capillaries and are carried to the fetus in a single umbilical vein. Waste products and carbon dioxide are carried to the placenta in the two umbilical arteries and diffuse into the mother's blood.

Many materials pass to the fetus from its mother. Some of these – such as drugs (both prescription and illegal), nicotine and alcohol – have the potential to seriously harm the fetus, which is why pregnant people are encouraged not to smoke or drink alcohol during pregnancy and to be careful with any medicines they may take.

8.4.6 Feedback mechanisms in the menstrual cycle and birth

Positive and negative feedback are both important in controlling the menstrual cycle and also the processes of birth.

Negative feedback is the most common type of feedback in living systems. In most cases the body will try to maintain a stable internal state. For example, negative feedback is important in maintaining blood sugar and body temperature at the correct levels to ensure the body functions properly ([Section 8.5](#)).

During most of the menstrual cycle, the hormones estrogen and progesterone influence, or feed back to, the pituitary gland and regulate the levels of FSH and LH that are released. But during days 12–14 of the cycle a greater amount of these hormones is required to stimulate ovulation (the release of the egg from the ovary), so at this time estrogen has a positive feedback influence on the pituitary gland, so that more LH and FSH are released to stimulate the ovary ([Figure 8.4.18](#)). Positive feedback increases the deviation from the stable, steady state to produce a reaction, in this case ovulation.

In mammals, birth is mediated by a positive feedback relationship between the hormone oxytocin from the pituitary gland and contraction of the uterus. After about 9 months in humans, as the end of pregnancy approaches, the levels of progesterone and estrogen produced by the placenta fall ([Figure 8.4.19](#)) and this signals the onset of the uterine contractions known as labour. At this time, the endometrium secretes a group of hormones known as prostaglandins, which initiate the contraction of the uterus. Stretch receptors in the cervix then stimulate the hypothalamus, which triggers the release of the

hormone oxytocin, secreted by the posterior lobe of the pituitary gland in the brain. Oxytocin stimulates the uterus muscles to continue their contractions. At first, the contractions are mild and infrequent but oxytocin is a hormone that is controlled by positive feedback. A small contraction of the uterus muscle stimulates the release of further oxytocin, which in turn stimulates more and stronger contractions. As the uterus contracts, the cervix widens and the amniotic sac breaks, releasing the amniotic fluid. Contractions continue for several hours and the baby is pushed through the cervix and out of the mother's body down the vagina. Gentle contractions continue until the placenta, now known as the afterbirth, is also expelled from the uterus.

KEY POINT

negative feedback occurs when a deviation from the normal level is detected and corrective mechanisms in the body act to return the system to normal. Many homeostatic mechanisms, such as the control of body temperature, work by negative feedback.

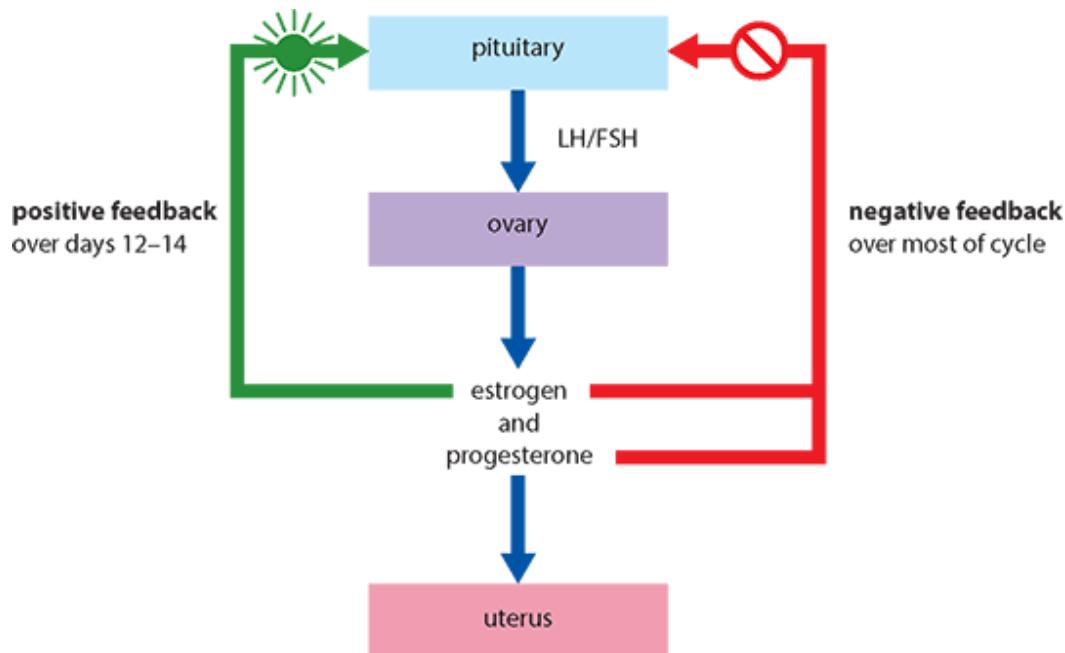


Figure 8.4.18: Negative and positive feedback in the menstrual cycle.

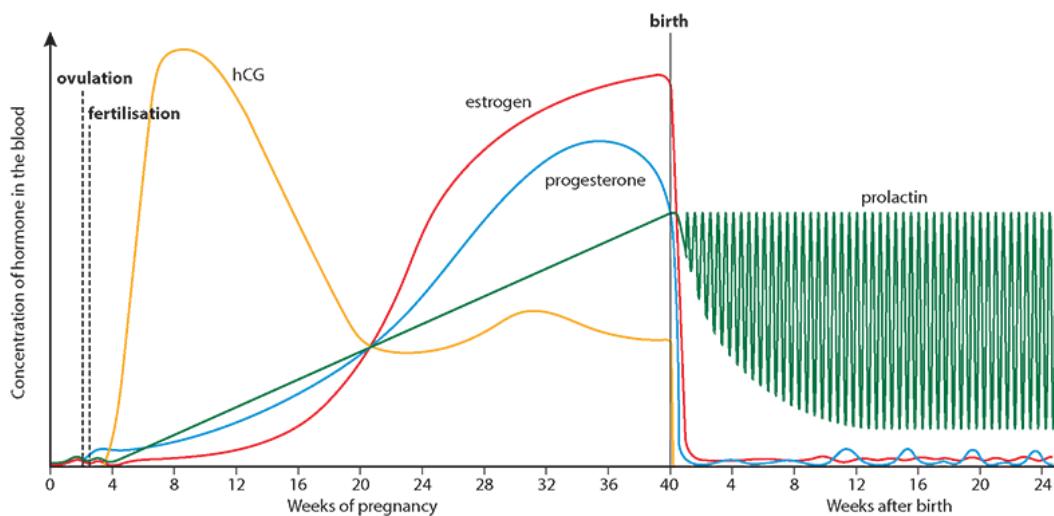


Figure 8.4.19: Changes in the levels of hormones during pregnancy and after the birth.

KEY POINTS

oxytocin hormone released by the pituitary gland in the brain that stimulates contraction of the uterus at birth.

positive feedback occurs when a deviation from the normal level in a system causes the change to increase, so that a reaction is amplified to make it stronger or occur more quickly; for example the contractions of the uterus during the birth of a baby. Positive feedback mechanisms are unusual in living organisms.

prolactin hormone stimulates milk production by the mammary glands.

After birth, blood levels of the hormone prolactin, from the anterior pituitary gland, increase. This hormone stimulates milk production by the mammary glands. As a baby suckles, prolactin secretion is maintained and oxytocin is also released from the posterior pituitary gland. Oxytocin causes milk to be released from milk ducts. This is another example of a positive feedback system. The more milk a baby drinks, the more prolactin is produced and thus more milk is produced. When a baby is weaned and stops suckling, milk, prolactin and oxytocin production cease.

NATURE OF SCIENCE

Hormone replacement therapy (HRT) - risks and benefits

Hormone replacement therapy is a treatment to relieve the symptoms of the menopause, the time when a woman's hormone levels decline and she stops menstruating. HRT replaces hormones that are at a lower level at the menopause. Some treatments contain combinations of estrogen and progesterone, others are estrogen only. HRT not only helps

with menopausal symptoms such as hot flushes but also helps prevent the thinning of the bones (osteoporosis) that is much more common after the menopause.

Early epidemiological studies published over the last 15 years suggested that HRT led to a reduced risk of coronary heart disease (CHD) and this was thought to be a cause and effect relationship. But later studies using randomised, controlled samples show that HRT actually leads to a slight but not significant increase in CHD and is not a cause and effect relationship. Most people who use HRT are in a higher socioeconomic group and this status does have a causal relationship with lower CHD risk. Recent evidence says that risks of CHD and strokes are small and are usually outweighed by benefits especially if treatment begins before 60 years of age.

SCIENCE IN CONTEXT

Diagnosing genetic diseases and congenital disorders before and after birth

Several genetic diseases can be diagnosed while a baby is still in the womb, so that parents will be aware of any conditions their child will have when it is born.

Amniocentesis is one of a number of techniques used in prenatal testing to check human fetuses for abnormalities. A fine needle is inserted through the mother's abdomen into the amniotic sac and a small sample of amniotic fluid is taken. The fluid contains fetal cells, which can be cultured for 3–4 weeks until the cells divide and chromosomes become visible. The chromosomes are stained to produce a karyogram (Section 4.5), which can be checked for mutations.

Karyograms can also be carried out after birth using cells from a child or adult (Section 4.5).

An alternative procedure, which can be done earlier in the pregnancy, is chorionic villus sampling (CVS). In this case, a sample of cells is taken for examination from the chorionic villi, via the cervix. More fetal cells are obtained in this way and the results are produced more quickly. However, CVS does have a greater risk of inducing a miscarriage than amniocentesis. Analysis of fetal genetic material can enable doctors to detect conditions including cystic fibrosis, Duchenne muscular dystrophy, sickle cell disease, Tay–Sachs disease and thalassemia.

Ultrasound scans that take place at several stages during pregnancy check that a baby is developing normally, but a scan can also reveal conditions such as spina bifida, heart defects and cleft palate if, for example, heart or kidney abnormalities or spinal problems are seen (Figure 8.4.20).

Ultrasound waves pass through body tissues and when they bounce back from different structures, they create echoes that are turned into a moving image of the developing baby. The image is displayed on a monitor while the scan is carried out.

As well as amniocentesis and ultrasound scans, pregnant people may also be offered a blood test, the maternal serum alpha-fetoprotein (MSAFP) test, between the 15th and 20th weeks of their pregnancy. The MSAFP test measures the level of alpha-fetoprotein, a protein produced by the fetus, in the mother's blood. If levels are not normal it may indicate the possibility of Down syndrome or a neural tube defect such as spina bifida, which can then be confirmed by ultrasound or amniocentesis.

After a baby is born it can also be given a heel prick test. This involves taking a tiny sample of blood from the baby's heel. The blood is checked for inherited conditions including sickle cell disease, cystic fibrosis and phenylketonuria (an inability to break down the amino acid phenylalanine) and hypothyroidism (shortage of the hormone thyroxine). If these conditions are diagnosed early in the child's life they are easier to treat before serious problems arise.



Figure 8.4.20: An ultrasound probe produces high-frequency sound waves.

To consider:

- 1 Discuss the advantages and disadvantages of prenatal screening.
- 2 Should parents always be told about the gender of their unborn child?

TEST YOUR UNDERSTANDING

- 26** Outline the difference between positive and negative feedback in a living organism.
- 27** What is the role of hCG in early pregnancy?
- 28** Name two maternal hormones whose levels fall at birth and one whose level rises.

8.4.7 Sexual reproduction in plants

Angiosperms (flowering plants) produce haploid gametes in the male and female parts of their flowers (Figure 8.4.21), but the dominant generation of an angiosperm lifecycle is diploid.

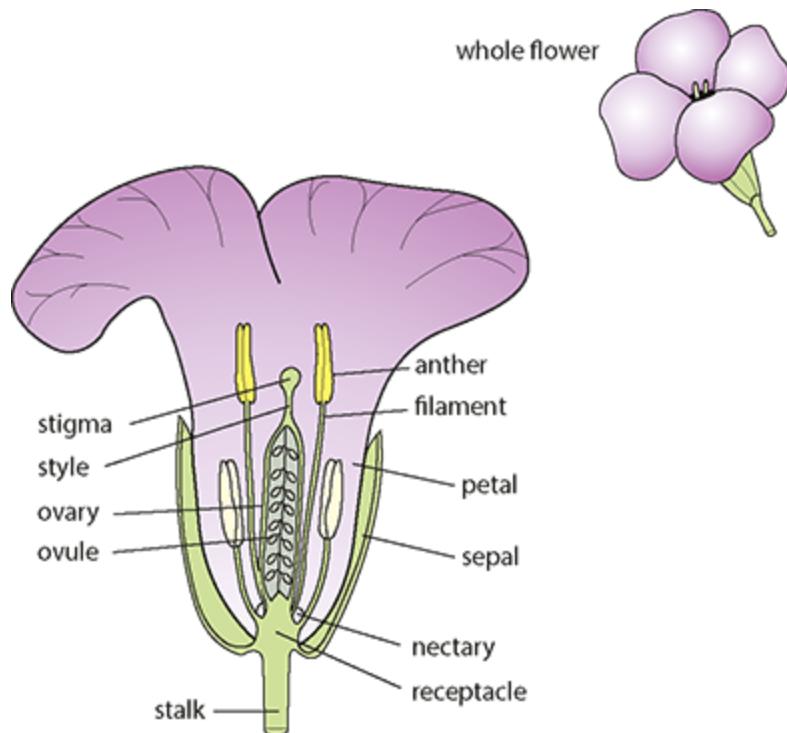


Figure 8.4.21: Half-flower of wallflower (*Cheiranthus cheiri*). The flower is about 2.5 cm in diameter. It is pollinated by bees and hoverflies. Its petals are usually brightly coloured and fragrant.

Male gametes are produced in anthers inside pollen sacs. Pollen grains are not independently mobile and must be carried by the wind or by an insect, bird or other animal to the female parts of a plant before fertilisation can take place. Female gametes are produced in the ovary.

Plants have adaptations to ensure that their pollen is transmitted to the female gametes (refer to Table 8.4.4). Petals of animal-pollinated flowers are often brightly coloured to attract insects or other animals that may visit. Many have nectar guides, which are markings on the petals that tempt pollinators deep into the flower.

Pollen, containing the male gametes, is produced in the anthers, which are held up on long filaments in many flowers, so that as pollinators enter they brush past the anthers and are dusted with pollen.

The female organs are the stigma, style and ovary. The stigma receives pollen grains, which arrive with pollinators as they delve into a flower to obtain nectar. The sticky stigma has sugars present on its surface that cause pollen grains to germinate.

Pollination and fertilisation

Pollination is the transfer of pollen from the anther to the stigma. Pollination occurs when pollen grains land on the stigma. Wind-pollinated plants rely on gusts of wind to transfer their pollen and are structurally different from animal-pollinated plants. They must produce a large amount of pollen because much of it is wasted and does not reach the stigma of another plant. It may be carried in the wrong direction or fall to the ground if there is no wind. Animal-pollinated plants must attract their animal pollinators to their flowers when the anthers are producing pollen. They have features such as scent, colour or a reward of nectar that make them attractive to their pollinators. Some of the differences between wind- and animal-pollinated flowers are summarised in Table 8.4.5.

Feature	Wind-pollinated	Animal-pollinated plant
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	plant	
petals	small, inconspicuous	large and colourful, may be arranged to form a landing platform for visiting insects, or a tube for small birds
odour	not present	attracts specific pollinators, <i>e.g.</i> rotting smell attracts blow flies
nectar	not present	nectar produced inside the petals ensures pollinators partly enter the flower
stamens and pollen grains	long feathery stamens produce large amounts of light pollen	enclosed stamens produce sticky pollen grains
stigma	hang outside the flower and are often feathery to catch pollen	enclosed in the flower with a flat, sticky stigma

Table 8.4.5: Comparison of the features of wind- and animal-pollinated flowers.

If pollen travels from the anther of one plant to the stigma of another plant, the process is known as cross-pollination. If pollen is deposited on the stigma of the same plant that produced it, self-pollination occurs. Self-pollination produces less genetic variation than cross-pollination and different plants have different strategies to prevent it.

Preventing self-pollination

- 1 Many plants have **self-incompatibility** mechanisms to prevent inbreeding and increases genetic variation. If pollen grains from a plant land on the stigma of the same plant, or another plant with a very similar genetic make-up or genotype, incompatibility mechanisms prevent fertilisation. The germination of pollen may be prevented, or pollen-tube growth may be blocked, so that fertilisation and embryo development is prevented and no seeds are produced.
- 2 Other plants time the release of their pollen and the maturation of their stigmas so that they are not mature at the same time in the same flower. When pollen is released, the stigma will not be receptive so pollen will not stick to its own flower.
- 3 Some plants have separate male and female flowers, or male and female flowers on separate plants. Dioecious plants such as holly, papaya and kiwi have their male and female flowers on separate plants. Monoecious plants have separate male and female flowers on the same plant. Examples include squash and cucumber.
- 4 In some flowers, the positions of the stamens and stigmas prevent self pollination. The stamens are situated below the stigma and ovary so that pollen does not fall on its own flower. Examples include flowers of tulips, antirrhinum and tomato plants.

KEY POINTS

pollination the transfer of pollen from the anther to the stigma of a flower.

cross-pollination the transfer of pollen from the anther of one flower to the stigma of another flower on a different plant of

the same species.

dicotyledonous a plant that has a seed that contains two embryonic leaves or cotyledons.

incompatibility mechanisms methods used by a plant to reject pollen from the same plant or one that is genetically closely related.

self-pollination the transfer of pollen from the anther to the stigma of the same flower, or another flower on the same plant.

Most flowering plants use a mutualistic relationship with a pollinator to enable them to reproduce. Both the plant and pollinator benefit in this type of relationship. For example, a bee that visits a flower benefits by receiving food in the form of nectar, while the flower benefits as it receives pollen to fertilise its ovules. The pollen is carried on the bee's body from flowers it has already visited.

Fertilisation occurs when male and female gametes fuse to form a zygote. This occurs in the ovule of the flower. When pollen grains from a plant of the right species arrive on the stigma, they germinate and each produce a **pollen tube**, which grows down the style to the ovary (Figure 8.4.22). The tube enters the ovary and a pollen nucleus passes down the tube to fuse with and fertilise the nucleus of the female gamete in the ovule.

Seed structure and dispersal

Fertilised ovules develop over time into seeds, which protect the developing embryo inside. Seeds are held within a seedpod, fruit or nut, which can be dispersed to new locations so that when they

germinate the new plants that develop do not compete with their parents.

Seeds of flowering and non-flowering plants have all the necessary components to ensure successful germination and the growth of a new plant. Within every seed is an embryo root and shoot, ready to develop when the time is right. Once a seed has been formed in the ovary, it loses water so that it can enter a dormant phase and not develop further until conditions for growth are favourable.

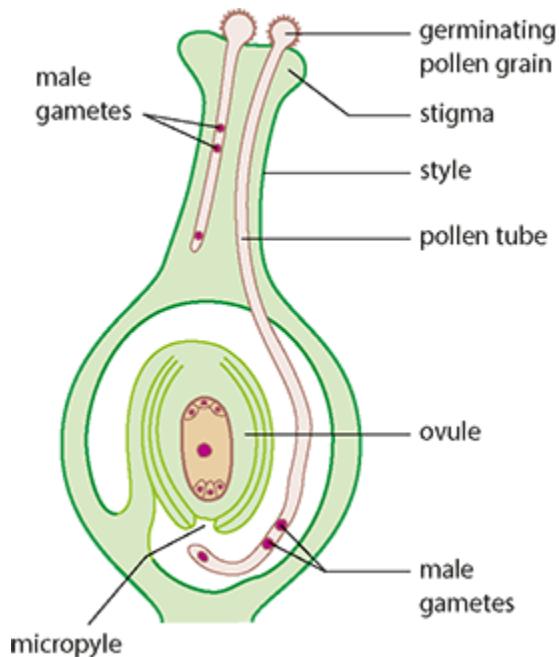


Figure 8.4.22: Fertilisation of an ovule in the ovary of a plant.

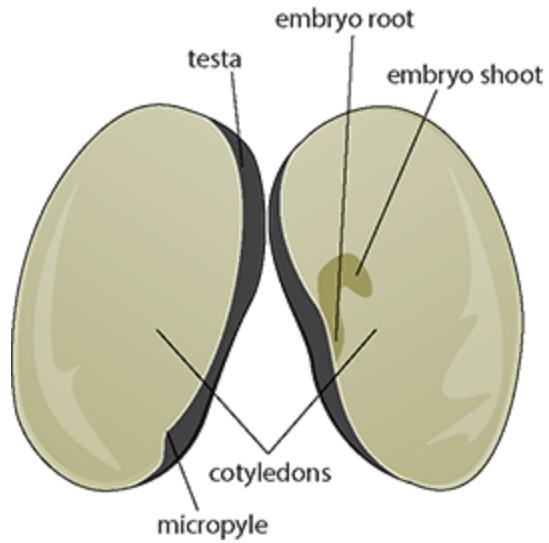


Figure 8.4.23: Two halves of a broad bean seed showing the main parts of a dicotyledonous plant.



Figure 8.4.24: Dandelion seeds can be dispersed over long distances by the wind.



Figure 8.4.25: Squirrels carry away acorns from oak trees and bury them in the ground.

Most plants have mechanism to ensure that they are dispersed at some distance from their parent plant. This reduces competition between parent and seedlings and prevents overcrowding of plants. Most seeds are dispersed by the wind or animals. Wind dispersed seeds have wings or parachutes to help them travel Fig 8.4.24. Animals may carry seeds away stuck to their fur, while some animals eat seeds but cannot digest them so they are deposited in faces some distance away. Squirrels carry nuts away and bury them to eat later but some are forgotten and are left to germinate. Fig 8.4.25.

One group of plants, the **dicotyledonous** plants have two embryonic seed leaves, or cotyledons, inside their seeds. These cotyledons store the food reserves needed for germination (Figure 8.4.23). Other plants such as grasses, bamboo and corn have only one cotyledon. The cotyledons are surrounded by a

hard protective seed coat called the testa. Many seeds have to endure quite harsh environmental conditions, so the testa protects the delicate tissues inside. In the wall of the testa is a pore called the micropyle through which water is absorbed to begin the process of germination.

Germination

Germination is the development of the seed into a new plant (Figure 8.4.26). A dormant seed needs three vital factors to be in place for germination to occur.

Temperature: A suitable temperature is essential for the enzymes in a seed to become active. They cannot work in cold conditions, and very high temperatures also inhibit their activity. Many seeds remain dormant until the temperature is at a particular level so that they germinate when the seedling will have the best chance of survival.

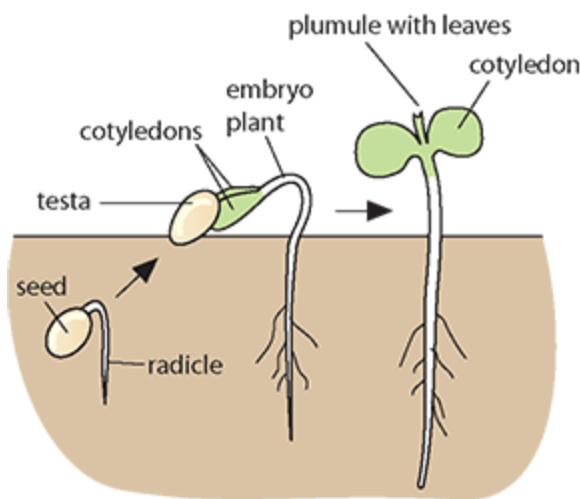


Figure 8.4.26: Germination and early growth in a dicotyledonous plant.

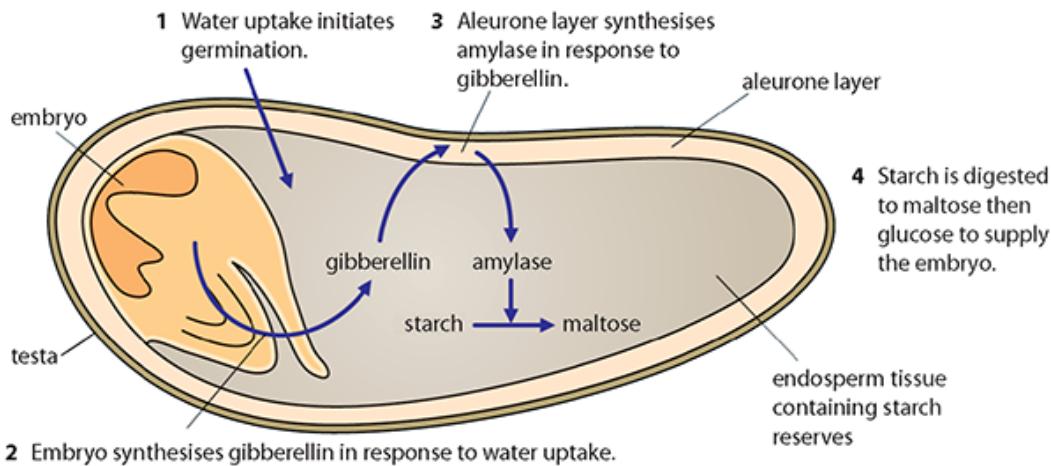


Figure 8.4.27: Longitudinal section through a barley seed, showing how secretion of gibberellin by the embryo results in the mobilisation of starch reserves during germination.

Water: Most seeds contain only about 10% water, so water must be taken in to start the germination process. Water rehydrates the seed and the enzymes contained within it. The enzymes break down food stores to provide energy for the emerging root and stem.

Oxygen: This is essential to provide energy for aerobic respiration.

Germination begins as water is absorbed by the seed in a process known as **imbibition**. Water enters through the micropyle of the testa.

Water rehydrates stored food reserves in the seed and, in a starchy seed such as a barley grain, it triggers the embryo plant to release a plant growth hormone called **gibberellin** (Figure 8.4.27). The gibberellin in turn stimulates the synthesis of **amylase** by the cells in the outer **aleurone layer** of the seed. The amylase hydrolyses starch molecules in the **endosperm** (food store), converting them to soluble maltose molecules. These are

converted to glucose and are transported to the embryo, providing a source of carbohydrate that can be respiration to provide energy as the **radicle** (embryo root) and **plumule** (embryo shoot) begin to grow, or used to produce other materials needed for growth, such as cellulose.

Absorption of water by the seed splits the testa, so that the radicle and plumule can emerge and grow. When the leaves of the seedling have grown above ground, they can begin to photosynthesise and take over from the food store in the seed in supplying the needs of the growing plant.

Seeds contain the embryo plant and energy reserves to fuel germination. Once the seed has grown, the plant's reproductive cycle is complete.

TEST YOUR UNDERSTANDING

- 29** Name the female reproductive structures of an angiosperm (a flowering plant).
- 30** What is the advantage to a plant of a self-incompatibility mechanism?

REFLECTION

How well do I contribute to discussions about ethical issues that arise as a result of studying this topic?

Link

How do relationships between different species help in the reproductive strategies of some organisms? (Chapter 12)

8.5 Homeostasis

LEARNING OBJECTIVES

In this section you will:

- define homeostasis as the maintenance of a constant internal environment
- learn that temperature, blood pH and blood glucose levels are all maintained within certain limits
- recognise that feedback mechanisms allow organisms to detect, process and respond to changes to regulate internal conditions. Both nervous and hormonal control is used in feedback systems
- recognise that negative feedback returns a condition to the normal level but positive feedback make changes away from the normal
- understand the methods used by the human body to regulate body temperature

- understand the role of the kidney in osmoregulation and excretion
- recognise the functions of the glomerulus, Bowman's capsule, and loop of Henle in excretion and osmoregulation
- recall that, in animals, excess carbon dioxide leads to an increase in respiratory rate

- recall that, in plants, carbon dioxide and oxygen are regulated at the stomata
- recognise that low blood pressure is controlled by epinephrine
- learn that many diseases such as diabetes are a result of failed homeostasis.

GUIDING QUESTIONS

- How do organisms maintain constant internal conditions?
- How are changes to the external environment detected?
- How essential is homeostasis for survival?

8.5.1 Homeostasis

The internal environment of the bodies of most animals remains constant, within certain limits, despite changes that occur in the external environment. The control process that maintains conditions within these limits is known as homeostasis. The factors that are controlled include water balance, blood glucose concentration, blood pH, carbon dioxide concentration and body temperature. Each of these has a ‘normal’ or set point, although they may vary slightly above or below it. Both the nervous system and the endocrine system are involved in homeostasis. The **endocrine system** consists of ductless endocrine glands, which release different hormones (Figure 8.5.1). **Hormones** circulate in the bloodstream but each one is a chemical messenger that only affects the metabolism of specific target cells.

Feedback mechanisms

Feedback mechanisms allow organisms to regulate internal conditions and maintain equilibrium in response to changes in their surroundings or in their bodies. Any feedback system has three components:

- 1 receptors that detect a change from a normal set point
- 2 processing the information by a control centre, for example the brain
- 3 response to the change by effectors that receive signals from the control centre to return the system to the normal level (set point) or, in the case of positive feedback, to increase the deviation from the set point.

A feedback loop such as the one that regulates body temperature is a typical example of negative feedback. During temperature regulation, temperature receptors in the skin detect any changes and communicate information to the brain (the control centre) that processes the information and sends messages to the effectors, which are the blood vessels and sweat glands in the skin. These adjustments are made continuously to keep body temperature at the set point of 37 °C as the internal and external environment changes. Another example of a feedback loop is the regulation of blood glucose, shown in Figure 8.5.2 and discussed in detail in [section 7.3.2](#).

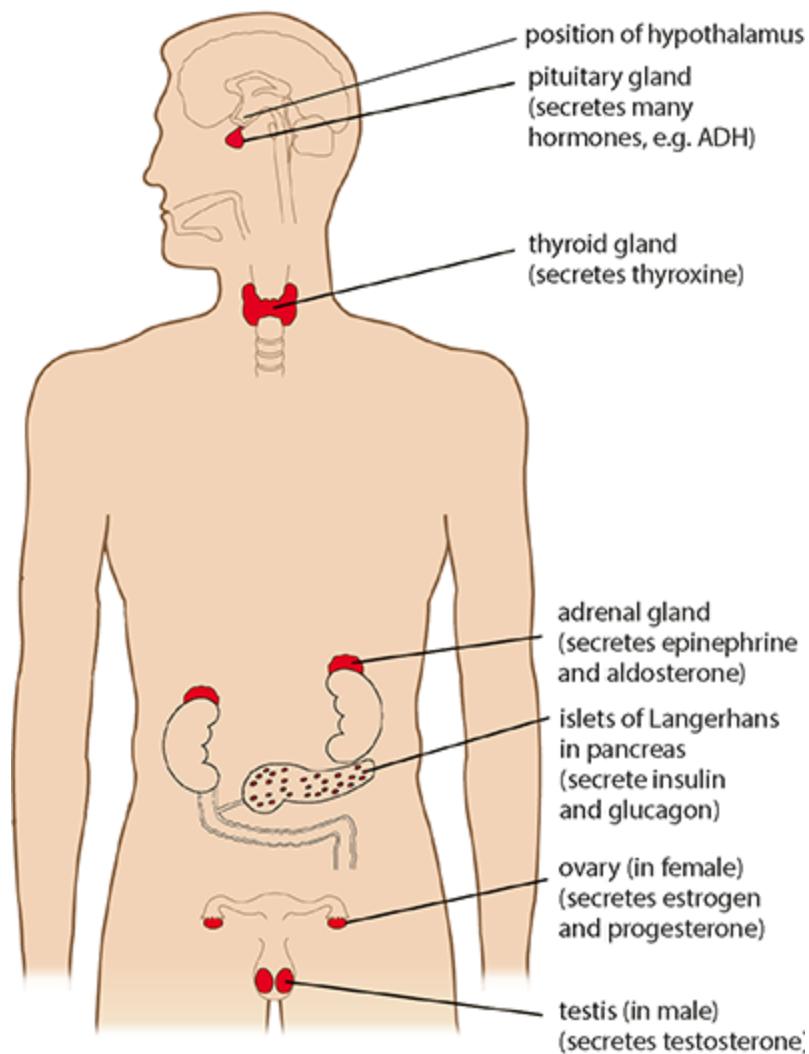


Figure 8.5.1: The positions of some endocrine glands in the human body. Endocrine glands have no ducts and secrete hormones directly into the bloodstream, which carries them to target cells.

KEY POINTS

endotherm animals that maintain a constant body temperature, independent of the environment.

homeostasis maintenance of internal environment of the body within constant limits, independent of the external conditions.

thermoregulation the ability to keep body temperature within certain limits when the surrounding temperature is different.

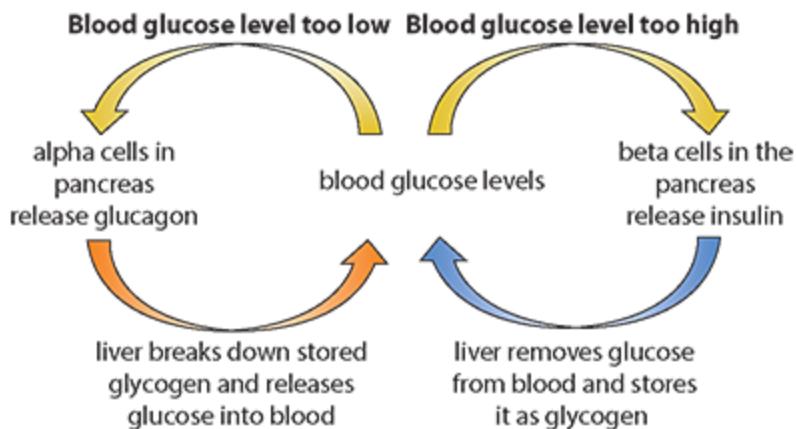


Figure 8.5.2: Control of blood glucose levels is achieved by negative feedback. Insulin produced by beta cells, and glucagon produced by alpha cells, of the islets of Langerhans control the storage or release of glycogen in the liver to keep blood glucose levels constant.

Positive feedback is less common in biological systems. One example of a positive feedback system is the one that controls the

contractions of the uterus when a baby mammal is born ([Section 8.4](#)). In this case there is a positive feedback relationship between the hormone oxytocin from the pituitary gland and contraction of the uterus. When a baby is large enough and ready to be born it creates pressure on the cervix (the neck of the uterus). Stretch receptors in the cervix stimulate the hypothalamus and this triggers the release of the hormone oxytocin from the pituitary gland. Oxytocin stimulates the uterus muscles so that they contract. At first, the contractions are mild and infrequent, but a small contraction of the uterus muscle stimulates the release of more oxytocin, which in turn stimulates more and stronger contractions. This cycle continues until the baby is born and contractions and oxytocin release cease.

Thermoregulation: control of body temperature

Endotherms can maintain a constant body temperature by both physiological and behavioural means. This is known as thermoregulation. In humans, body temperature is monitored and controlled by the hypothalamus in the brain. The ‘set point’ for human body temperature is 37 °C, which is optimum for the efficient functioning of the body’s enzymes and cell processes. The hypothalamus responds to nerve impulses from receptors in the skin and also to changes in the body’s core temperature. If body temperature fluctuates above or below the set point, the hypothalamus coordinates responses to bring it back to normal (Table 8.5.2). Body temperature can also be influenced by the hormone thyroxin which influences metabolism and how much blood vessels dilate and thus affects how much heat can be lost from the body. Cold temperatures also activate brown adipose (fat) tissue which breaks down blood sugar and fat molecules to create heat and help maintain body temperature. This is an example of negative feedback. Nerve messages are carried from

the hypothalamus to organs that bring about warming or cooling of the body. Table 8.5.1 lists some of the body's responses to changes in temperature.

	Responses to a rise in body temperature	Responses to a fall in body temperature
Arterioles in the skin	dilate (widen) so that more blood flows to skin capillaries and excess heat is lost from the skin, a process called vasodilation	narrow to restrict flow of warm blood to the skin capillaries: heat is retained in the body, a process called vasoconstriction
Sweat glands	produce more sweat, which evaporates from the skin surface to cool it	cease production of sweat
Muscles	remain relaxed	muscular activity such as shivering generates heat
Metabolic rate	may decrease to minimise heat production	thyroxin increases metabolic rate
Hair in the skin	hairs lie flat to reduce layer of insulation	hairs stand erect and create an insulating layer between skin and the air

Table 8.5.1: The body's responses to changes in core temperature.

Most mammals can sweat and use vasodilation (widening of the small blood vessels in the skin) to cool their bodies but there are many different behavioural strategies among different species that also assist in maintaining a constant temperature. Some animals, such as the jerboa, a desert rodent found throughout the Arabian Peninsula and northern Africa, live in burrows to avoid the heat of the day, only emerging when temperatures are cooler at night.

KEY POINTS

hypothalamus small area of the brain above the pituitary gland that releases neurohormones to stimulate or inhibit the pituitary gland and link the nervous and endocrine systems.

receptor an organ that senses changes in the environment and sends a signal to a control centre, usually the brain, which generates a response.

Most birds have a body temperature of 40 °C, higher than the set point of mammals, and many birds are able to withstand higher temperatures if they are exposed to the heat of the sun. In warm climates, many birds roost out in the open where they are exposed to high temperatures for long periods. They avoid becoming overheated by using evaporation to cool their bodies. These birds dissipate heat by gular fluttering (Figure 8.5.3). They open their beaks and increase the blood flow to the tissues of their mouth, then vibrate the moist gular (throat) area rapidly.

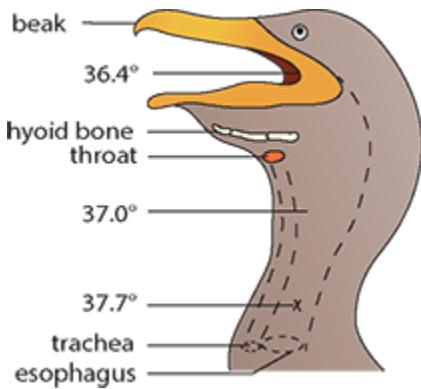


Figure 8.5.3: Gular fluttering can reduce a bird's temperature as water evaporates from the throat.

Camels also withstand extremely high temperatures in their desert habitats but they are still able to store fat that many other animals use as an insulating layer to keep them warm. Camels do this by storing fat in one place: in their humps. This uneven distribution of fat enables them to retain a store of energy that does not enclose and insulate their body against heat loss.

Elephants use a different strategy to keep cool; their large ears have a huge surface area through which heat can be lost. Their ears are very thin and have rich supply of blood brings heat to the surface efficiently. Large ears can also act as cooling fans.

Another strategy involves losing heat by evaporation from moist surfaces. Animals such as dogs pant with their mouths open and tongues out when they are hot, to increase this evaporation.

In cold climates animals must work to conserve heat and protect themselves from the cold. Warm blood is retained inside the body as small blood vessels in the skin become narrower and restrict flow to the surface. This is known as vasoconstriction. Avoiding the cold can also help. Animals, such as the arctic hare, burrow under the snow where they are protected from strong winds and insulated from the cold. Humans wear clothes to keep

warm but birds grow soft thick layers of down feathers close to their skin to provide an insulating layer to their bodies. Feathers can be fluffed up to trap a layer of air between the bird's body and cold outside air. Mammals, such as snow leopards and polar bears, grow thick coats of fur that have the same role. Aquatic mammals such as seals and whales that live in cold oceans have thick layers of fat called blubber that enclose and insulate their bodies against the freezing water.

Mammals have a high metabolic rate, which helps to keep their body temperatures constant. However, it means that many mammals need a way of reducing their energy expenditure in cold winter months. Smaller mammals, such as bats and mice, have a large surface area to volume ratio and lose heat very quickly. This makes them especially vulnerable to cold weather so that they may need to adjust their behaviour and metabolism. One way in which small mammals overcome the problem of heat loss is to become less active. Some mammals let their body temperatures fall, either by going into hibernation or by entering a state of torpor. Torpor involves a short-term drop in body temperature that reduces the animal's metabolism whereas hibernation is a much longer period of inactivity.

EXAM TIP

Make sure that you are able to distinguish between physiological and behavioural methods that animals use to maintain their body temperatures.

Melatonin and control of circadian rhythms

Melatonin is a hormone produced by the pineal gland, a pea-sized gland located just above the middle of the brain. One of the key influences of melatonin is to maintain the body's circadian

rhythms and especially sleep–wake cycles. A vital factor in human sleep regulation is the exposure to light or darkness. Exposure to light stimulates a nerve pathway from the retina in the eye to the hypothalamus. Cells in the hypothalamus (the supra-chiasmatic nucleus, SCN) send signals to parts of the brain that control hormones, body temperature and other functions that have a role in our feelings of sleep or wakefulness. The SCN produces a signal that can keep the body on an approximately 24-hour cycle of activity. But the ‘internal clock’ is not exactly set to 24 hours and environmental clues, the most important of which is light, are needed to reset the clock each morning and keep a person in step with their external environment.

During the day the pineal gland is inactive, but during the hours of darkness, it is ‘turned on’ by the SCN and begins to produce melatonin, which is released into the blood. Rising levels of melatonin cause our feelings of sleepiness. The level of melatonin remains high for about 12 hours until the following morning when light causes it fall to a minimal level in the blood.

Even if the pineal gland is stimulated, it will not produce melatonin unless a person is in a dimly lit environment – even artificial indoor lighting can be bright enough to prevent the release of melatonin. The amount of melatonin released at night also varies between individuals, but on average children secrete more melatonin than adults.

Jet lag

Jet lag is caused by the disruption of the body’s day–night (circadian) rhythms caused by long-distance travel and arrival in a new time zone. These rhythms indicate the right times for eating and sleeping, and also regulate hormone production. After a long journey the day–night patterns may no longer correspond

to the new environment or time zone and some people need many days to adjust.

Jet lag upsets the body clock because the expected patterns of light and darkness are out of alignment. Light is the strongest stimulus for the sleep–wake pattern so jet lag can be controlled by avoiding bright light so that the body clock is reset. Melatonin tablets are sometimes used to adjust a person’s body clock but the effectiveness of these treatments is not proven. The effect of melatonin may be very short term and the correct doses and times to take the hormone are not easy to determine. Melatonin is not approved for sale in some countries. In the USA it can be bought in pharmacies but in other countries it is only available with a doctor’s prescription.

Control of blood glucose levels

Blood glucose level is the concentration of glucose dissolved in blood plasma. It is expressed as millimoles per decimetre cubed (mmol dm^{-3}). Normally blood glucose levels stay within narrow limits, between 4 and 8 mmol dm^{-3} . This ensures that the osmotic balance of the blood remains constant and body cells receive sufficient glucose for respiration. Levels are higher after meals because glucose is absorbed into the blood from the intestine. They are usually lowest in the morning, as people do not eat overnight when they are asleep.

Glucose levels are monitored by cells in the pancreas. If the level is too high or too low, cells in regions of the pancreas known as the islets of Langerhans produce two hormones, insulin and glucagon, that turn on control mechanisms to correct it. This is another example of negative feedback (Figure 8.5.2). The regulation of blood glucose and how insulin influences cells is described in [Section 7.3.2](#).

SCIENCE IN CONTEXT

The international standard measure for blood glucose levels is millimoles per decimetre cubed ($\text{mmol}\cdot\text{dm}^{-3}$). For humans the normal range is between 4.4 and 6.1 $\text{mmol}\cdot\text{dm}^{-3}$. In the United States and some other countries it is usually measured in milligrams per decimetre cubed ($\text{mg}\cdot\text{dm}^{-3}$), making the normal range for blood glucose $80\text{--}110 \text{ mg}\cdot\text{dm}^{-3}$. The molecular weight of glucose is 180 and so the difference between the two units is a factor of 18. Thus, $1 \text{ mmol}\cdot\text{dm}^{-3}$ of glucose is equivalent to $18 \text{ mg}\cdot\text{dm}^{-3}$.

Range of tolerances

Although many organisms are able to control the internal conditions of their bodies, different organisms have different ranges within which they can survive.

The body temperatures of different mammals and birds vary, as shown in Table 8.5.2. Each species survives best at its own set point.

Organism	Normal average body temperature / $^{\circ}\text{C}$
human	37.0
bird	40.0
horse	38.0
sheep	39.0
elephant	36.5

Table 8.5.2: Average body temperatures for different species.

These ranges of tolerance cannot be exceeded if the animal is to survive. For example, humans cannot survive for long if body temperature falls to less than 35 °C. We suffer from hypothermia because our metabolism slows down too much to allow chemical reactions to take place at this temperature. And if our body temperature rises to over 40 °C for more than a very short time, humans can suffer from hyperthermia (heatstroke), as enzymes cannot function properly. Untreated hyperthermia causes many deaths each year.

Blood glucose levels are also different in different organisms. For example, a horse has a glucose level of between 3.3 and 6 mmol·dm⁻³, but a chicken has a normal level of between 7.2 and 14.8 mmol·dm⁻³. Excessively high or low blood glucose levels in humans can cause tiredness, a coma or weakness and blurred vision. In the most serious cases a diabetic coma can be fatal. Other animals are affected in a similar way.

THEORY OF KNOWLEDGE

Defining key terminology is generally seen as the starting point for academic enquiry. How could knowledge be gained without definition of key terms?

- 1** Why do you think it is important to define key terms before examining an issue or topic in more detail?
- 2** What problems might arise if terms were not clearly defined?

TEST YOUR UNDERSTANDING

- 31** Define homeostasis.

- 32** List three ways in which a human can regulate body temperature.
- 33** Draw a simple diagram to show how a feedback loop controls blood glucose levels.
- 34** Name a process that involves a positive feedback loop.

8.5.2 The role of the kidneys in osmosregulation and excretion

KEY POINTS

Osmoregulation is the control of the water potential of body fluids by the regulation of water and salt content, usually measured in osmoles per litre (osmol L⁻¹)

Excretion is the removal from the body of waste products of metabolic pathways via the skin, kidneys and lungs

Humans, like all mammals, use kidneys to regulate the water content of our bodies. We have two kidneys, situated in the lower back, one on either side of the spine. Each receives a blood supply from a renal artery, which is a branch of the main artery from the heart, the aorta. After passing through the kidney, blood returns to the circulation via a renal vein that joins the vena cava. Because of the processes occurring in the kidney, the composition of the blood in the renal vein is quite different from that in the renal artery. Urea, water content and salt levels are adjusted by the kidney so that they are at the correct levels as blood leaves the kidney, but glucose, protein and the cellular content of blood remain unchanged. Figure 8.5.4 shows a kidney in longitudinal section. Three regions are visible – the outer cortex, the central medulla and the inner renal pelvis. Urine produced by the kidney collects in the renal pelvis and is carried down to the bladder in the ureter.

Each kidney is made up of more than 1 million tiny structures called nephrons. These are the functional units of the kidney, selectively filtering and reabsorbing substances from the blood.

Figure 8.5.4 shows the structure of a **nephron**, which consists of a filtering unit (a complex of capillaries called a **glomerulus** surrounded by a **Bowman's capsule**) together with a tube that extends from the filtering unit to the renal pelvis. This tube is divided into four regions – the proximal convoluted tubule, the **loop of Henle**, the distal convoluted tubule and finally a collecting duct. Each of these regions has a specific role to play in urine formation.

Kidneys filter blood continuously. The blood that comes into the kidney enters millions of tiny kidney tubules called nephrons. At the start of each nephron is the glomerulus, or a tiny knot of capillaries, where blood is filtered so that only plasma, minus large proteins, enters the tubule. Each nephron has several sections: the proximal convoluted tubule, the U-shaped loop of Henle with a thin descending and a thick ascending limb, and the distal convoluted tubule, which winds and twists back up again, before emptying into the collecting duct, which collects the final urine (Figure 8.5.5).

Osmoregulation

The final adjustments to the water content of urine produced by the kidneys are made in the collecting duct, as described earlier in this section. But the process of osmoregulation also occurs in other parts of the kidneys to ensure that the solute and water balance of the body is kept constant. Each kidney is made up of more than 1 million tiny structures called nephrons. These are the functional units of the kidney, selectively filtering and reabsorbing substances from the blood. Figure 8.5.5 shows the structure of a nephron, which consists of a filtering unit (a complex of capillaries called a glomerulus surrounded by a Bowman's capsule) together with a tube that extends from the

filtering unit to the renal pelvis. This tube is divided into four regions:

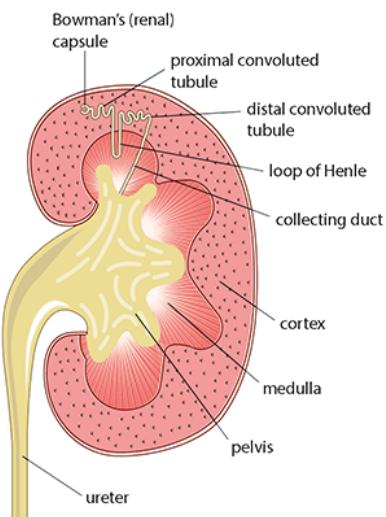
- 1 the proximal convoluted tubule,
- 2 the loop of Henle,
- 3 the distal convoluted tubule and finally
- 4 a collecting duct.

Each of these regions has a specific role to play in urine formation.

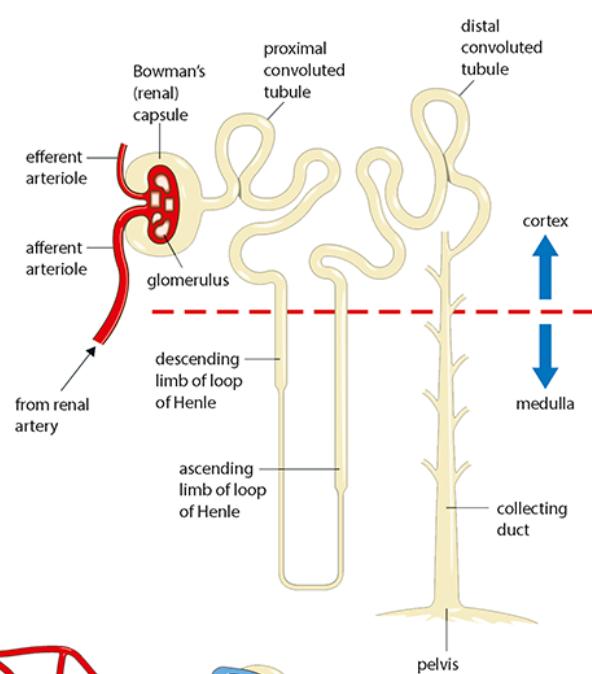
Bowmans capsule and proximal convoluted tubule

Ultrafiltration occurs in the glomerulus where blood plasma is filtered. Only small molecules can pass through the Bowman's capsule into the nephron; water, salts, glucose and amino acid enter the nephron and the amounts of each are unregulated. This means that the filtrate contains many useful substances which the body needs and these are reabsorbed in the proximal convoluted tubule. Cells in this region of the nephron have many mitochondria. They fuel active transport through membrane pumps that selectively reabsorb ions and glucose from the tubular fluid. All the glucose in the filtrate is actively reabsorbed together with almost 80% of sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) ions. Chloride ions (Cl^-) are absorbed passively and water follows by osmosis as the solute concentration of the cells rises due to the active uptake of ions and glucose. The remaining filtrate now moves into the loop of Henle.

Position of a nephron



Structure of a nephron



Blood supply associated with a nephron

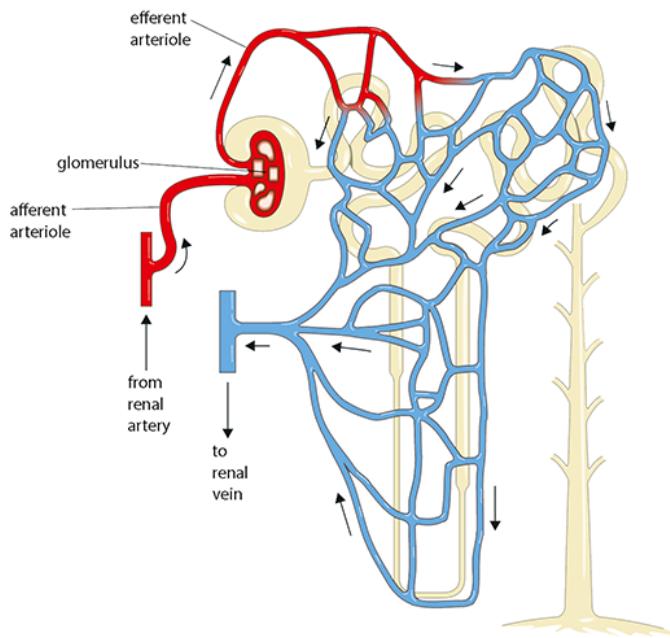


Figure 8.5.4: The structure of the kidney and nephron.

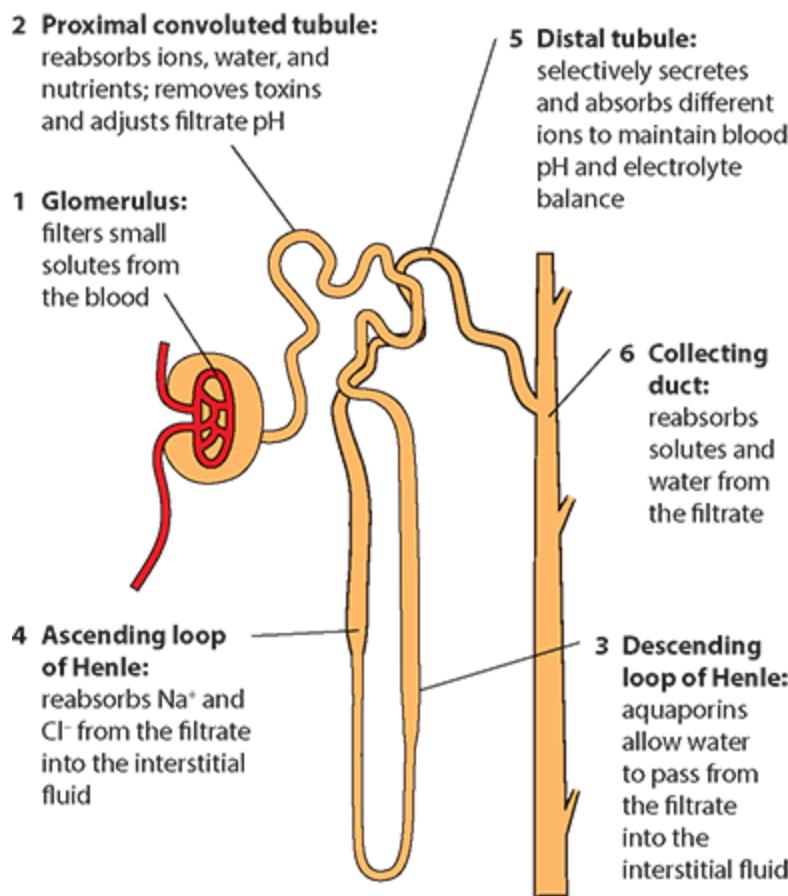


Figure 8.5.5: The structure of a nephron and the functions of the different parts of the tubule.

The loop of Henle

The filtrate that enters the loop of Henle still contains much of the water that was filtered from the blood. The wall of the descending limb of the loop is permeable to water but relatively impermeable to salts, whereas the ascending limb is impermeable to water, but allows salt to be passed through its walls. Na^+ and Cl^- ions move by active transport out of the ascending limb into the tissue fluid of the medulla, creating hypertonic conditions (a high salt concentration) in this region. This means that as the descending limb of the loop of Henle passes down into the medulla, water leaves passively by osmosis.

and enters the surrounding blood capillaries (Figure 8.5.6). The hypertonic environment in the medulla of the kidney produced by the loop of Henle is also essential for the fine-tuning of the water content of the blood by the collecting duct.

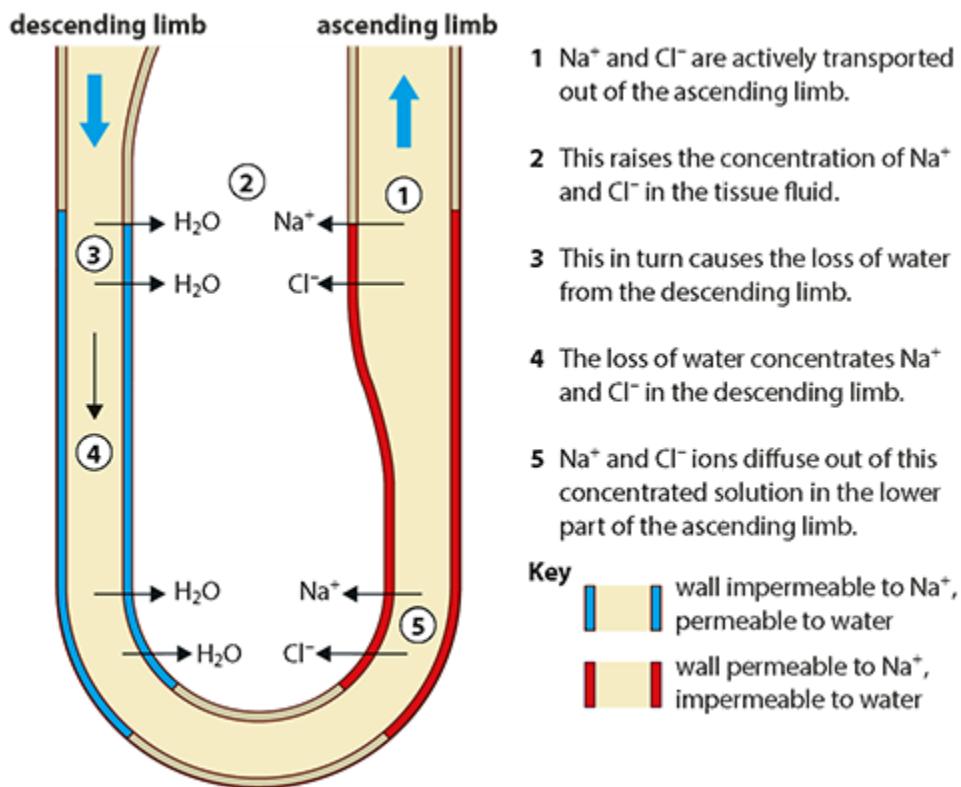


Figure 8.5.6: The counter-current mechanism in the loop of Henle builds up a high Na^+ ion and Cl^- ion concentrations in the tissue fluid of the medulla.

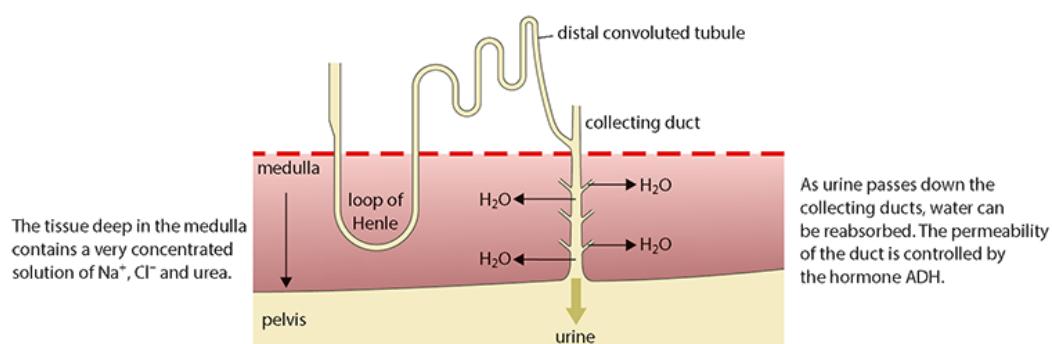


Figure 8.5.7: Water can be drawn out of the collecting duct by the high salt concentration in the surrounding tissue fluid of the medulla.

The length of the loop of Henle is different in different species. Its length is related to an animal's need to conserve water. Terrestrial animals, such as camels, that live in dry environments and need to conserve water, produce small volumes of very concentrated urine. These animals have a longer loop of Henle relative to their size than species such as otters and beavers, which live in places where dehydration is not a problem. Animals that live in wet environments tend to have very short loops of Henle and excrete dilute urine.

The distal convoluted tubule and the collecting duct

Despite the loss of water from the loop of Henle, the filtrate that enters the next section of the tubule still has a high water content. Ions are exchanged between the filtrate and the blood in the distal convoluted tubule. Na^+ , Cl^- and Ca^{2+} ions are reabsorbed into the blood while H^+ and K^+ ions may be actively pumped into the tubule.

The last portion of the nephron is the collecting duct where the final adjustment of water is made (Figure 8.5.7). The permeability of the duct depends on the presence or absence of **antidiuretic hormone** (ADH). More ADH means that more water is reabsorbed into the blood and the urine produced is more concentrated. Less ADH makes the duct impermeable so that more dilute urine is produced.

The last portion of each nephron is the collecting duct where the final adjustments to water content in urine are made (Figure 8.5.4). These occur in response to changes in concentration of

the blood which are detected by osmoreceptors (receptors that detect changes in osmotic pressure) in the hypothalamus in the brain. If blood volume is low and there is insufficient water present, the hypothalamus stimulates the pituitary gland just beneath it to release the hormone antidiuretic hormone (ADH), (this hormone is also called vasopressin). This hormone controls the permeability of the collecting duct and regulates the amount of water that is excreted in urine. If ADH is released, membrane channels, called aquaporins, found in the walls of the collecting duct, will open. The duct becomes more permeable and water leaves the tubule and is taken back into the blood. If the water content of the blood is high, ADH is not produced so the aquaporin channels remain closed and the duct is impermeable to water. The water remains inside the nephron, so that more dilute urine is produced and excess water leaves the body.

SCIENCE IN CONTEXT

Caffeine, alcohol and cold conditions suppress ADH production and can lead to dehydration if too much water is lost in urine. This explains why a person is more likely to need to urinate in cold weather.

Stress and nicotine increase ADH production, producing the opposite effect.

Although the kidney can conserve water already present in the body, only intake of water by drinking or in foods can replace water that has already been lost.

THEORY OF KNOWLEDGE

Ethical issues and kidney donation

Today many organs can be transplanted between well-matched human donors and recipients. Kidneys, corneas, bone marrow and skin are all transplanted regularly for certain medical conditions. Donors usually carry a card or express the wish that they will donate their organs should they die, for example, in an accident. Successful kidney transplants and the drugs needed to prevent rejection of a donated kidney cost less than keeping a person alive using renal dialysis. The quality of life of the recipient is also better. Nevertheless, there is still a shortage of people willing to donate a kidney after their death.

It is possible to live a full and active life with only one functioning kidney, so a person who is in good health can donate a kidney to help someone who desperately needs a kidney transplant. Kidneys are the most commonly donated organ by people who are still alive. Donating a single kidney to a close relative, partner or good friend, is called directed altruistic donation. But some people decide to donate to someone with whom they have no previous connection.

To consider:

- 1 Some governments adopt policies that make organ donation compulsory rather than voluntary unless an individual has strong moral objection. Is this right?
- 2 What are the ethical issues associated with altruistic donation? Should a person be allowed to choose who they donate to?

TEST YOUR UNDERSTANDING

- 35 Define the term ‘osmoregulation’.

- 36** Outline the role of the loop of Henle in regulating water content of urine.
- 37** Outline the role of ADH in controlling the water content of urine.

8.5.3 Further examples of homeostasis

KEY POINTS

baroreceptor receptors that monitor blood pressure

chemoreceptor a sensory neurone that responds to pH or the concentration of a chemical, such as carbon dioxide, in the body.

Carbon dioxide levels in the blood

In [Section 8.3](#) you can study the effect of excess carbon dioxide levels in the blood and how they are controlled by an increase in gas exchange at the alveoli. This is triggered by chemoreceptors in the medulla of the brain stem.

EXAM TIP

Recall that regulation of carbon dioxide and oxygen levels in plants is controlled by the stomata in the leaves.

Blood sugar levels

In [Section 7.3](#) you can study the control of blood sugar levels and how a failure of the homeostatic processes can lead to either Type I or Type II diabetes.

Blood pressure and feedback control of heart rate

Another important factor that the body must control is blood pressure. Several mechanisms regulate the flow and pressure of blood throughout the body. Changes in blood pressure are made

so that the correct levels of nutrients, including glucose and oxygen, reach all parts of the body at the right time and that wastes such as carbon dioxide are removed. For example, when we exercise muscles require additional oxygen and glucose, and carbon dioxide must be carried away, but the supply of blood to the intestines can be reduced for a short while. Changes to blood pressure can be made by altering our heart rate or the amount of blood that the heart pumps out with each beat. Blood pressure is also affected by changing the diameter of blood vessels that alters the resistance to blood flow. A narrow vessel will resist the flow of blood and so the pressure inside it will increase. A combination of increased blood flow or volume and narrowed vessels raises blood pressure.

There are several ways in which blood pressure is monitored and regulated, as follows.

- 1 Chemoreceptors in the cardiovascular centre in the medulla (brain stem) (Figure 8.5.8) send nerve impulses to the sinoatrial node (SAN) in the heart if heart rate needs to increase. These impulses stimulate the SAN to raise or lower the heart rate and output of the heart to supply the body's needs.

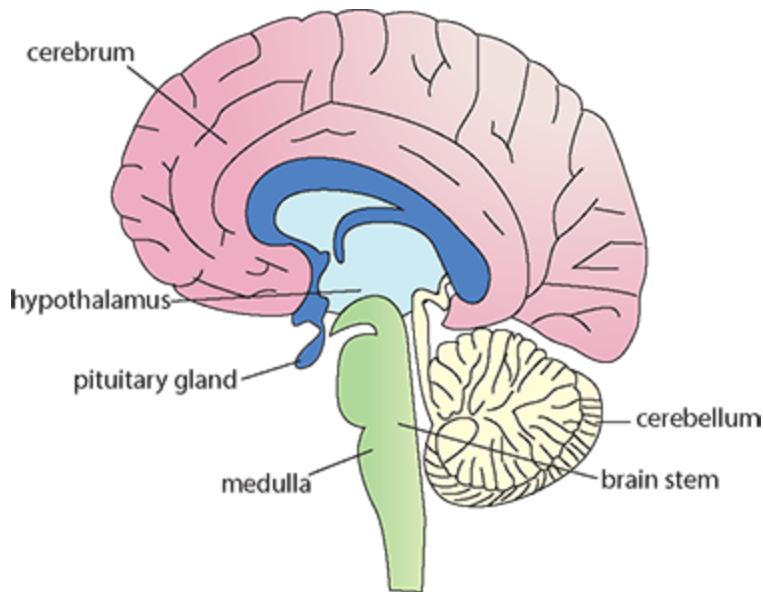


Figure 8.5.8: The medulla is located in the brain stem and controls automatic functions such as breathing, heart rate and reflexes such as swallowing.

- 2 Baroreceptors in the carotid arteries and aortic arch monitor blood pressure and send messages to the medulla if blood pressure is too high. Low pressure receptors are present in the atria and ventricles as well the blood vessels of the lungs.
- 3 Blood pressure and the distribution of blood can also be regulated by the hormones epinephrine (adrenaline) and norepinephrine secreted by cells of the adrenal medulla in the adrenal glands (Figure 8.5.1). Both hormones are part of the ‘fight-or-flight response’, which prepares the body for danger or to respond in a frightening or dangerous situation. The two hormones raise blood pressure by increasing heart rate and by causing vasoconstriction of arteries, arterioles and veins. Adrenaline also causes air passages to dilate to provide the muscles with the oxygen they need to either fight danger or flee. It triggers the blood vessels to contract

to re-direct blood toward major muscle groups, including the heart and lungs. ([Section 8.2](#)).

- 4 Chemoreceptors in the aortic and carotid arteries, which respond to levels of CO₂, send message to the medulla oblongata to increase heart and breathing rates ([Section 8.3](#)). This increases blood pressure and ensures that the respiratory and circulatory systems work in unison (Figure 8.5.9).
- 5 The kidneys also regulate blood pressure under the influence of hormones that control blood volume. When blood pressure is too high, a reduction in blood volume can reduce it to a normal level.

Water reabsorption under the control of ADH

The walls of the second convoluted tubule and the collecting duct are influenced by antidiuretic hormone (ADH). This hormone is produced in the hypothalamus but secreted by the pituitary gland. ADH is released when there is too little water in the blood so that its concentration rises and blood pressure falls. ADH increases the permeability of the kidney tubule to water so that more water is returned to the blood from the filtrate in the tubule and more concentrated urine is produced. More water remaining in the blood will, in turn, raise blood pressure to the normal level.

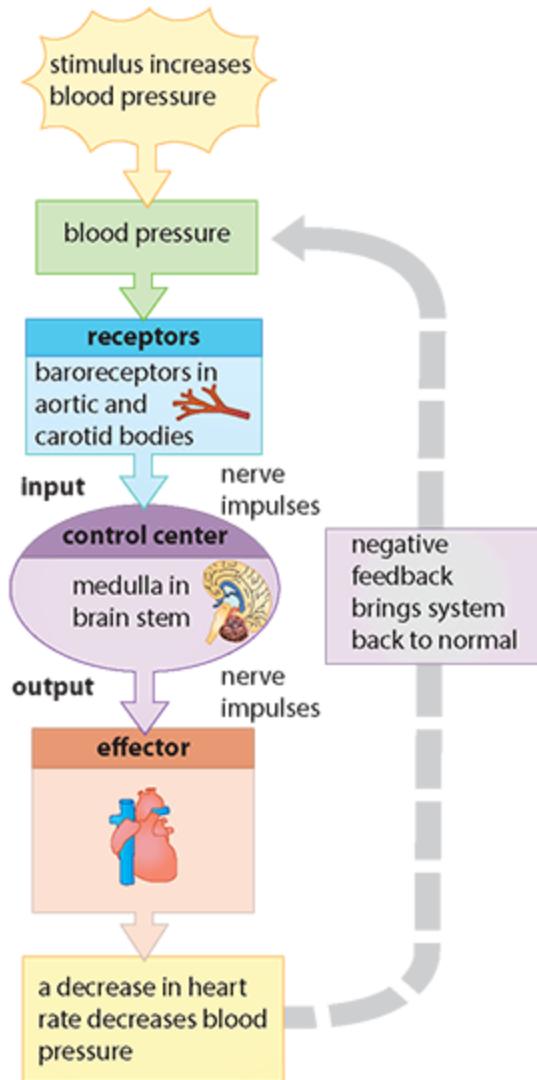


Figure 8.5.9: Blood pressure is also controlled by a feedback system.

SCIENCE IN CONTEXT

Untreated high blood pressure in older people can cause many health problems. Blood vessels can be damaged becoming narrow or leaking and high blood pressure can also cause blood clots to form in the arteries to the brain, blocking blood flow and potentially causing a stroke. If blood clots form in the arteries that supply the heart, they can cause a heart attack.

People who suffer from high blood pressure are encouraged not to smoke. This is because nicotine in tobacco raises blood pressure by increasing vasoconstriction and by stimulating the adrenal medulla to increase secretion of epinephrine and norepinephrine.

Other substances also affect blood pressure. One of these is alcohol, which lowers blood pressure by causing vasodilation and by inhibiting the release of ADH so that more water is lost in urine and blood volume decreases. This also explains why drinking alcohol leads to dehydration and causes a headache known as a hangover.

If blood pressure rises due to excess water in the blood and, as a result, blood concentration falls, the release of ADH is inhibited. The release of ADH is controlled by a negative feedback loop (Figure 8.5.10).

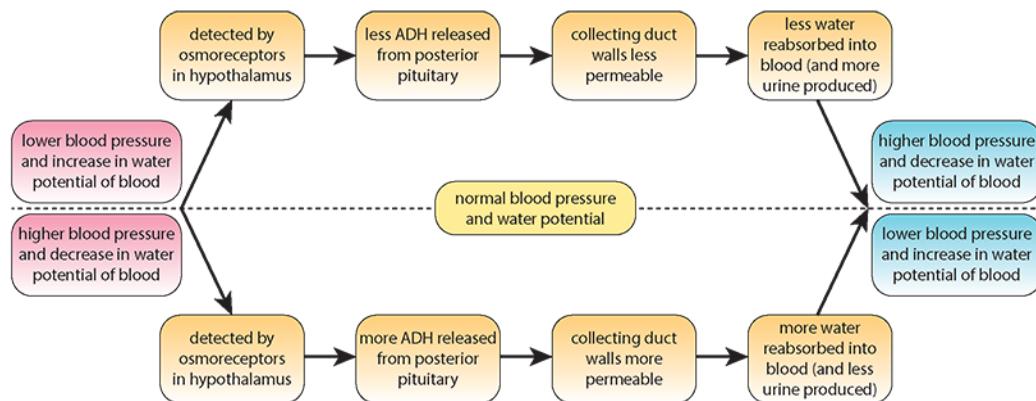


Figure 8.5.10: Control of water content of the blood by negative feedback.

Adrenaline – the fight or flee hormone

Adrenaline is an important hormone which causes changes in many parts of the body to prepare us for action or get us ready to

react if we are threatened or in danger. A sudden release of adrenaline can feel like anxiousness, nervousness, or pure excitement as your body gets ready for an event or activity. There are certain activities like skydiving that will cause a rush of adrenaline but even watching a scary movie or waiting to take an important exam can produce a similar effect. The body's responses ensure we can see, breathe and move quickly and that we are not distracted by functions such as digestion that can be paused for a while. The effects of adrenaline include:

- increasing the rate of heartbeat
- increasing blood pressure and respiration rate
- dilating (widening) bronchi
- increasing metabolic rate
- increasing the release of glucose in the liver and muscles
- dilating the pupils of the eye
- inhibiting peristalsis and digestion
- inhibiting bladder contraction.

TEST YOUR UNDERSTANDING

38 What effect does constriction of arterioles have on blood pressure?

REFLECTION

Could I explain the key points of this topic to someone else?
What is the most difficult aspect?

Links

- How do hormones play a role in homeostasis? (Chapter 7)
- Can homeostasis influence evolution? (Chapter 11)

SELF-ASSESSMENT CHECKLIST

Think about the topics covered in this chapter. Which parts are you most confident with? Which topics require some extra practice?

I can...	Subsection	Needs more work	Nearly there	Confident to move on
state that multicellular organisms are composed of cells that form tissues and organs	8.1.1			
describe how emergent properties occur as a result of cell interactions in multicellular organisms	8.1.1			
outline the importance of stem cells in the formation of a multicellular organism	8.1.2			
identify the three	8.1.2			

types of stem cell and their properties				
state that stem cell niches are found in human bone marrow and hair follicles	8.1.2			
explain the importance of a circulatory system to a multicellular organism	8.2.1			
identify the features of arteries, veins and capillaries	8.2.1			
understand how to take a pulse measurement, explain how and why pulse rate and blood pressure change with activity	8.2.1			
recognise the causes and consequences of blockages in arteries	8.2.1			

distinguish between a single and double circulation	8.2.1				
draw a diagram of the heart showing valves that separate the four chambers	8.2.1				
recognise the stages in the cardiac cycle	8.2.1				
outline the structure and function of the lymphatic system	8.2.2				
describe how blood pressure is maintained and how it is important in capillary exchange	8.2.2				
describe how water is transported from roots to leaves during transpiration	8.2.3				
summarise the	8.2.3				

features of xylem needed for transport of water				
draw distribution of tissues in transverse sections of roots and stems	8.2.3			
explain how root pressure and active transport cause water movement in roots	8.2.3			
summarise the adaptations of phloem sieve tubes for translocation	8.2.3			
explain why transpiration is a consequence of gas exchange in a leaf	8.2.5			
explain the importance of gas exchange surfaces and their properties	8.3.1			
describe how concentration	8.3.1			

gradients are maintained for gas exchange				
describe the adaptation of mammalian lungs for gas exchange	8.3.1			
describe how ventilation rate is adapted to meet the need for gas exchange	8.3.2			
describe the adaptations of pneumocytes in alveoli	8.3.2			
describe how oxygen is carried by hemoglobin	8.3.3			
draw a dissociation curve and explain its shape	8.3.3			
describe the dissociation curve of the Bohr shift and for fetal hemoglobin	8.3.3			
draw a labelled diagram of a leaf	8.3.4			

and describe how it is adapted for gas exchange and capturing light				
summarise the differences between asexual and sexual reproduction	8.4.1, 8.4.2			
outline the role of meiosis and fusion of gametes in sexual reproduction	8.4.2			
outline the stages of the menstrual cycle and the hormones involved	8.4.2			
annotate diagrams of male and female reproductive systems to explain their functions	8.4.2			
summarise the stages of fertilisation	8.4.2			
describe the stages in an IVF	8.4.3			

treatment				
outline the control of changes at puberty by GnRH	8.4.4			
describe spermatogenesis and oogenesis and adaptations of human sperm and egg cells	8.4.4			
summarise the mechanisms that prevent polyspermy	8.4.4			
outline the formation of the blastocyst and the role of hCG in pregnancy and in pregnancy testing	8.4.4			
describe the development of a blastocyst and implantation and the role of the placenta	8.4.4			
explain the hormonal control of pregnancy and childbirth	8.4.5			

understand the effects of HRT	8.4.5				
describe positive and negative feedback in the human menstrual cycle and mammalian birth	8.4.5				
outline the sexual reproductive strategies of plants	8.4.6				
recognise the features of an insect-pollinated flower	8.4.6				
describe how angiosperms are pollinated and how they prevent self-pollination	8.4.6				
recall that dispersal and germination of seeds complete a plant's life cycle	8.4.6				
define homeostasis and explain why it is important	8.5.1				

define thermoregulation and explain physiological and behaviour strategies to maintain body temperature	8.5.1				
recall that blood glucose regulation, blood pH, heart rate and ventilation rate regulation are examples of homeostatic processes	8.5.1				
describe a negative feedback system and explain how it differs from a positive feedback system	8.5.1				
recall that individuals have a range of tolerance for internal conditions	8.5.1				
describe the role of the kidney in	8.5.1				

osmoregulation and excretion				
explain the functions of the different sections of the kidney tubule in osmoregulation and excretion	8.5.1			
describe osmoregulation by the collecting ducts and ADH	8.5.1			
outline feedback control of heart rate following sensory input from baroreceptors and chemoreceptors	8.5.2			
recall the roles of the hypothalamus and pituitary gland in homeostasis	8.5.2			
describe how sleep patterns are modulated by melatonin	8.5.2			
list the effects of	8.5.2			

adrenaline on the body.

EXAM-STYLE QUESTIONS

You can find questions in the style of IB exams in the digital coursebook.



› Chapter 9

Coordination, muscles and motility

C3.1, B3.3

INTRODUCTION

The brain and spinal cord act to integrate the organs of the body that enable us to move. Some of these movements are involuntary and we cannot control by thinking about them, while other movements we can think about and control voluntarily. Adaptations for movement are a feature of almost all living things which move to escape, search for food or search for mates.

9.1 Coordination and muscle contraction

LEARNING OBJECTIVES

In this section you will:

- understand that inputs to the spinal cord and cerebral hemispheres arrive through sensory neurones
- recognise that outputs from the cerebral hemispheres via motor neurones enable muscles to contract.
- understand that nerves are bundles of both sensory and motor neurones
- discover that reflex arcs lead to involuntary responses with skeletal muscle as the effector
- learn that the cerebellum coordinates skeletal muscle contraction and balance
- understand that peristalsis in the digestive system is controlled by both voluntary and involuntary muscle contraction

9.1.1 Stimulus and response in the nervous system

KEY POINTS

central nervous system (CNS) the brain and spinal cord

peripheral nervous system the sensory and motor nerves outside the CNS

reflex rapid unconscious response to a stimulus

response reaction or movement as a result of a stimulus

stimulus change in the environment that is detected by a receptor and causes a response

Receptors are parts of the nervous system that detect a stimulus and initiate a nerve impulse. There are many different receptors, for example in the skin there are pain, temperature and pressure receptors and the retina of the eye contains light receptors. Nerve impulses are carried by neurones to effectors which may be muscles or glands. The effectors carry out the response.

The pathway between receptor and effector involves the central nervous system ([Section 7.2](#)) which comprises the brain and spinal cord (Figure 7.2.1). The type of neurone that carries the message towards the CNS is a sensory neurone and the one that carries the impulse from the CNS to the effector is called the motor neurone. These sensory and motor neurones make up the peripheral nerves and within the CNS interconnecting relay neurones connect the sensory and motor neurones via synapses. (Figure 9.1.2(a))

Inputs from sensory neurones are carried from receptor cells to the spinal cord and cerebral hemispheres of the brain. The spinal cord co-ordinates involuntary responses while the cerebellum of the brain (Figure 7.2.3) is primarily responsible for muscle control, including balance and movement. The cerebellum plays a major role in adapting and fine-tuning responses so that we can make accurate movements such as catching a ball by practising or through trial and error.

The cerebellum controls voluntary movements such as walking, posture, balance, coordination, eye movements and speech. All these movements require sensory inputs from peripheral nerves and motor outputs from the brain to the muscles that are involved. Outputs from the spinal cord and brain stimulate muscles to contract and cause movement.

Reflex actions

Autonomic and involuntary responses are together known as reflex actions. A reflex is a specific reaction that is always produced in response to a particular stimulus and which does not require prior learning. Sometimes a rapid response to a stimulus is vital for an animal's survival and reflex actions take place quickly and automatically. Human reflexes include the pupil reflex which reduces the diameter of the pupil in very bright light to prevent damage to the retina and the coughing reflex, which occurs when a piece of food enters the trachea.

The pain withdrawal reflex takes place if you touch something that causes pain. For example, if you touch a very hot object or are stung by a bee, you pull your hand away quickly, without thinking about it at all. The pain withdrawal reflex is an example of a reflex action which uses a rapid and simple neural pathway called a reflex arc (Figure 9.1.1).

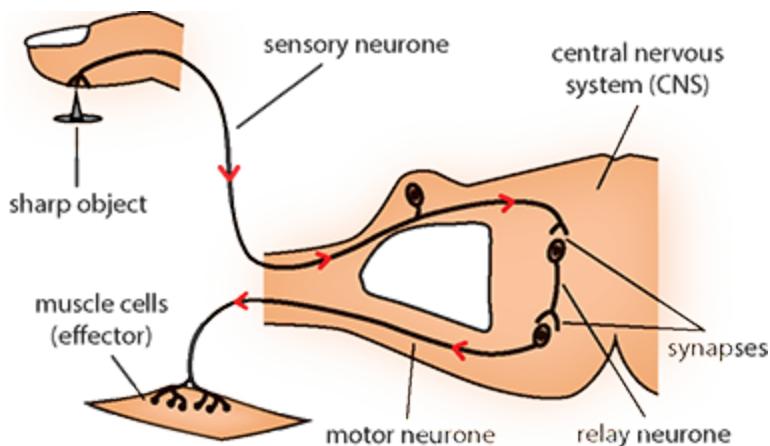


Figure 9.1.1: A spinal reflex arc for a pain withdrawal reflex

The reflex arc involves a receptor in the fingertip, a sensory neurone, a relay neurone in the spinal cord and a motor neurone that stimulates the effector, in this case a muscle in the arm, to contract and draw your hand away.

Relay neurones also connect to neurones going up and down the spinal cord. These ascending and descending neurones carry information to and from the brain. So if you do touch something that causes pain, not only do you remove your hand immediately but information is sent to the cerebral hemispheres of the brain so that you can remember what happened and not do it again.

The pathway of a reflex arc is genetically determined so that appropriate responses to different stimuli occur. There are several different reflexes that are controlled by the spinal cord such as the pain withdrawal reflex and the knee jerk reflex. The brain also controls some reflex actions such as the blinking reflex which happens if something touches the surface of the eye.

EXAM TIP

Review [Chapter 7.2](#) and remind yourself about the structure of the nervous system and the importance of myelinated neurons in transmission of nerve impulses.

Structure of nerves and muscles

Nerves

Nerves that make up the peripheral nervous system throughout the body are made of bundles of different types of neurone (Figure 9.1.2(b)). Some of the fibres are dendrites of sensory neurones that carry impulses towards the CNS, others are axons which carry impulses away from the CNS to effectors. Some nerve fibres are enclosed in a myelin covering which speeds up the transmission of impulses, others are unmyelinated. A layer of connective tissue called the perineurium surrounds the groups of fibres which are known as fascicles and an outer layer called the epineurium encloses several groups of these together.

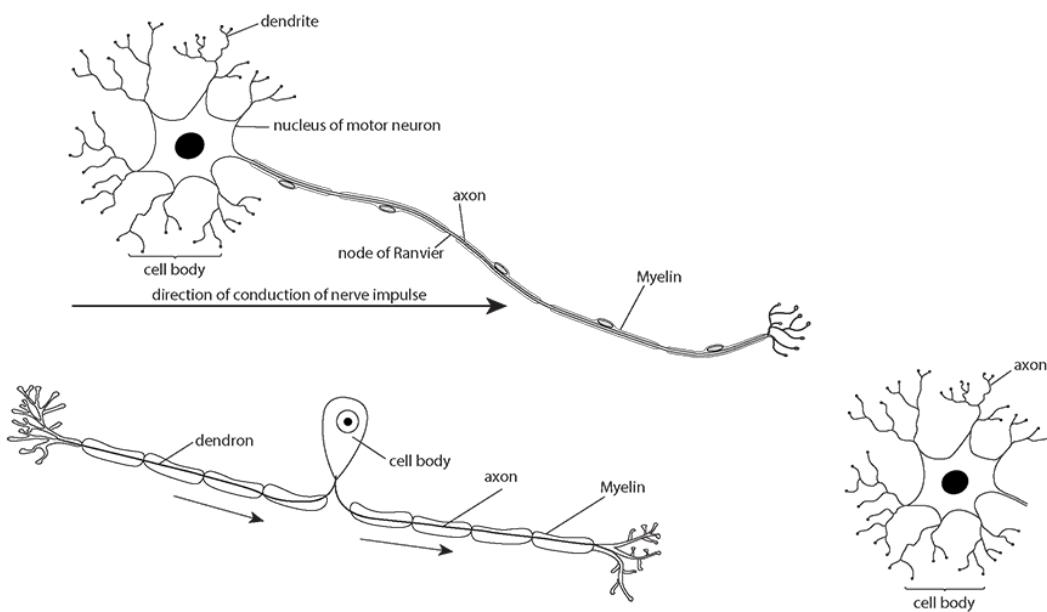


Figure 9.1.2 a: Sensory neurones carry messages to the CNS but their cell bodies are contained in ganglia outside the spinal cord. Motor neurones carry messages away from the CNS, their cell bodies make up the grey matter in the spinal cord. Intermediate neurones form connections between sensory and motor neurones in the CNS.

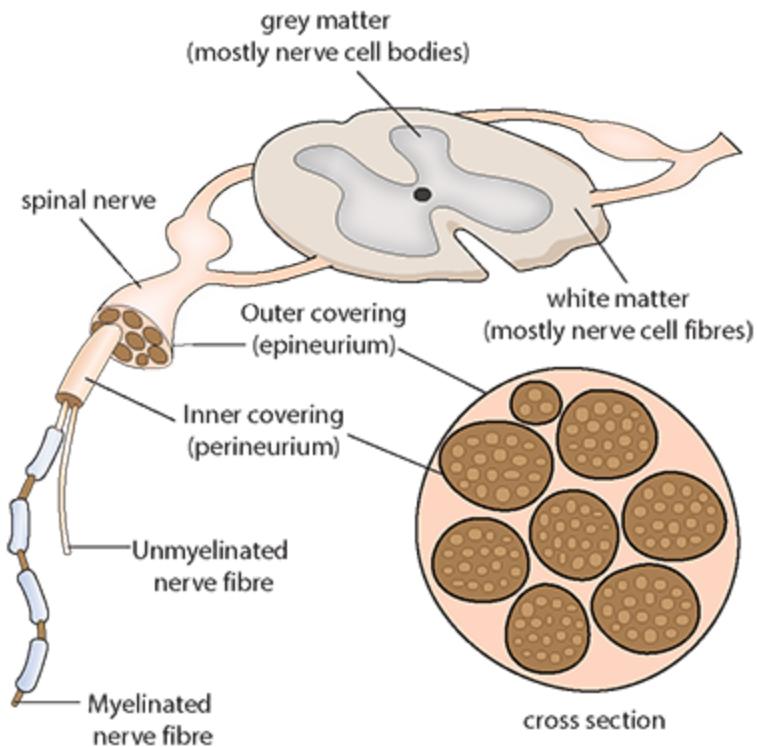


Figure 9.1.2 b: Peripheral nerves consist of bundles of sensory and motor neurones enclosed in a protective sheath

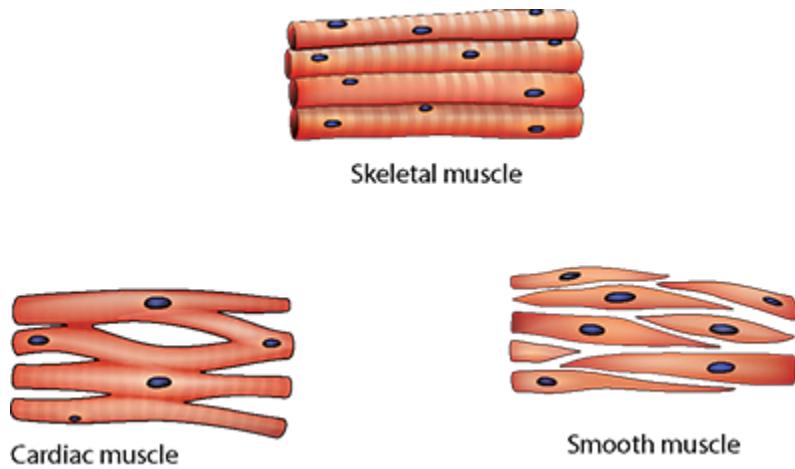


Figure 9.1.3: Three different types of muscle which cause movement in the body

Muscle tissue

There are three different types of muscle tissue in the human body (Figure 9.1.3)

Skeletal or striated muscle is the muscle that causes movement of our joints. It is sometimes called voluntary muscle. Under the light microscope it has a striped appearance, and it is made of cells with many nuclei known as muscle fibres (see Figure 9.2.9). Surrounding each fibre is a plasma membrane called the sarcolemma.

Heart muscle has a unique composition that adapts it for the conduction of waves of excitation from fibre to fibre. It is made up of short, striped muscles fibres which branch and are also joined together at their ends by linking structures known as intercalated discs. (see Figure 9.2.9). This arrangement of linkages between cells allows action potentials to spread rapidly and enables the heart muscle fibres to act together and produce a more powerful beat as they contract simultaneously.

Smooth muscle fibres are found in organs such as the liver, bladder, and intestines. Smooth muscle cells are spindle-shaped and work involuntarily. We have no control over the contraction of our involuntary muscles.

Control of peristalsis in the digestive system

KEY POINTS

Enteric nervous system part of the autonomic nervous system that controls smooth muscle in the digestive system

peristalsis muscle contraction that moves food along the digestive system

ingestion taking in food, eating

egestion removal of waste from the body during defecation

The central nervous system plays a key role in the movement of food along the digestive system. Both voluntary and involuntary control are involved. We take in and chew solid food in our mouths and swallow it so that it passes down the esophagus (food pipe) to the stomach. The acts of chewing and swallowing are voluntary. We can choose to chew and when to swallow and these actions are controlled and coordinated by the CNS.

Once food has entered the digestive system it is moved along the intestine by a sequence of muscle contractions known as **peristalsis**. Peristalsis is under involuntary control and is regulated by the **enteric nervous system** (Figure 9.1.4).

Peristalsis involves two layers of involuntary muscle which make up the intestine wall. Longitudinal muscles run along the length of the intestine (Figure 9.1.5) while circular muscles encircle the intestine. Contractions of the bands of circular muscle squeeze

the area of the intestine behind a portion of food while longitudinal muscle relaxes and extends to accommodate it. The two sets of muscles then relax and contract respectively so that food is gradually pushed along the intestine in waves. The action of the enteric nervous system ensures that the movement of food is coordinated. As food moves along it is mixed with digestive enzymes, useful substances are absorbed, and eventually only waste and undigested material remain in the large intestine. This waste material forms feces which are egested through the anus. Egestion of feces is under voluntary control.

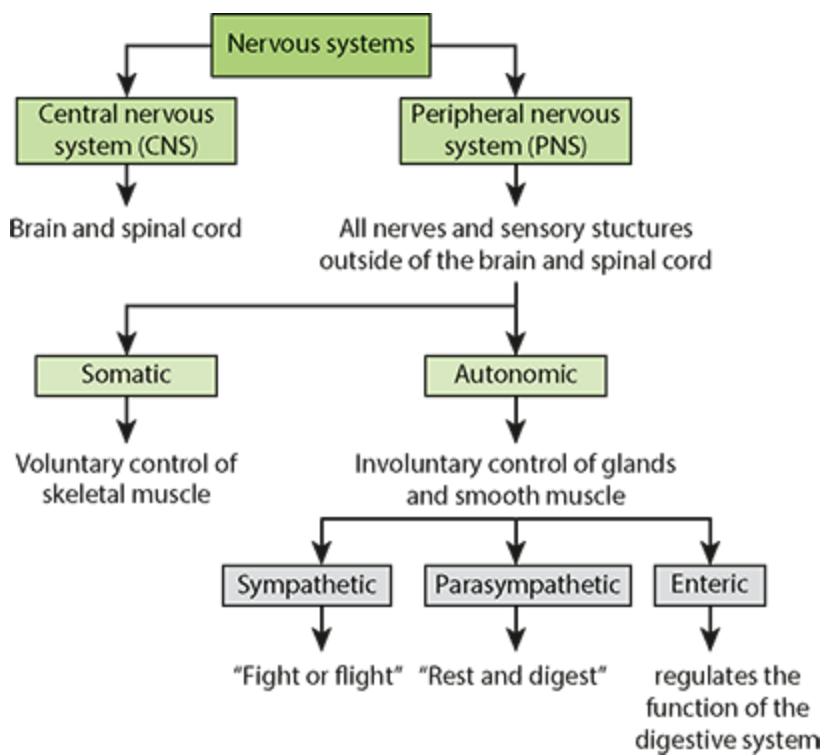


Figure 9.1.4: This diagram shows the relationship between the different parts of the nervous system

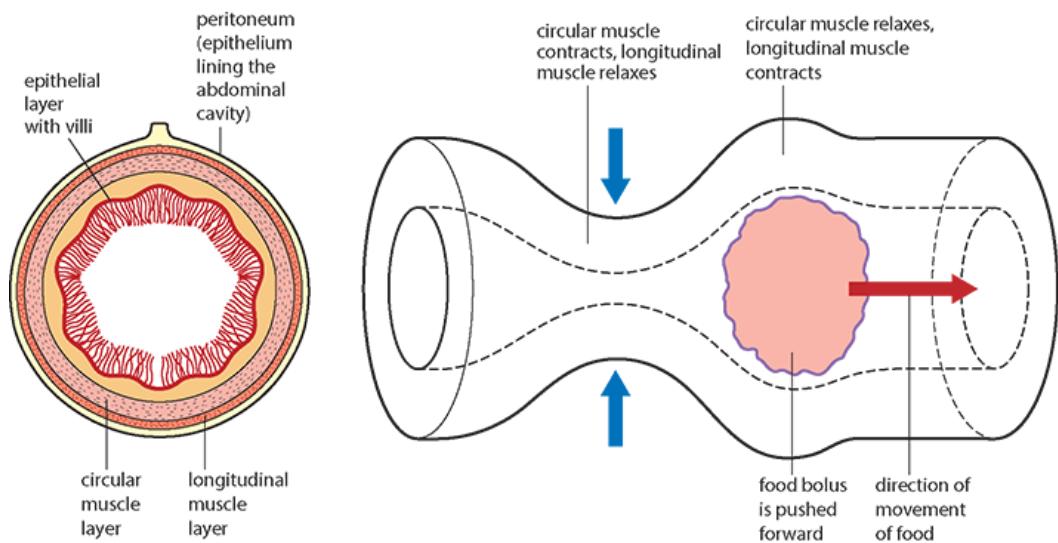


Figure 9.1.5: The actions of longitudinal and circular muscles in the intestine move food along in waves of peristalsis coordinated by the enteric (non-voluntary) nervous system

TEST YOUR UNDERSTANDING

- 1 List the components of a reflex arc
- 2 Distinguish between the central nervous system and peripheral nervous system
- 3 Where would you find each of these muscle types i striated muscle ii cardiac muscle iii smooth muscle

9.2 Muscles and motility

LEARNING OBJECTIVES

In this section you will:

- learn that adaptations for movement are found in all living organisms
- understand how actin and myosin are involved in muscle contraction
- learn that the protein titin and antagonistic muscles are needed for muscle relaxation
- recognise the structure and function of motor units in skeletal muscle
- distinguish between exoskeletons and endoskeletons as anchorage points for muscles
- understand the structure of a synovial joint and the range of movement of different joints.
- recognise an example of antagonistic muscles in breathing
- distinguish between movement and locomotion and understand the reason for locomotion
- recognise the adaptations of marine mammals for swimming.



9.2.1 Types of movement

Movement is the ability of an organism to change its position or place. Most organisms can carry out simple movements and this is a characteristic of life but these movements may not cause a change of location.

Plants turn their leaves to face the sun and adjust their positions so that leaves do not overlap one another, and many flowers open and close their petals during the day and night. These movements are known as heliotropisms, a form of tropism. Movements may occur daily or with the seasons in response to the position of the sun.

KEY POINTS

movement the ability to change position, not always resulting in a change of location.

tropism a growth response of plants in which the direction of growth is determined by the direction of a stimulus.

Plants bend towards light by growth (phototropism) but we can observe many other faster movements in the plant kingdom. Some movements are related to defence. The sensitive plant, *Mimosa pudica*, has leaves that droop almost immediately when they are touched or hit by a drop of rain (Figure 9.2.1). Others are food-related movements. For example, the Venus flytrap has hinged leaves that snap shut when two of its sensitive hairs are touched at the same time by a fly walking near them, while some underwater pitcher plants have a flap on the pitcher that suddenly opens when a sensitive hair is touched so that an insect can be swept in by the current of water.



Figure 9.2.1: *Mimosa pudica*, the sensitive plant, will fold its leaves instantly if they are touched

Sedentary (sessile) animals

In the animal kingdom, some organisms stay in the same place throughout their lives. They are known as sedentary or sessile. Some of these sedentary organisms such as sea anemones (Figure 9.2.2) do move parts of their bodies for example in response to threats, contracting them inward and downward or to find food when they extend their tentacles and reach out into the water.



Figure 9.2.2: Sea anemones extend their tentacles to feed

Amphibians, such as frogs and toads, are not sedentary and can move from place to place, but they can remain motionless, waiting for prey to approach, before extending only their long tongue to capture a worm or slug.

Walking and running

Four-legged animals walk or run and can vary the speed of their motion to suit the situation. As Figure 9.2.3 shows, not all the animal's feet are in contact with the ground all the time but by balancing their weight, the animal remains stable. Legs support the animal's body. The gallop or run is the fastest movement a horse can achieve and this can average at between 40 and 48 kilometres per hour.

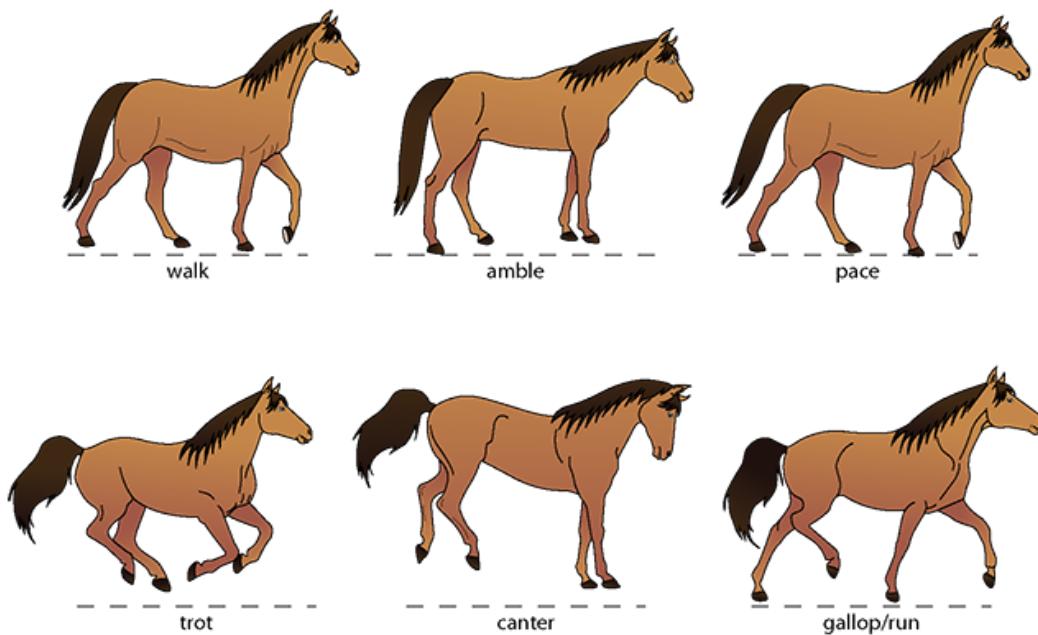


Figure 9.2.3: A horse adapts the movement of its limbs to change its speed of locomotion.

9.2.2 Skeletons and joints

Exoskeletons

Exoskeletons are hard coverings or cuticles that form a protective layer over the bodies of arthropods such as insects and crustaceans. This exoskeleton is outside the body and the muscles that move it are on the inside. Figure 9.2.4 shows the inside of an insect's leg. There are two muscles: one flexor, which bends the leg at the joint, and one extensor, which extends the leg. At a joint an exoskeleton has a flexible membrane instead of a cuticle so that the limb can bend easily.

Exoskeletons allow arthropods to move.

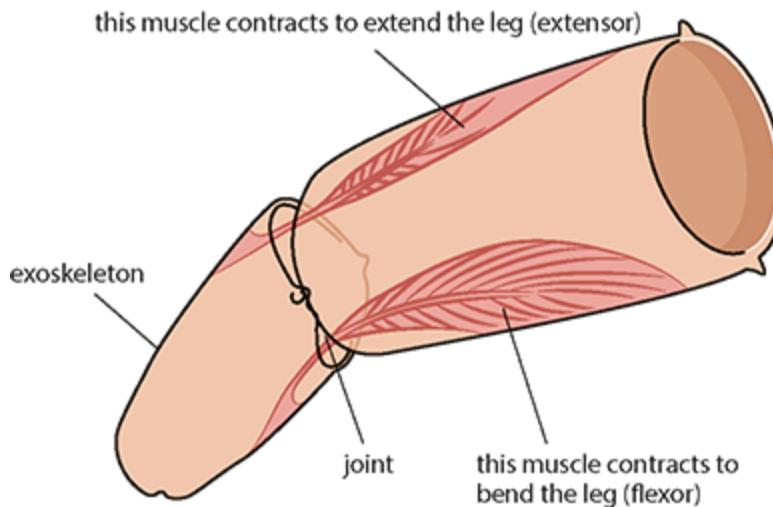


Figure 9.2.4: Part of an insect limb showing exoskeleton and muscle attachment.

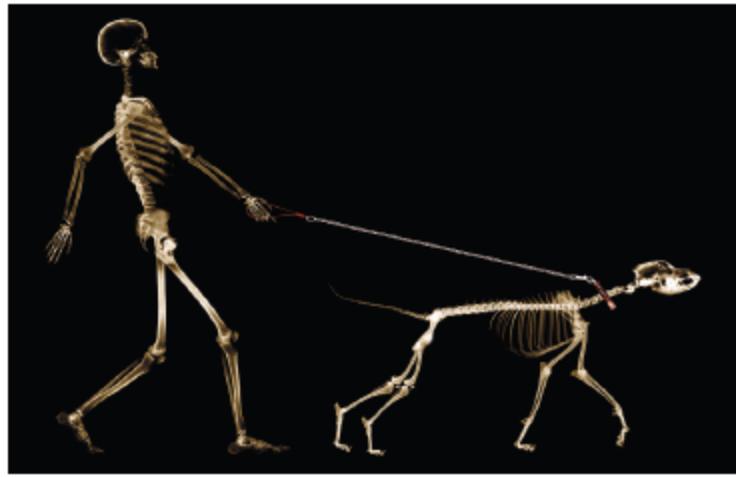


Figure 9.2.5: The skeleton supports the bodies of vertebrates.

Endoskeletons

Vertebrates have **endoskeletons** composed of firm, hard bones that do not change their shape. An internal skeleton allows an animal to move, and to move from place to place. It also provides support and, together with muscles, holds the body up and maintains its shape (Figure 9.2.5). The skeleton encloses and protects the soft parts of the body. For example, the rib cage encloses the lungs and heart and the skull protects the brain.

Bones meet at joints. Some of these joints, such as those between the vertebrae, permit very little movement. Others, such as those between bones in the arms and the legs, allow animals to bend into new positions to move their bodies. Muscles are attached to the bones of the skeleton by tendons. When a muscle contracts, it pulls a bone into a new position. Bones act as levers when they are moved by muscles. Levers are moved at a fixed point called the pivot.

Joints

A joint is a place where two or more bones meet. Joints between bones in the human body, together with the muscles that are attached to them, enable us to move and support the body. Most joints involve bones, muscles, cartilage, tendons, ligaments and nerves.

- Bones provide a framework that supports the body. They protect vital organs such as the brain and the lungs. Blood cells are formed within bones which contain bone marrow. Bones also act as a site for the storage of calcium and phosphate.
- Ligaments attach bones to one another at a joint. Some strap joints together while others form a protective capsule around a joint. They are tough and fibrous and provide strength and support so that joints are not dislocated.
- Tendons attach muscles to bones. They are formed of tough bands of connective tissue made of collagen fibres and are capable of withstanding tension as muscles contract.
- Muscles provide the force needed for movement. They can contract in length and as they do so they move the joint into new positions. Muscles only cause movement by contraction so they occur in antagonistic pairs – one muscle of the pair causes a movement in one direction while the other returns it to its original position.
- Motor neurones stimulate muscle contraction ([Section 9.1](#)) Sensory neurones transmit information from proprioceptors (position sensors) in the muscles so that movements can be coordinated and monitored.

The hip joint

The hip is a ball and socket joint. It is called this because it consists of the ball-shaped head of the femur (thigh bone) which fits into a socket in the hip. Ball and socket joints allow movement in more than one direction and allow us to make rotational movements. (Figure 9.2.6). It is an example of a synovial joint. The capsule that seals the joint is lined by a membrane that secretes lubricating synovial fluid so that the bones move smoothly against one another and friction is reduced. Smooth cartilage covers the ends of the bones at the joint and helps to reduce friction and absorb pressure as the joint moves.

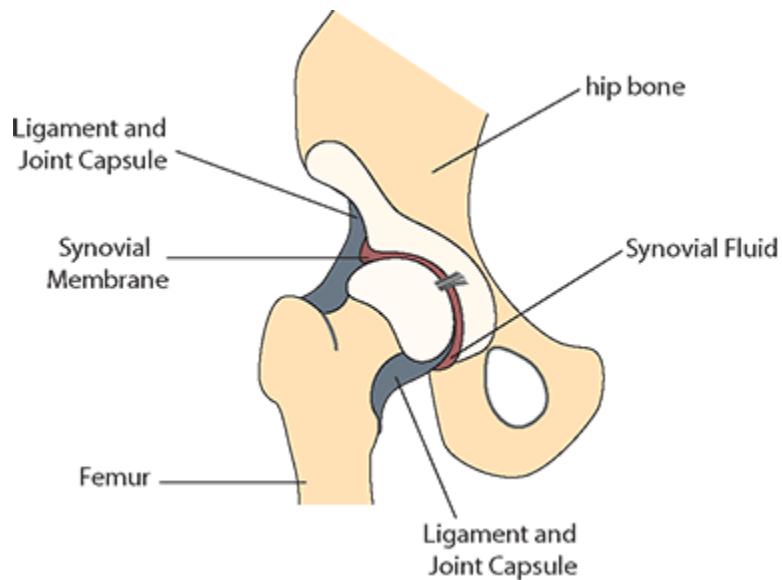
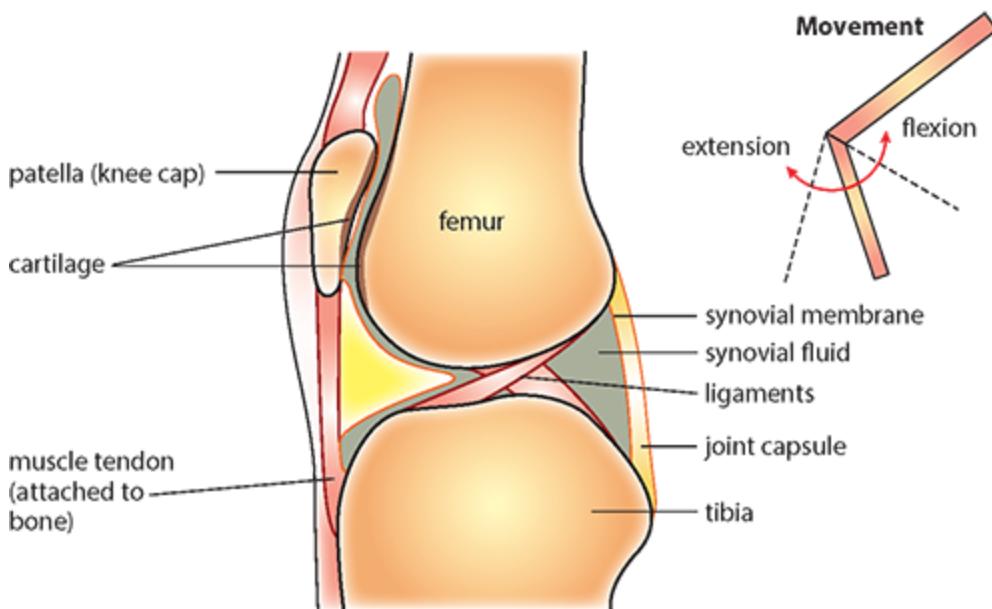


Figure 9.2.6: Diagram to show the structure of the hip joint.

Knee joint and movement at the knee



Hip joint and movement at the hip

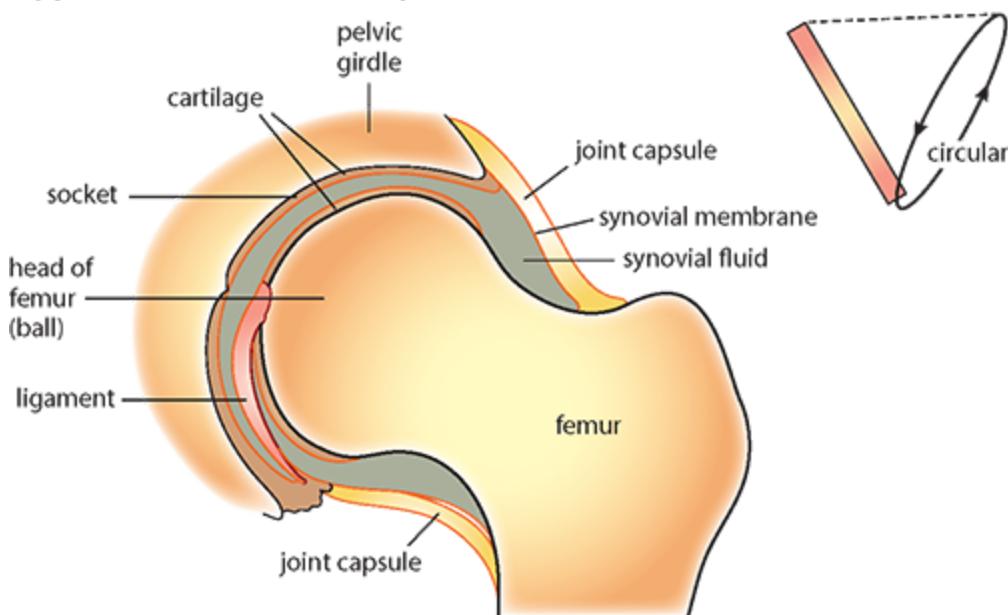


Figure 9.2.7: Longitudinal sections of the knee and hip joints, and the degree of movement they allow.

The hip joint is formed of the thigh bone (femur) of the leg and bones of the pelvis. Tendons attach sets of muscles to these

bones. As they contract the leg can be rotated or moved up and down. Pairs of muscles permit movement in opposite directions and are an example of antagonistic muscles.

The knee and elbow joints

The knee and elbow joints are examples of hinge joints and move to allow movement in only one direction. These joints are so-called because they move in a similar way to the opening and closing of a door hinge. Like the hip joint, both are synovial joints. Figure 9.2.7 shows the range of movement of a hinge joint.

9.2.3 Antagonistic muscles

Muscles can only cause a movement when they contract so they can only cause movement in one direction. To achieve movement in two directions most muscles work in antagonistic pairs which means that they work in opposition to each other. We can see an example of antagonistic muscles in the way we breathe; two sets of antagonistic muscles, the external and internal intercostal muscles of the ribcage together with the diaphragm cause us to breathe in and out. When the inspiratory external intercostal muscles contract, the expiratory internal intercostal muscles relax and we breathe in and vice versa.

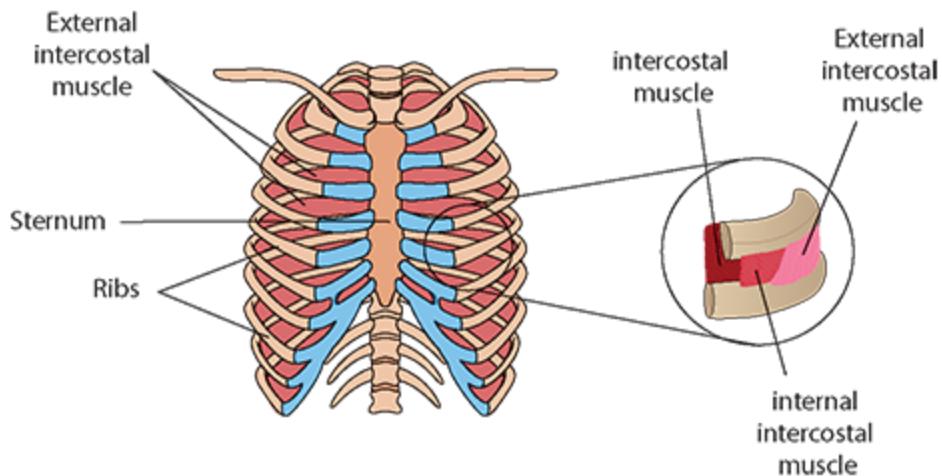


Figure 9.2.8: Arrangement of antagonistic muscles in the rib cage

The intercostal muscles of the rib cage are arranged in layers with fibres that run in opposite directions (Figure 9.2.8). The external intercostal muscles contract to expand the ribcage and move it upwards and increase the volume inside the chest cavity so that air is drawn in. As these muscles contract, they stretch the internal intercostal muscles which store potential energy in

the sarcomere protein titin ([section 9.2.1](#)) ready for exhalation (breathing out). During a strong exhalation the antagonistic internal intercostals and muscles of the abdomen contract to compress the chest cavity so that air is forced out. As this happens the external intercostal muscles will be relaxed.

Sliding filament model of muscle contraction

If skeletal muscle is examined with an electron microscope, it is possible to see that surrounding each myofibril is a system of membranes called the sarcoplasmic reticulum (which resembles smooth endoplasmic reticulum) and between the closely packed myofibrils are many mitochondria (Figure 9.2.9). Myofibrils are made up of repeating subunits called sarcomeres, which produce the striped appearance of a muscle fibre and are responsible for muscle contraction. The ends of a sarcomere are called the Z lines.

There are two types of filament that form the striped pattern of a muscle. These filaments are formed from the contractile proteins actin and myosin. The narrow filaments of actin are attached to the Z lines and extend into the sarcomere. Thicker filaments of myosin run between them. Where myosin is present, the myofibril has a dark appearance and a light band is seen where only actin is present. Myosin filaments have ‘heads’ which protrude from their molecules and are able to bind to special sites on the actin filaments.

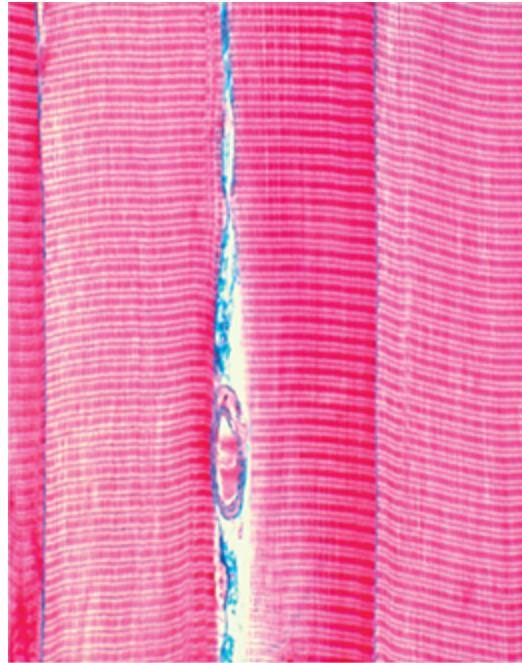


Figure 9.2.9: Light micrograph of striated muscle, stained to show the banding in muscle fibres.

Muscle tone

Contraction of a muscle causes shortening, and this in turn moves bones into a new position. If only a few fibres in a muscle contract, the muscle tightens but does not cause movement. Partial contraction produces muscle tone, which is important in maintaining posture and body shape.

Muscle contraction – the sliding filament theory

Muscle contraction is explained by the ‘sliding filament theory’, which describes how actin and myosin filaments slide over one another to shorten the muscle. Contraction is initiated by the arrival of a nerve impulse from a motor neurone, which stimulates the sarcolemma of the muscle fibre. This, in turn, causes the release of calcium ions (Ca^{2+}) from the sarcoplasmic reticulum and begins the process that causes actin filaments to

slide inward towards the centre of the sarcomere. The series of events is shown in Figure 9.2.11.

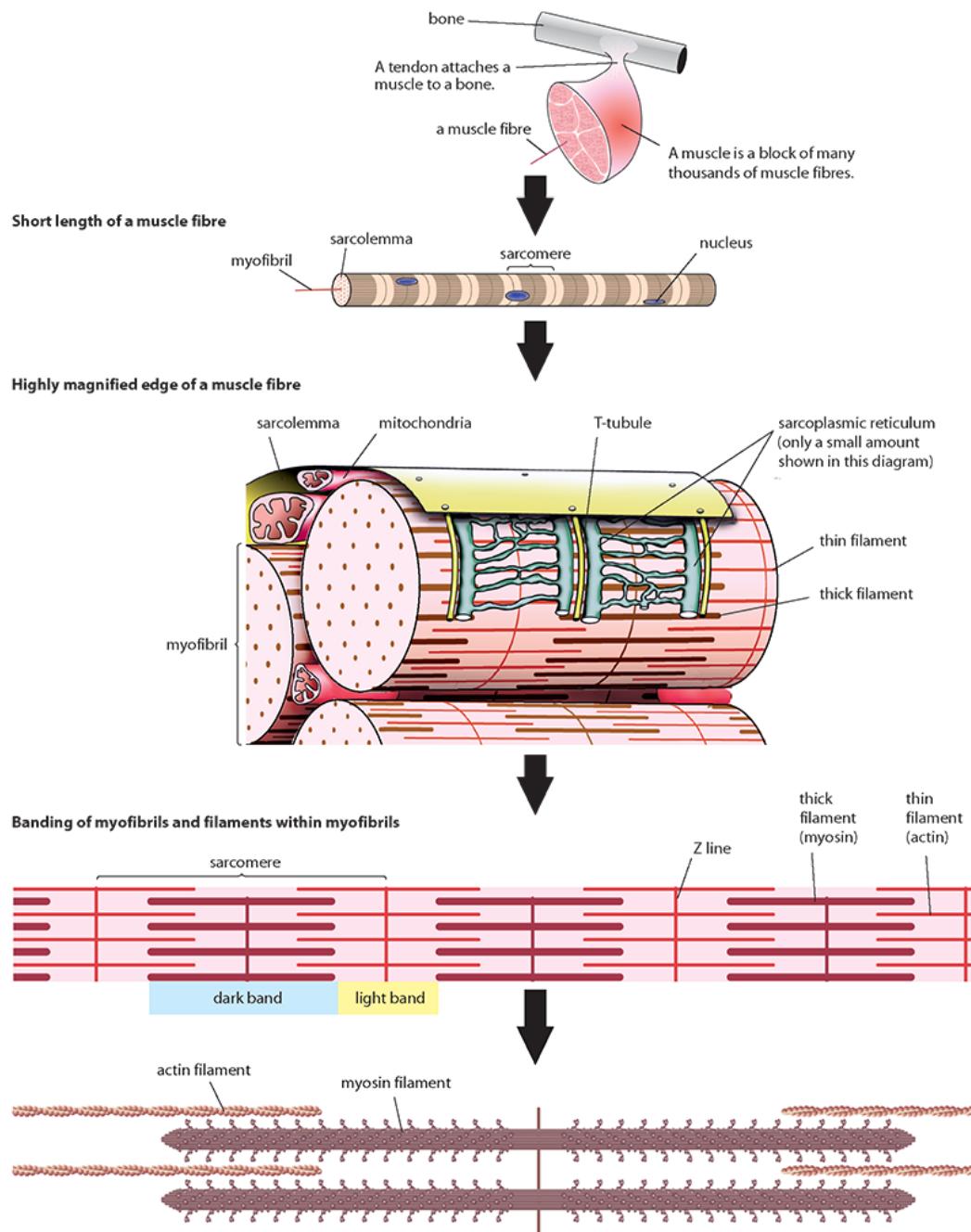


Figure 9.2.10: The structure of skeletal muscle.

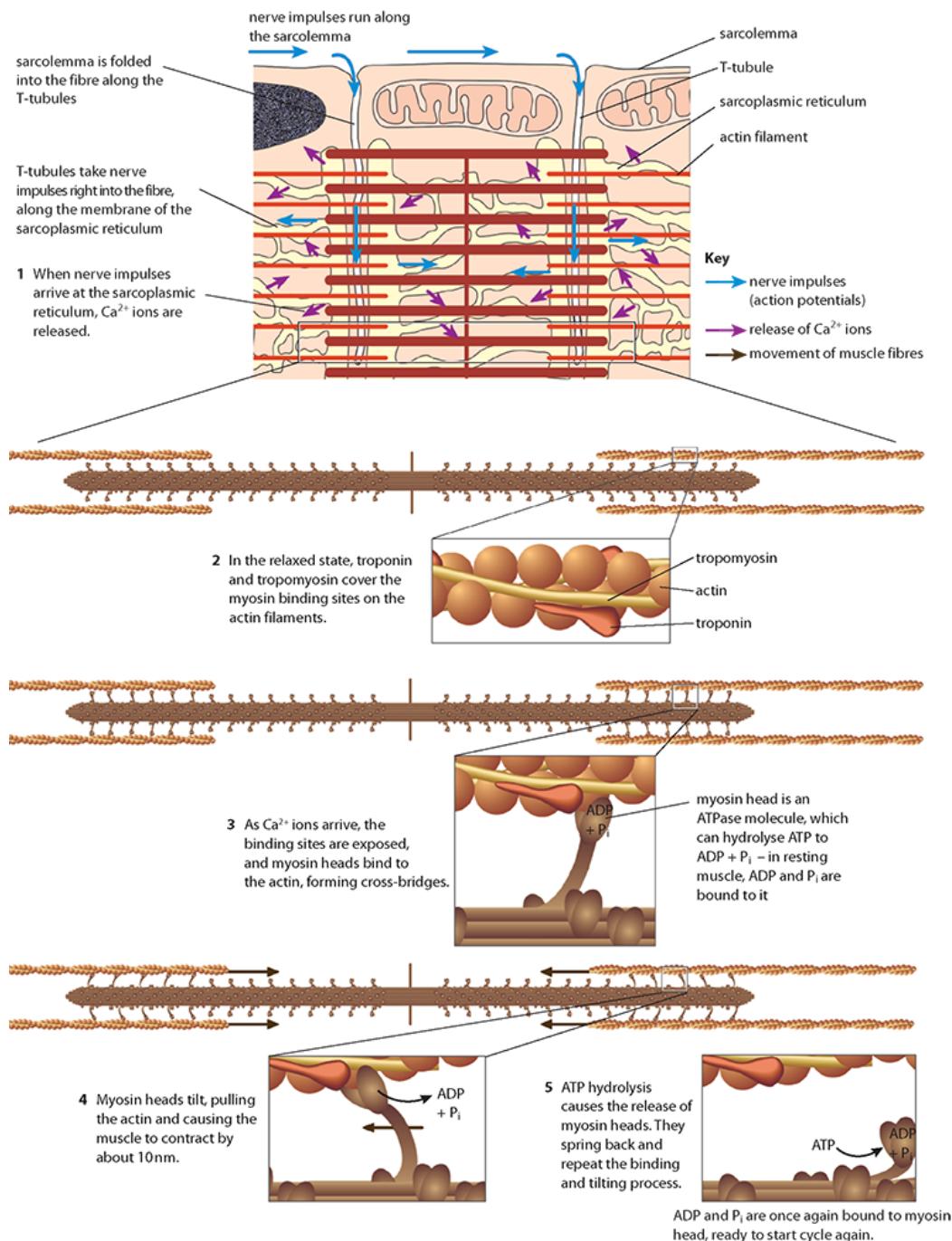


Figure 9.2.11: Muscle contraction.

- 1 Nerve impulses (action potentials) travel along the muscle fibre membrane, or sarcolemma, and are carried down into the fibre through infoldings called T-tubules. The impulses

then spread along the membrane of the sarcoplasmic reticulum, causing Ca^{2+} ions to be released.

- 2 Before contraction, binding sites for myosin heads on the actin filaments are covered by two molecules, troponin and tropomyosin. The myosin heads are prepared in an erect position as ATP binds to them.
- 3 Now Ca^{2+} ions bind to the actin filaments, causing the troponin and tropomyosin to change shape and expose the myosin binding sites. The myosin heads bind to the actin filaments at the exposed binding sites, forming cross-bridges.
- 4 This causes inorganic phosphate (Pi) to be released and, as each cross-bridge forms, ADP is also released. The myosin heads bend towards the centre of the sarcomere, pulling the actin filaments inward past the myosin filaments, by about 10 nm. This produces a ‘power stroke’.
- 5 New ATP molecules bind to the myosin heads, breaking the cross-bridges and detaching them from the actin filaments. ATP is used and the myosin heads return to the start position. If the muscle receives further stimulation, the process is repeated and the myosin heads attach further along the actin filaments.

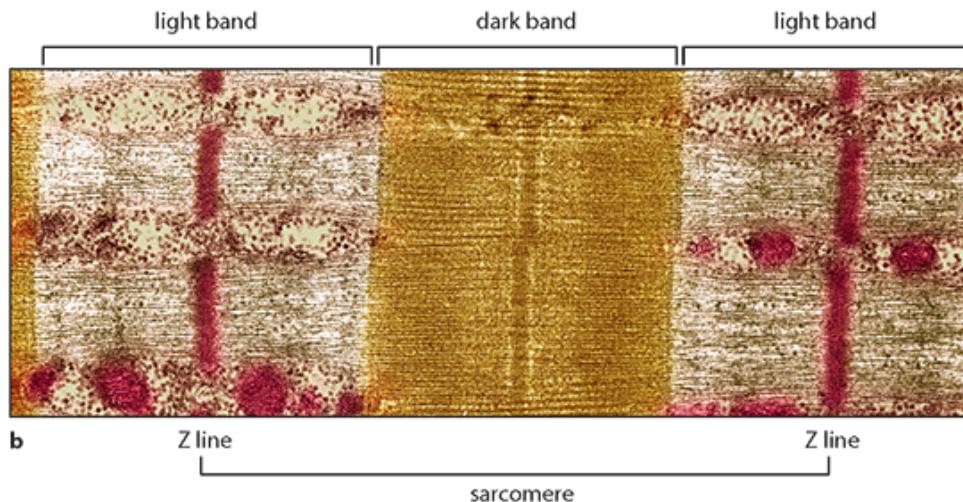
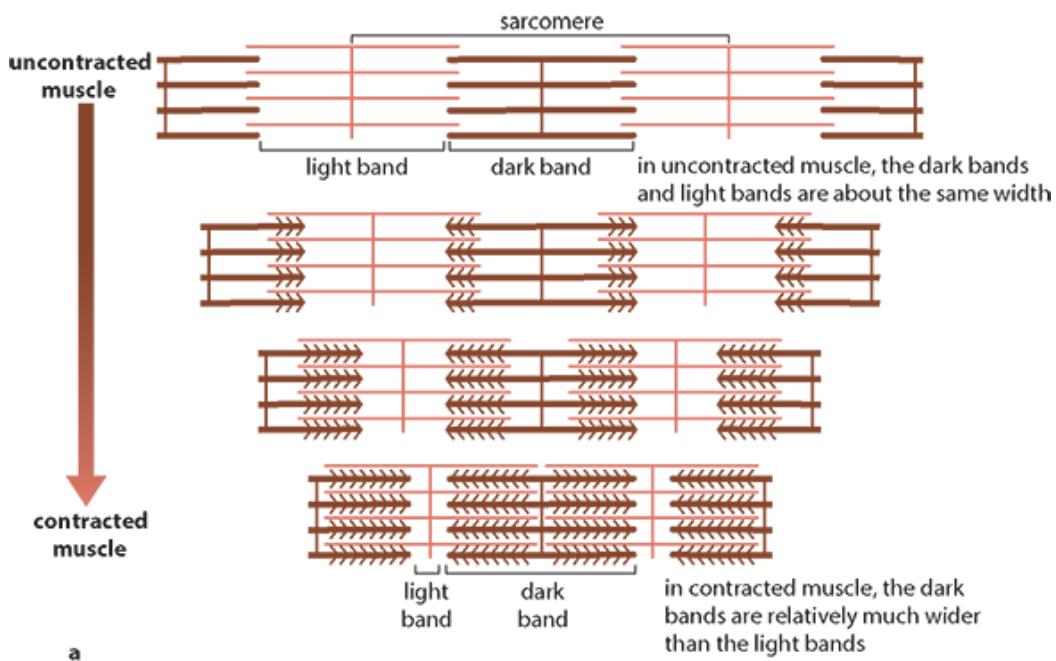


Figure 9.2.12: (a) When muscle contracts, the interleaved fibres slide inward, past each other. This makes the light bands appear narrower, but the dark bands remain the same width. (b). Coloured electron micrograph of a longitudinal section through striated muscle

Although the actin and myosin filaments do not change in length when a muscle contracts, the appearance of the banding patterns

in the sarcomere is changed. The light bands become reduced, and as the overall length of the sarcomere decreases the dark bands take up a greater proportion of the length (Figure 9.2.12).

The role of titin

Titin is the largest known protein, it is more than 1 μm in length. One of its main jobs is to provide structure, flexibility, and stability to muscle cell structures. Titin interacts with actin and myosin, to keep the components of sarcomeres in place as muscles contract and relax. Titin molecules are fixed in the Z-disc and extend to the centre of the sarcomere. Titin acts as a sort of molecular spring which maintains the precise arrangement of thick and thin filaments and keeps muscles firm.

The most important molecule for contraction in striated muscle and heart muscles is the thick filament of myosin. Titin helps to keep this thick filament at a precisely controlled length which determines the force that muscles generate and how this force varies with muscle length. Titin helps sarcomeres to recoil after they have been stretched and prevents muscles overstretching. It also stores potential energy in preparation for the action of an antagonistic muscle.

Motor units in skeletal muscle

A single motor neuron can stimulate many muscle fibres. Each muscle fibre has one neuromuscular junction which is a synaptic connection between the end of the motor nerve and the muscle. It is the site where an action potential is transmitted from nerve to the muscle. A **motor unit** consists of a neurone plus the muscle fibres it supplies. There are many motor units that together provide stimulation to a muscle to generate a contraction. Muscle fibres are stimulated to contract by the release of acetylcholine from the end of a motor neurone. Each