Credit value: 10

5 Anatomy and physiology for health and social care

If you are studying for a career in health and social care, you need to have a basic knowledge of where organs are in the body and how they do their jobs. You must have this knowledge to ensure the safety of those you are caring for, and also to maintain your own health and well-being – because you cannot give good care to others if you cannot look after yourself!

This unit explains the basic anatomy and physiology of the human body before moving on to look at selected body systems. The body is made of billions of cells and, after looking at the structure and functioning of cells, you will discover how these work together, managing the energy we use. You will also learn how other body systems are controlled – for example, how your body temperature remains the same, whether you are sunning yourself in summer or shivering in a winter snowstorm.

This unit provides a basic understanding of human physiology that underpins the specialist physiology units. It also provides an overview of body functioning that is valuable for anyone working in health and social care.

Learning outcomes

After completing this unit, you should:

1 know the organisation of the human body
2 understand the functioning of the body systems associated with energy metabolism
3 understand how homeostatic mechanisms operate in the maintenance of an internal environment
4 be able to interpret data obtained from monitoring routine activities with reference to the functioning of healthy body systems.

Assessment and grading criteria

This table shows you what you must do in order to achieve a **pass**, **merit** or **distinction** grade, and where you can find activities in this book to help you.

To achieve a pass grade, the evidence must show that you are able to:	To achieve a merit grade, the evidence must show that, in addition to the pass criteria, you are able to:	To achieve a distinction grade, the evidence must show that, in addition to the pass and merit criteria, you are able to:
P1 Outline the functions of the main cell components **See Assessment activity 5.1, page 183**		
P2 Outline the structure of the main tissues of the body **See Assessment activity 5.2, page 191**		
P3 Outline the gross structure of all the main body systems **See Assessment activity 5.3, page 197**		
P4 Explain the physiology of two named body systems in relation to energy metabolism in the body **See Assessment activity 5.4, page 216**	**M1** Discuss the role of energy in the body. **See Assessment activity 5.4, page 216**	**D1** Analyse how two body systems interrelate with each other to perform a named function/ functions. **See Assessment activity 5.4, page 216**
P5 Explain the concept of homeostasis with reference to the control of heart rate, breathing rate, body temperature and blood glucose levels **See Assessment activity 5.5, page 235**	**M2** Discuss the probable homeostatic responses to changes in the internal environment during exercise. **See Assessment activity 5.5, page 235**	**D2** Evaluate the importance of homeostasis in maintaining the healthy functioning of the body. **See Assessment activity 5.5, page 235**
P6 Follow guidelines to interpret collected data for heart rate, breathing rate and temperature before and after a standard period of exercise. **See Assessment activity 5.5, page 235**	**M3** Present data collected before and after a standard period of exercise with reference to validity. **See Assessment activity 5.5, page 235**	

How you will be assessed

This unit is internally assessed by your tutor. Various activities, exercises and scenarios have been included to assist you with studying different aspects of anatomy and physiology and in preparation for assessment.

Mia, 17 years old

At school, I wasn't really into science although I did know it was important to pass my GCSE because of all the nagging from my parents. There seemed to be so many bits to it, and it was really difficult to see how it fitted together. Uncle Pete hadn't been well that year. He was losing a lot of weight and his skin turned a yellowy-brown and the whites of his eyes went yellow. I was really worried about him and went to see him a lot. My Mum told me that he had jaundice and was very ill. He died later, only 44 years old – I really miss him, he always made me smile.

After the funeral, I wanted to know what exactly had been the matter with Pete. My mum showed me the death certificate, which said that Pete had died from cancer of the pancreas – I had only a vague memory of the pancreas and had no idea what it did. The family expected me to know more just because I am now studying Health and Social Care. I realise that it is important to have an understanding of the human body, even for everyday life. After doing this unit, I know more about the pancreas but am still not sure about the skin. It is more interesting to focus on one branch of science now. I think I will write about Uncle Pete in Physiological Disorders next year and I *will* find out about yellow skin.

Over to you!

1 How good is your understanding of the human body?

2 Which parts of this unit do you think you will enjoy the most?

3 How does the unit relate to your life and what you would like to do in the future?

1 Know the organisation of the human body

Get started

Build on what you know!

In small groups, make a list of the human body systems that you already know about (on a large sheet of paper), and the organs associated with each system. Using your list, write down all the functions of each system that you can think of. If you bounce ideas off other members of your group, you will be surprised at how much knowledge you can collect.

Each group can then share their list with the rest of the class.

1.1 Organisation of the body

Every individual is composed of billions of microscopic units called **cells**. The cells carry out vast numbers of chemical reactions and processes that make up the essence of life itself.

Cells rarely exist in isolation; they are usually grouped together with other similar cells carrying out particular tasks. Groups of cells are known as tissues.

Different types of tissues are commonly grouped together to form an organ, which carries out a particular function.

Finally, groups of organs that are responsible for major tasks or functions in the body are called organ systems or sometimes body systems.

Activity 1: Sorting out

Get into groups. Each group should write on four large pieces of paper: 'cells', 'tissues', 'organs' and 'body systems'. Each group member should then write out the name of a type of cell, tissue, organ and body system on four smaller slips of paper. Mix them up and give four to every individual. Each member should place their slips under the correct label. The group can then discuss the accuracy of their decisions.

If you are working on your own, you can sort the following examples into cells, tissues, organs and body systems: heart, bone, blood, skeleton, red blood cell (or erythrocyte), cartilage, nervous system, kidney, brain, digestive system, skin, stomach, muscle cell, bladder, muscle, renal system.

PLTS

Reflective learner: This activity will enable you to demonstrate reflective learning by drawing on previous knowledge.

1.2 Cells

The largest cell in the human body is the female ovum, which can just be seen with the naked eye. Most cells are much smaller than this, and microscopes are required to view them. Ordinary light microscopes, such as those found in school or college laboratories, are quite good for viewing tissues and organs, but not very useful for looking inside individual human cells.

Electron microscopes are necessary to see the detail of cell contents. However, as these are highly expensive instruments requiring trained operators to prepare and interpret the specimens, we use diagrams and **photomicrographs** instead.

Details of the interior of a cell are often referred to as the ultrastructure of the cell ('ultra' means 'beyond what is considered normal'). This is because they can only be seen with immense magnification. Before the electron microscope was developed, the inside of a cell was considered to be a granular sort of 'soup' but

Key terms

Cell – The basic unit of living material.

Electron microscope – A very powerful type of microscope needed to see inside cells.

Photomicrograph – A photograph taken of an object magnified under a microscope.

we now know that the ultrastructure is highly organised and composed of many different bodies carrying out their own functions.

Do you remember the definition of an organ? The very tiny bodies inside a cell are known as **organelles** because they have different physical (and chemical) compositions and carry out their own functions.

Although you will learn about a typical human cell, there are actually lots of different types of cells each with their own characteristics. The 'typical cell' exists only for study purposes and has no specialisation. When studying actual cells in the body, you must therefore adapt your knowledge to the specific type of cell being considered. For example, a mature red blood cell does not have a **nucleus**, so any description of the ultrastructure of a red blood cell would not include the nucleus.

Living material making up a whole cell is called **protoplasm** and this is subdivided into the **cytoplasm** and nucleus.

Under the light microscope, cytoplasm appears granular with no distinct features. This is the site of most complex chemical reactions, mainly directed by the nucleus, which is also responsible for inherited characteristics. The nucleus is a dark body, usually centrally placed; a smaller, darker spot, the nucleolus, is often visible. Both the whole cell and the nucleus are surrounded by a membrane, which appears as a single line (see Figure 5.1).

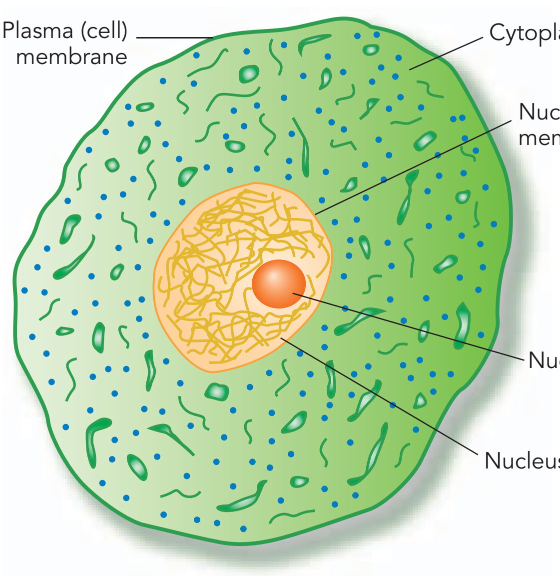


Fig 5.1: Diagram of a cell viewed under a light microscope (× 300)

Cell ultrastructure is so complex and highly organised that a separate branch of science has arisen – cytology, the study of cells. In this unit you will learn about the structure and functions of the cell membrane, the organelles in the cytoplasm, and the nucleus.

Cell (or plasma) membrane

The electron microscope shows the cell membrane to be a phospho-lipid-protein bi-layer. The lipids are small, fatty molecules in two layers (bi-layer), with larger protein molecules inserted at intervals partly or completely through the bi-layer. The lipid molecules are phospholipids; the phosphate head is water soluble and two lipid chains are insoluble in water. This is why the two layers align themselves, with the lipid chains facing one another. The fluid surrounding cells (called tissue fluid) and the cytoplasm are both watery environments next to the phosphate heads (see Figure 5.2, next page).

Protein molecules often form channels through the membrane for substances to pass to and from the cell. The protein molecules also act as identity markers or reception sites for other molecules such as hormones, which are important to those cells. This structure is often termed the 'fluid mosaic model' of the cell membrane.

Cytoplasm

Cytoplasm is a semi-fluid material likened to a gel and capable of flowing slowly. Many chemical reactions are carried out here. The collective term for these reactions is **metabolism** and you will find that this term is frequently used in physiological and biological texts. Complex storage sugars such as glycogen and melanin

Key terms

Organelle – A tiny body inside a cell, which carries out its own functions.

Nucleus – The central part of the cell, which is usually darker than the rest because it absorbs stain quickly.

Protoplasm – The word means 'first material'; the protoplasm refers to anything inside the cell boundary. Cell or plasma membrane surrounds the protoplasm.

Cytoplasm – The word means 'cell material'; the cytoplasm refers to anything inside the cell boundary and outside the nucleus.

Metabolism – The metabolism is the sum of all the chemical reactions occurring in human physiology and these involve using or releasing energy from chemical substances.

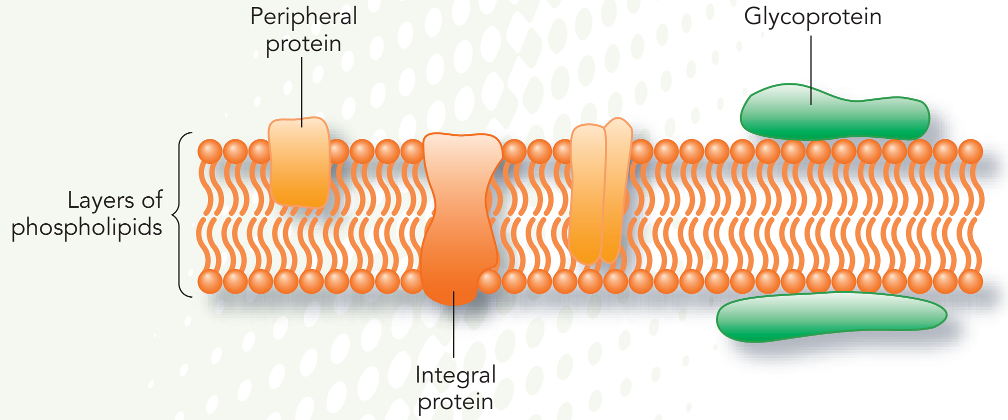


Fig 5.2: Model of the structure of the cell membrane magnified several thousand times

(the dark pigment responsible for skin and hair colour) are found in cytoplasm.

Nucleus

This is usually the largest structure inside the cell and, as it takes up dyes or stains very easily, it stands out as a dark shape. Most cells have a single, central, spherical nucleus but there are many variations. Some muscle cells have many nuclei and are therefore called 'multinucleate'; some red blood cells have lost their nucleus during development and are said to be 'anucleate'; and some white blood cells have distinct, lobed nuclei. Apart from red blood cells (which cannot reproduce and have a limited lifespan), most cells that are separated from their nuclei will die.

The nuclear membrane has a structure similar to that of the cell membrane but contains gaps or pores, through which proteins and nucleic acids pass. When a cell is not dividing (known as 'resting') the nuclear material appears like a thick, tangled mass and is called the **chromatin network**. A smaller, darker sphere is often visible, the nucleolus, and this is a source of **ribonucleic acid (RNA)**, one of the nucleic acids. There may be more than one nucleolus present in some cells. When a cell is in the process of dividing, the chromatin network separates into distinct black threads known as **chromosomes**. There are 23 pairs of chromosomes in a human cell, containing specific sequences of **deoxyribonucleic acid (DNA)**, another nucleic acid, which is responsible for all our inherited characteristics such as hair and eye colour. The sequences of DNA are our genes.

The nucleus controls nearly all the activities of the cell and has been likened to the architectural drawing or blueprint from which the cell operates.

Cell organelles

Organelles are various components of a cell with a distinct structure and their own functions and can be likened to miniature organs (hence the term 'organelles').

Organelles include:

- mitochondria
- the endoplasmic reticulum
- the Golgi apparatus
- lysosomes.

Before looking at the organelles in detail, you will see in Fig 5.3 a diagram of a typical cell that might be seen under the electron microscope; refer to the diagram as you learn about the organelles. Note that the magnification is still not sufficient to make out the full structure of the cell and nuclear membranes.

Key terms

Chromatin network – The dark tangled mass seen in the nucleus of a resting cell.

Ribonucleic acid (RNA) – A nucleic acid found in both the cell and the nucleus. RNA is responsible for the manufacture of cell proteins such as pigments, enzymes and hormones.

Chromosomes – Long threads of DNA and protein seen in a dividing cell. They contain the genetic material or genes responsible for transmitting inherited characteristics.

Deoxyribonucleic acid (DNA) – A nucleic acid found only in the chromatin network and chromosomes of the nucleus. DNA is responsible for the control and passing on of inherited characteristics and instructions to the cell.

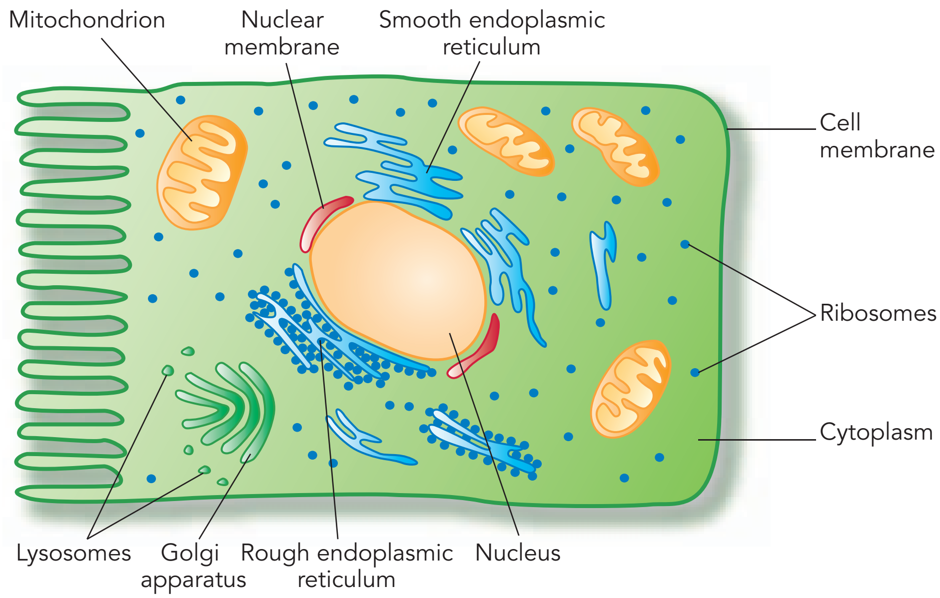


Fig 5.3: A typical human cell appearance from an electron micrograph

Activity 2: Organelle recall

You may be feeling somewhat bewildered by these difficult terms that are also hard to spell. Don't be disheartened! It really is surprising how quickly you can learn them if you keep repeating them over and over and pointing them out in electron micrographs. When you feel confident about recognising their shapes, try adding their functions too. Your tutor will be able to find different copies of electron micrographs and you can research your own for practice. One image is included on page 182. Try identifying each organelle on the image and list each one with its main function.

PLTS

Effective participator: You will demonstrate effective participation when planning and carrying out research on cell organelles.

Functional skills

ICT: You will use ICT skills to access, search for and use information on cell organelles in different types of cells.

Mitochondria

Every cell in the body has at least 1000 of these rod-shaped or spherical bodies, and very energy-active cells (like muscle and liver cells) will have many more. **Mitochondria** are concerned with energy release. Each mitochondrion (singular) has a double-layered membrane like the cell membrane but the inner layer is folded at intervals, producing a series of 'shelves' or ridges known as **cristae**. The enzymes responsible for the end stages of glucose oxidation (or cell respiration) are located on the cristae. The energy released from glucose is trapped and stored until required by a 'chemical battery' called **adenosine triphosphate (ATP)**. When energy is required for building complex molecules or doing work like contracting muscles, ATP breaks down to **adenosine diphosphate (ADP)**, releasing energy to build chemical bonds. The ADP is then recycled, to be built up once more into ATP, using the energy released from glucose. This occurs in the mitochondria.

Key terms

Mitochondria – Spherical or rod-shaped bodies scattered in the cytoplasm and concerned with energy release.

Cristae – Folds of the inner layer of mitochondrial membrane on which the enzymes responsible for the oxidation of glucose are situated.

Adenosine triphosphate (ATP) – A chemical in mitochondria that is capable of trapping lots of energy in the last chemical bond: for example, A-P-P~P, where P is a phosphate group (an ordinary chemical bond) and ~ is a high energy bond.

Adenosine diphosphate (ADP) – A chemical left after ATP has released its stored energy to do work.

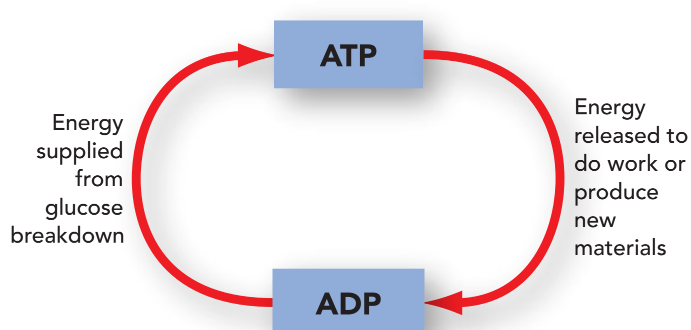


Fig 5.4: Flow chart of energy production in cells

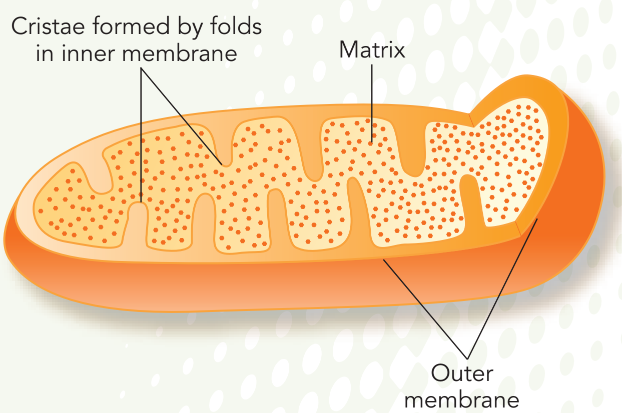


Fig 5.5: Structure of a single mitochondrion

Endoplasmic reticulum

This can be shortened to ER. There are two variations, called rough and smooth ER. 'Endo-' means 'within' and 'reticulum' is a technical term for 'a network'. ER is a branching network that fills the cell interior. The membrane of the channels is similar in structure to the cell membrane and continuous with the nuclear membrane. The channels form passageways for transporting materials to and from different parts of the cell.

- *Rough ER* is so-called because it is studded with tiny black bodies, known as ribosomes, and has the function of making cell proteins and acting as a temporary storage area. Sometimes sugars are added to the proteins to make glycoproteins, in secretions such as mucus.
- *Smooth ER* has no attached ribosomes and is involved in the metabolism of lipids or fats.

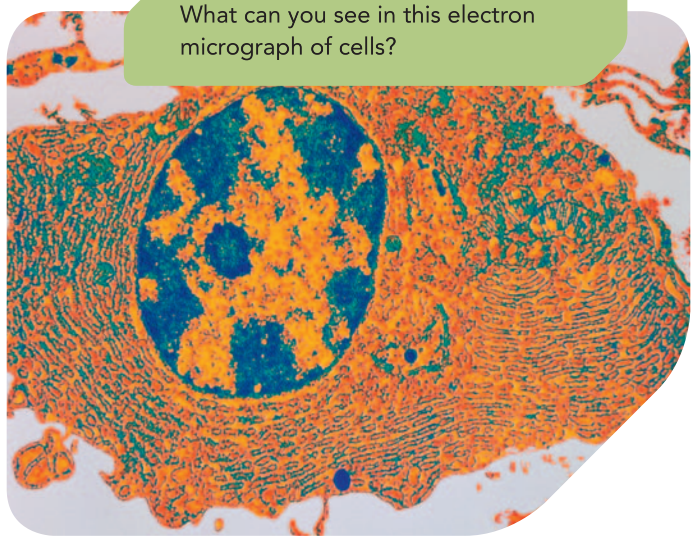
Golgi apparatus

This appears as a series of flattened, fluid-filled sacs stacked like pancakes. Many tiny fluid-filled globules or bags lie close to the main stack and these are often known as vesicles. Golgi was a famous Italian scientist who specialised in cells and tissues in the nineteenth and twentieth centuries and this organelle takes its name from him. It is believed that the Golgi apparatus packages proteins for delivery to other organelles or outwards from the cell in secretions. The Golgi apparatus is also responsible for producing lysosomes.

Lysosomes

Lysosomes can be found in all parts of the cell cytoplasm and are also small vesicles produced by part of the Golgi apparatus. Because they contain powerful enzymes capable of digesting all major chemical components of living cells, they are sometimes called 'suicide bags'. Lysosomes can travel freely throughout the cell and, by releasing their contents, they can destroy old or damaged organelles and even entire cells. Another of their functions is to destroy bacteria and other foreign materials, such as carbon particles, that enter the cell. They do this by taking the foreign matter into their vesicles. After destroying the foreign matter with their enzymes, the lysosomes release the digested or broken-down material.

What can you see in this electron micrograph of cells?



Some types of white blood cells – phagocytes (literally 'eating cells') and monocytes – and tissue cells known as macrophages (meaning 'large eaters') are loaded with lysosomes because their function is to destroy bacteria, viruses and foreign material entering the body cells and tissues.

Many disease-causing agents are thought to be capable of damaging lysosome membranes, bringing about internal cell destruction.

Now try Activity 3 and, when you feel that your learning is complete, try the assessment activity which follows. You can improve your work if you are not satisfied with it.

Did you know?

The electron microscope enables you to see extremely small objects to identify their structure but it does not tell you what the structures do. Researchers with a range of expertise (such as chemists, physicists and biochemists) have to separate out the different structures and carry out many tests to identify the functions of the tiny objects they observe.

Activity 3: Interpreting photographs of cells

Using a copy of the electron micrograph on the previous page and/or similar material from your tutor and the labelled diagram in Figure 5.3 (on page 181), match the different parts of a cell and the organelles. You can download some electron micrographs from the Internet as well. As you carry out this exercise, describe the appearance and the function of each part. You will soon realise that interpreting photographs of real cells is more difficult than it appears! Although you can carry out this activity on your own, you can learn more with a 'study buddy' because you can check each other's learning and interpretation of the cell parts. After each 'journey' through the cell parts, check your recall against this text and any class notes you may have. You and a small group of peers can carry out a 'thought shower' on the roles of cell organelles and carry out research on any you are not sure of.

Assessment activity 5.1

P1 BTEC

Using a large piece of paper, produce an annotated poster of a cell as it is seen under an electron microscope. You must include the following organelles: nucleus, cytoplasm, mitochondria, smooth and rough endoplasmic reticula, Golgi apparatus and lysosomes.

The notes accompanying the labels should include the main activities carried out by the organelles.

Grading tip

P1 To achieve P1, you need to outline the functions of the main cell components. This means giving an overview of the cell structure and function without including any more detail than is covered in the text. Although you are not obliged to include a separate image of each organelle, your work will clearly be more comprehensive if you do. If you download material from the Internet you must show clearly how you have adapted it to show your learning, as well as providing a detailed reference and acknowledgement. It would be acceptable to obtain an image and label it carefully yourself to show the relevant parts. Make sure that you use colour and make the poster clear, attractive and interesting.

1.3 Tissues

Tissues are groups of similar cells carrying out specific functions. In this unit you will learn about the following tissues:

- epithelial
- connective
- muscle
- nervous.

Epithelial tissues

Epithelia are the linings of internal and external surfaces and body cavities, including ducts (tubes or channels) carrying secretions from glands. They may be composed of several layers of cells, called compound epithelia, or just a single layer known as simple epithelia. The lowest or bottom layer of cells is attached to a basement membrane for support and connection. Part of the basement membrane is secreted by the epithelial cells. There are nerve supplies to epithelia but they are supplied with oxygen and nutrients from deeper tissues by **diffusion**. As they are surface tissues and exposed to friction, their capacity for growth and repair is greater than other tissues and usually occurs during sleep.

Simple epithelia

Simple epithelial cells may be squamous, cuboidal, columnar or ciliated. Squamous epithelial cells are

Key term

Diffusion – This is the passage of molecules from a high concentration to a low concentration.

very flat, with each nucleus forming a lump in the centre. The word 'squamous' means 'scaly', referring to the flatness of the cells. They fit together closely, rather like crazy paving. Clearly, such delicate thin cells cannot offer much protection and their chief function is to allow materials to pass through via diffusion and **osmosis**. Simple squamous epithelium is found in the walls of:

- lung alveoli
- blood capillaries
- Bowman's capsule of nephrons.

As their name suggests, cuboidal epithelial cells are cube-shaped, with spherical nuclei. They often line ducts and tubes and can allow materials to pass through in a similar way to squamous epithelia. They often occur in glandular tissues making secretions. They can be found in:

- kidney tubules
- sweat ducts
- glands like the thyroid gland and breast tissue.

Key term

Osmosis – The passage of water molecules from a region of high concentration (of water molecules) to one of low concentration through a partially permeable membrane such as the cell membranes of simple epithelial cells.

Columnar epithelial cells are much taller, with slightly oval nuclei. They can often be associated with microscopic filaments known as cilia and are then called ciliated epithelia. Cilia move in wave-like motions, beating towards the orifices, and are commonly found associated with goblet cells, which secrete mucus in the respiratory and alimentary tracts. The mucus traps unwanted particles like carbon, and the cilia transport the flow of 'dirty' mucus towards the exterior.

Columnar cells are found lining:

- the trachea and bronchi
- villi in the small intestine.

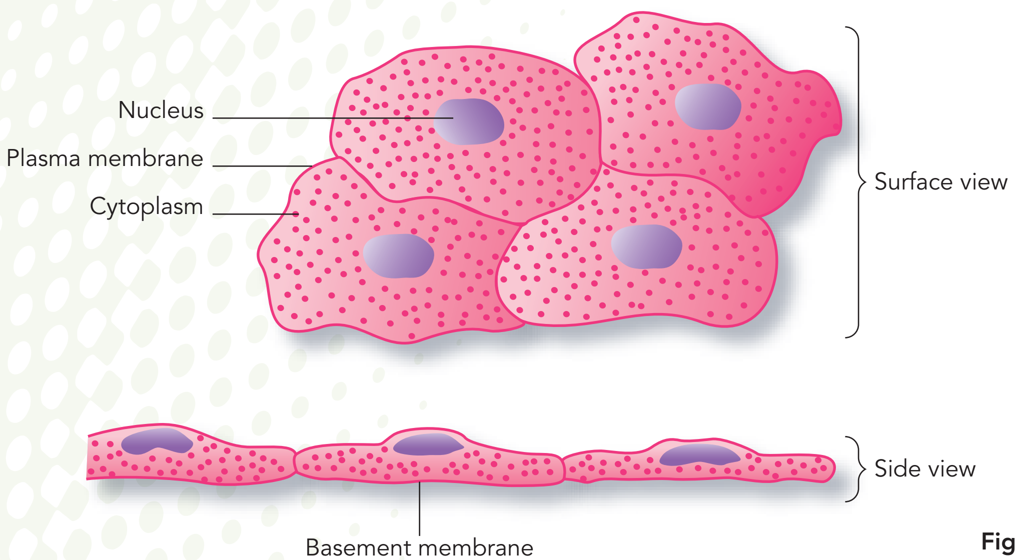


Fig 5.6: Simple squamous epithelium

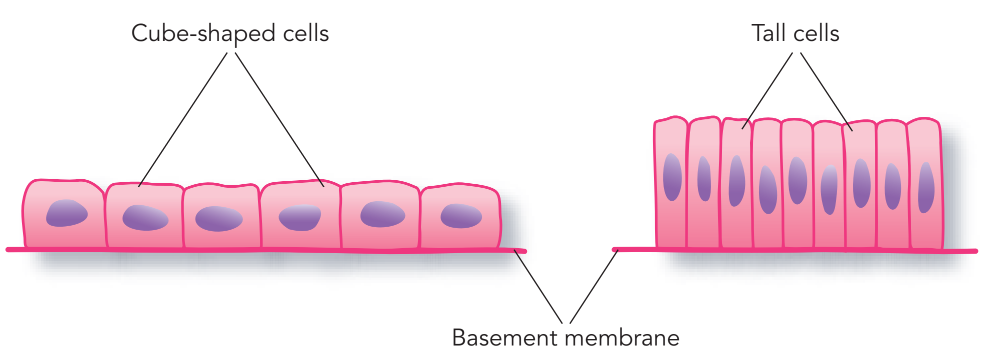


Fig 5.7: Simple cuboidal and columnar epithelia

Compound epithelia

The principal function of compound epithelia is to protect deeper structures, and multiple layers of cells hamper the passage of materials. The vagina, mouth, tongue and oesophagus are lined by stratified epithelia consisting of layers of squamous, cuboidal or columnar cells, which gradually become flattened by pressure from below as they reach the surface. The lowest layer of cells on the basement membrane actively divides and the older cells are pushed upwards. This type of epithelia is usually a pink colour and is often termed mucous membrane.

The skin has an outer layer of epithelium similar in structure to the stratified epithelium but with the important addition of a layer of flattened dead cells on the outside. This is known as the epidermis. As the cells advance from the basement membrane, they gradually become filled with a protein called keratin and are said to be keratinised or cornified. This layer is vital to prevent micro-organisms invading deeper structures, and it has a waterproofing effect on the skin. The skin can be variously coloured, with pigment produced by pigment cells in the lowest layer. The pigment melanin darkens under the influence of the sun. The numbers of pigment cells in the skin is genetically inherited, although they can divide during exposure to sunshine.

The structure of the skin epidermis can be seen in Figure 5.8 below.

Connective tissues

These tissues are the most widely distributed in the body and lie beneath the epithelial tissues, connecting different parts of the internal structure.

Various types of cells lie in a background material known as a **matrix**. The matrix may be liquid as in blood, jelly-like as in areolar tissue, firm as in cartilage, or hard as in bone. The matrix of a tissue is usually secreted by the connective tissue cells.

The functions of these tissues are to transport materials (as in blood), give support (as in areolar tissue and cartilage), and strengthen and protect (as in bone). Many tissues contain different fibres secreted by the cells to provide special characteristics.

In this unit you will learn about the connective tissues of:

- blood
- cartilage
- bone
- areolar tissue
- adipose tissue (fatty tissue).

Blood

Blood consists of straw-coloured plasma (the matrix), in which several types of blood cells are carried. Plasma is mainly water, in which various substances are carried, such as dissolved gases like oxygen and carbon dioxide, nutrients like glucose and amino acids, salts, enzymes and hormones. There is also a combination of important proteins, collectively known as the plasma proteins, which have roles in blood clotting, transport,

Key term

Matrix – Background material in which various types of cells lie.

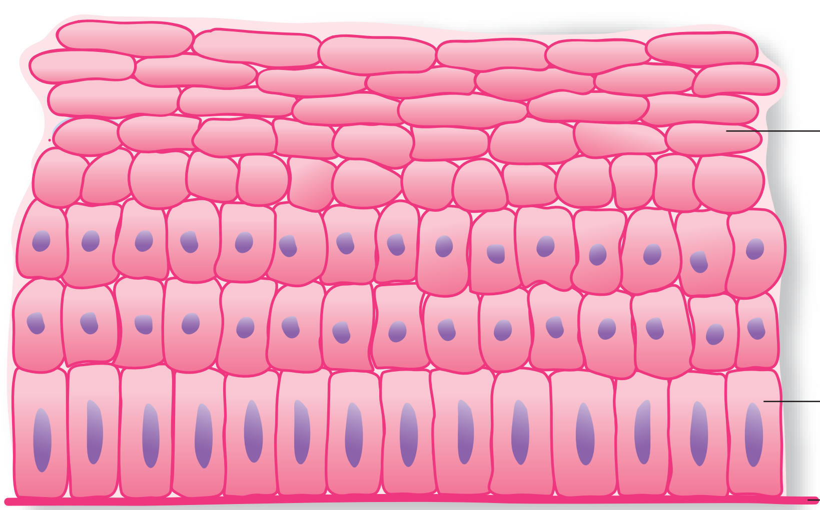


Fig 5.8: Section through stratified epithelium

defence against invading organisms (part of the immune system) and osmotic regulation.

The most common cells by far in the plasma are red blood cells, also known as erythrocytes. These are very small cells with an elastic membrane, which is important because the membrane often has to distort to travel through the smallest capillaries. Erythrocytes have no nucleus in their mature state (the loss produces a depression in the top and bottom of the cell, hence their bi-concave shape), which provides a larger surface area to be exposed to oxygen. They are packed with haemoglobin, which gives them a red colour. (This is why blood is red.) In oxygenated blood (**arterial blood**), the oxyhaemoglobin is bright red but, in deoxygenated blood (**venous blood**), after the dissolved oxygen is delivered to body cells, the reduced haemoglobin is dark red in colour.

Due to the absence of nuclei, erythrocytes cannot divide and have a limited lifespan of around 120 days.

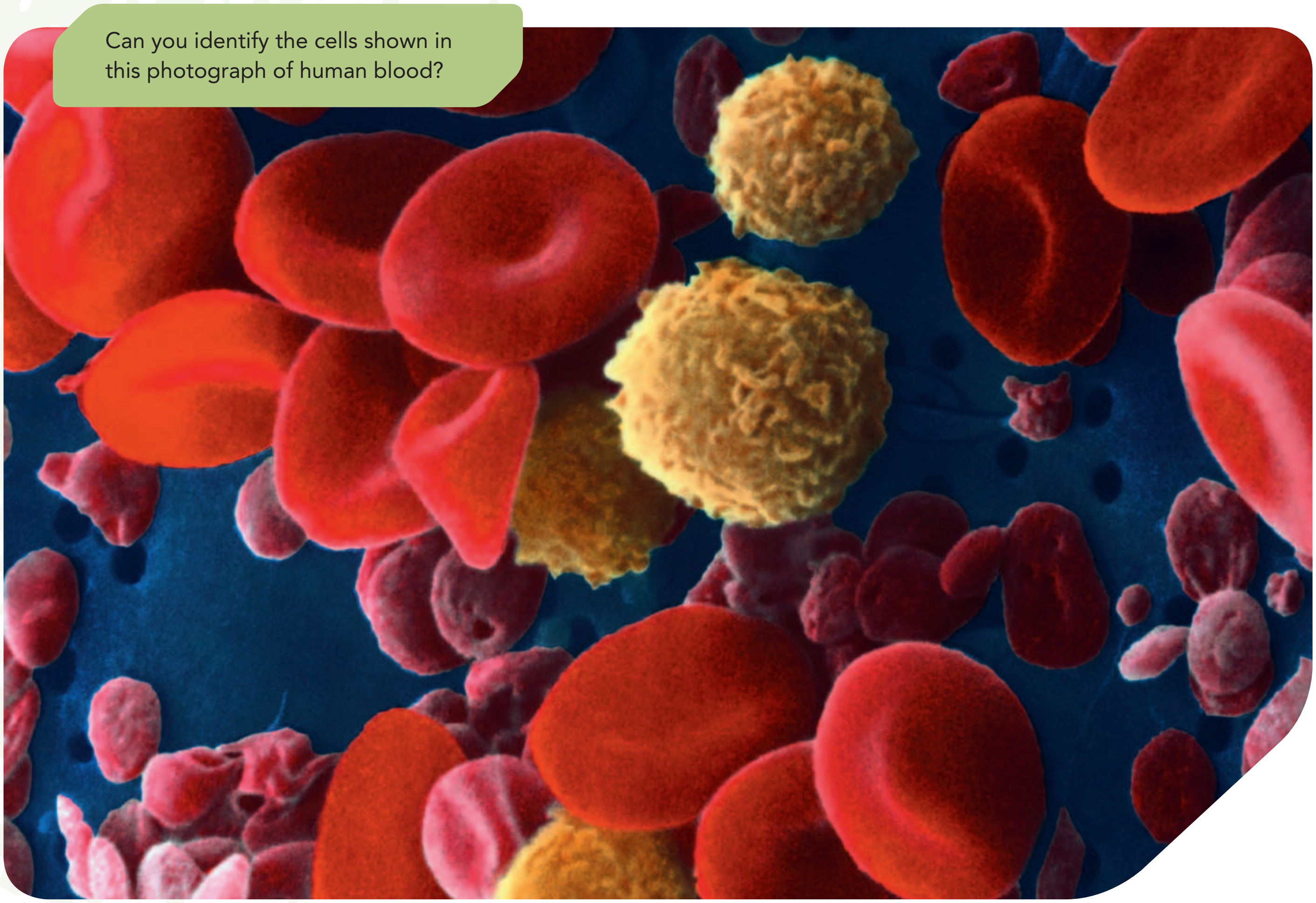
White blood cells (or leucocytes) are larger, nucleated and less numerous. There are several types but the most numerous are the granulocytes (also known as polymorphs, neutrophils and phagocytes). They are called granulocytes because they contain granules in their cytoplasm as well as lobed nuclei. They are capable of changing their shape and engulfing foreign material such as bacteria and carbon particles. This process is known as phagocytosis. A granulocyte acts rather like an amoeba and is sometimes said to be amoeboid. Granulocytes, because of their ability to engulf microbes and foreign material, are very important in defending the body against infection.

Key terms

Arterial blood – Blood flowing through arteries that are coming from the heart, usually carrying oxygenated blood to the tissues.

Venous blood – Blood flowing through veins that are returning blood to the heart from the tissues; the blood has left considerable amounts of oxygen behind to supply the cells and is known as deoxygenated blood.

Can you identify the cells shown in this photograph of human blood?



Did you know?

The number of granulocytes rises significantly in infections, so a blood count can often be a valuable indicator of infection when diagnosing illness.

Lymphocytes are smaller white blood cells with round nuclei and clear cytoplasm – they assist in the production of antibodies. Antigens are found on the surface coats of disease-causing microbes or pathogens and act as identity markers for different types of pathogens (rather like name tags on a school uniform). Antibodies neutralise antigens and prevent the microbes from multiplying. They can then be phagocytosed by granulocytes and monocytes. Antibodies are chemically globulins (types of protein carried in the plasma).

In a completely different way from granulocytes, lymphocytes also contribute to the defence of the body because of their role in the production of antibodies. They form an important part of the immune system.

Monocytes are another type of white blood cell, larger than lymphocytes. They also have large, round nuclei and clear cytoplasm. They are very efficient at phagocytosis of foreign material and, like granulocytes, can leave the circulatory blood vessels to travel to the site of an infection and begin phagocytosing pathogens very rapidly.

Thrombocytes are not true cells but are usually classed with the white blood cells. They are more commonly called platelets. They are products of much larger cells that have broken up and they have an important role in blood clotting.

Did you know?

Granulocytes, monocytes, platelets and red blood cells are made in bone marrow but lymphocytes are produced in lymphoid tissues.

Cartilage

This is the smooth, translucent, firm substance that protects bone ends from friction during movement, and forms the major part of the nose and the external ear flaps, called pinnae. The matrix is secreted by cartilage cells called chondrocytes and is a firm but flexible glass-like material of chondrin (a protein). ('Chondro-' is a prefix associated with cartilage.) The cells become trapped in the matrix and sometimes divide into two or four cells, giving a very characteristic appearance. It does not contain blood vessels and is nourished by diffusion from underlying bone.

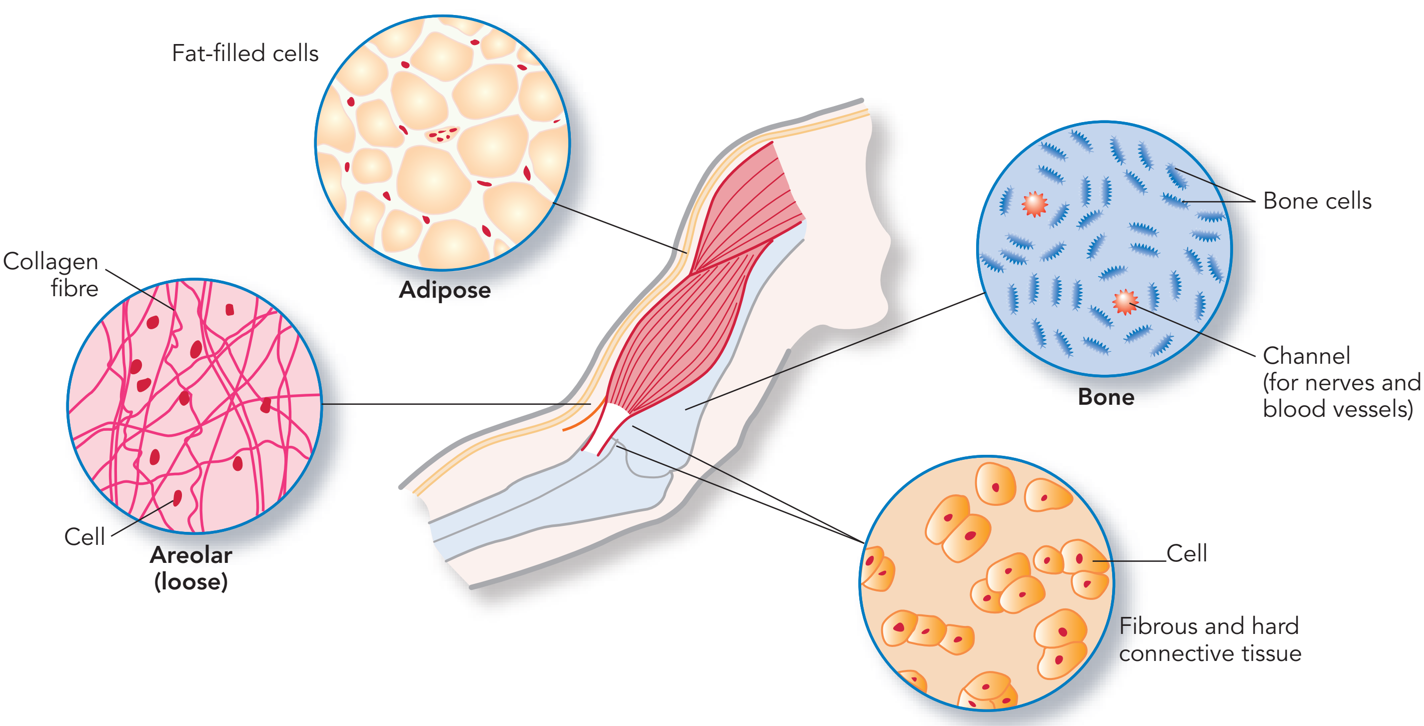


Fig 5.9: Other types of connective tissue

Bone

Bone is a much harder substance than cartilage but it can be worn away by friction. The rigid matrix has two major components:

- calcium salts, which form around **collagen** fibres and give bone its hardness
- collagen fibres, which offer some ability to bend under strain and prevent bone from being too brittle and therefore likely to fracture.

Osteocytes (or bone cells) are trapped in the hard matrix on concentric rings called lamellae. A system of these rings is known as a Haversian system or osteone. ('Osteo- ' is a prefix associated with bone.) Blood vessels and nerves pass through the hollow centre of each osteone.

Bone is designed to bear weight and the limb bones are hollow, like girders (the strongest mechanical structures). Bone is also used to protect vital weaker tissues such as the brain, lungs and heart. Bones contain marrow in their central hollow and in some bones, marrow makes vital blood cells.

Areolar tissue

This is the most common tissue in the body and you have probably never heard of it before! If you eat meat, you will have seen it many, many times. It is the sticky, white material that binds muscle groups, blood vessels and nerves together. The matrix is semi-fluid and it contains collagen fibres and elastic fibres secreted by the cells found in this loose connective tissue. Elastic fibres give flexibility to the tissue, which is located around more mobile structures. The deeper skin layer known as the dermis is a denser type of areolar tissue, with extra fibres and cells. Areolar tissue offers a degree of support to the tissues it surrounds.

Adipose tissue

Adipose is a technical term for fatty tissue and it is a variation of areolar tissue, in which the adipose (or fat) cells have multiplied to obscure other cells and fibres. When mature, an adipose cell becomes so loaded with fat that the nucleus is pushed to one side and, as fat is translucent, the cell takes on a distinctive 'signet ring' appearance. Adipose tissue is common under the skin and around organs such as the heart, kidneys and parts of the digestive tract. It helps to insulate the body against changes of external temperature, acts as a 'hydraulic shock absorber' to protect against injury, and is also a 'high-energy storage depot'.

> **Key term**
>
> **Collagen** – Structural protein, generally in the form of fibres for added strength.

Muscle tissue

Muscle is an excitable tissue because it is capable of responding to stimuli. There are three different types of muscle in the human body:

- striated
- non-striated
- cardiac.

Each is composed of muscle fibres that are capable of shortening (or contracting) and returning to their original state (known as relaxation). Contraction causes movement of the skeleton, soft tissue, blood or specific material such as urine, food and faeces. Muscle has both blood and nerve supplies.

> **Did you know?**
>
> Muscle activity generates heat and contributes to maintaining the body temperature.

Striated muscle

Most striated muscle (also called voluntary, skeletal or striped muscle) is attached to the bones of the

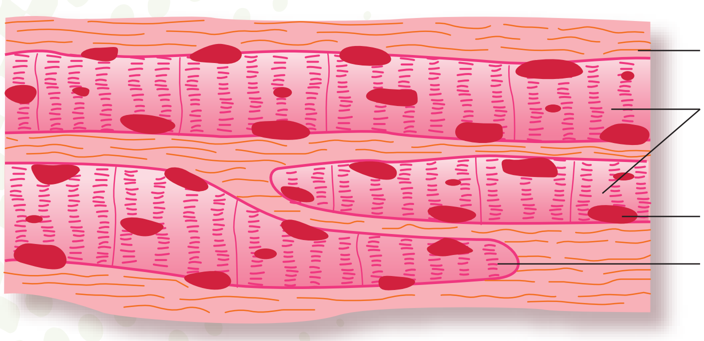


Fig 5.10: Microscopic appearance of striated muscle

skeleton, although some facial muscles are attached to skin. Striated muscle makes up the familiar animal meat seen in the butcher's. This type of muscle will contract when it receives nerve impulses controlled by conscious thought from the **central nervous system** – hence its alternative name of voluntary muscle. The name striated means 'striped'; each individual fibre shows alternate dark and light banding from the muscle protein filaments from which it is made.

Each fibre is cylindrical and multinucleate, lying parallel to its neighbours. There may be hundreds or thousands of fibres in a muscle, depending on its size. Some fibres are 30 centimetres long and one-hundredth of a millimetre wide. Muscle fibres contain many thousands of mitochondria to supply ATP for the energy used in muscular contraction.

Non-striated muscle

Although this type of muscle tissue (also called involuntary, smooth or plain muscle) still contains protein filaments, they do not lie in an ordered pattern and therefore do not produce the banding that is characteristic of striated muscle. The muscle fibres are spindle- or cigar-shaped, with single central nuclei, and dovetail with each other. This type of muscle tends to form sheets and, although still requiring nervous stimulation to effect contraction, this is not under conscious thought, but supplied by the **autonomic nervous system** (which is why it is called involuntary muscle). This type of muscle is found around hollow internal organs such as the stomach, intestines, iris of the eye, bladder and uterus; it is not attached to bones.

Non-striated muscle frequently occurs in two sheets running in different directions, known as **antagonistic muscles**. In the digestive tract, one sheet runs in a circular fashion around the intestines, while another outer sheet runs down the length. The two sheets are said to work antagonistically (against each other) to propel the food contents down the tract. This type of movement is known as peristalsis (see page 213).

In the iris of the eye, one set of muscle runs radially outward from the centre, like the spokes of a wheel, while the other set runs in a circular fashion around the central pupil. This arrangement allows for the control of light entering the eye and the pupil is said to be dilated (open) or constricted (narrowed).

Cardiac muscle

This type of muscle is found only in the four chambers (atria and ventricles) of the heart. It is said to be myogenic because it can rhythmically contract without receiving any nervous stimuli, and in this it differs from other muscle. The muscle cells branch repeatedly to form a network, through which contraction spreads rapidly. Each cell has a central nucleus and is both horizontally and vertically striped. The divisions between cells are known as intercalated discs and are specially adapted for transmission of impulses.

Under normal healthy circumstances, cardiac muscle is not allowed to contract myogenically because the atrial or upper chamber muscle has a different contraction rate to that of the lower ventricular muscle and this would lead to inefficient and uncoordinated heart action. The autonomic nervous system controls the rate of contraction via the nerves in order to adapt the flow of blood to specific circumstances such as rest and exercise.

Key terms

Central nervous system – The brain and spinal cord.

Autonomic nervous system – Part of the nervous system responsible for controlling the internal organs.

Antagonistic muscles – One muscle or sheet of muscle contracts while an opposite muscle or sheet relaxes.

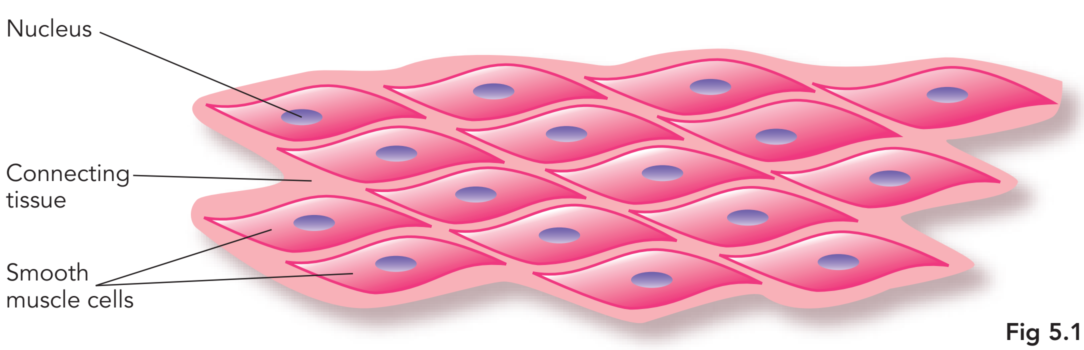


Fig 5.11: Non-striated muscle tissue

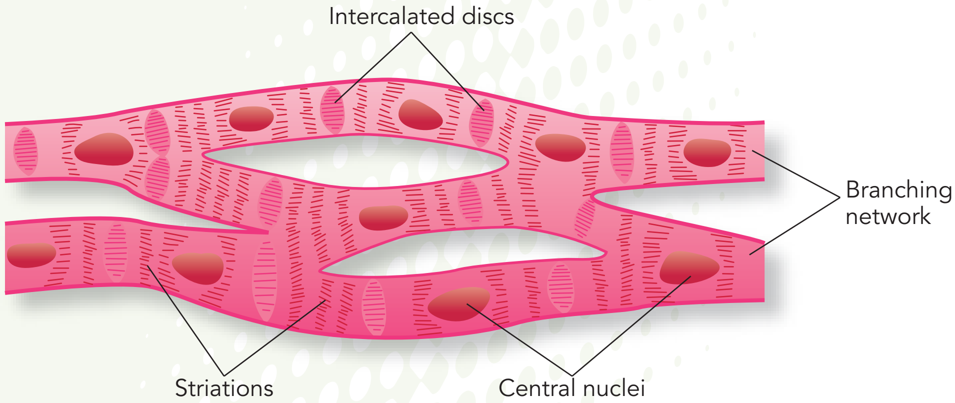


Fig 5.12: Cardiac muscle tissue

Nervous tissue

Nervous tissue is only found in the nervous system and consists of the brain, spinal cord and nerves. Receiving stimuli from both external and internal sources, it serves to create consistency (particularly regarding **homeostasis**), co-ordination, and communication between different parts of the body. The nervous system interprets stimuli from the sense organs so that vision, hearing, smell and the other senses become apparent.

Activity 4: Placing tissues within organs

Working in pairs, use the Internet, bioviewers or reference books to research the different tissues found in four organs of the body (take two each). Write a description of each tissue and outline the role it plays within the named organ.

Key term

Homeostasis – The process of maintaining a constant internal environment despite changing circumstances. For example, the pH, temperature, concentrations of certain chemicals and the water content in the fluid surrounding body cells (the internal environment) must be kept within a narrow range even when you are consuming acids (vinegar, lemon juice), are in a freezing climate, or are doing vigorous exercise.

PLTS

Independent enquirer: This activity will enable you to demonstrate independent enquiry skills when you plan and carry out research on the tissues of the body, and analyse and evaluate information on tissue types.

Functional skills

ICT: You will use ICT skills to access, search for and use information on different types of tissues in organs.

Nervous tissue is composed of:

- neurones – highly specialised nerve cells that transmit nervous impulses. They are present only in the brain and spinal cord, but their long processes (nerve fibres) form the nerves
- neuroglia – connective tissue cells, intermingled with neurones in the brain and spinal cord, that offer support and protection.

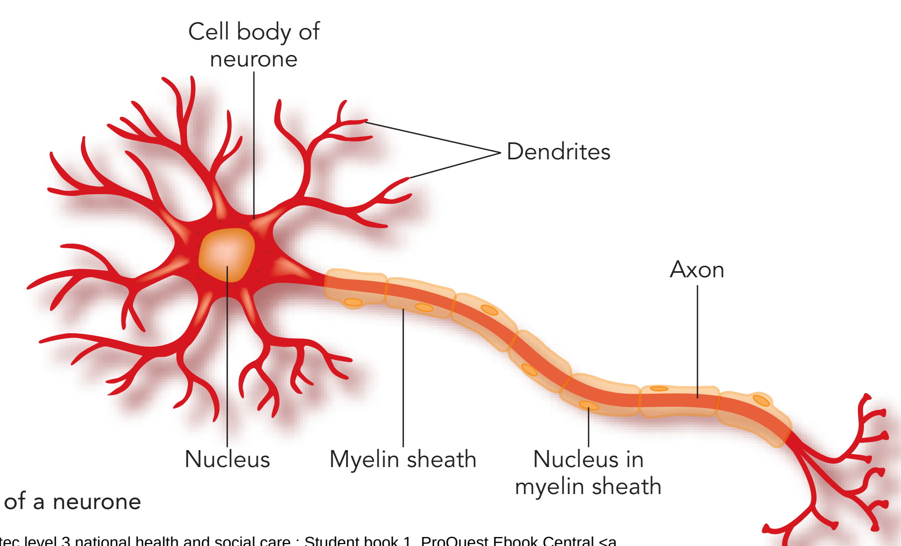


Fig 5.13: General features of a neurone

Assessment activity 5.2

P2 BTEC

Produce a written assignment that shows an understanding of the main tissue types and the roles they play in two named organs.

Two organs you could choose might be the stomach and skin. Here are some examples of tissue types that occur in these two organs:

1. The stomach has three layers of non-striated muscle in its wall and an inner lining of columnar epithelium with goblet cells. The tissue connecting the lining with the muscular coat is areolar tissue. Describe these three tissues and their roles in the functioning of the stomach.
2. Skin has an outer layer of keratinised stratified epithelium and a deeper layer of areolar tissue overlying adipose tissue and skeletal muscle. Describe keratinised stratified epithelium, adipose tissue and striated muscle and their roles in the functioning of the skin.

Grading tip

P2 To achieve P2, you need to outline the structure of the main tissues of the body. You could supplement your written description with large annotated diagrams of the named organs to provide illustrated accounts. Ensure that the functions you describe are specific to the named organs and not general.

PLTS

Independent enquirer: Planning and carrying out research on the tissues of the body will help you demonstrate your enquiry skills; this activity will also help you show that you can analyse and evaluate information on tissue types.

Table 5.1: The major organs and where they can be found

Body organ	Associated body system	Location description
Heart	Cardiovascular	Middle of the chest, between the lungs, with apex lying to the left.
Lungs (2)	Respiratory	Each lung lies to one side of the heart, filling the chest or thorax.
Brain	Nervous	Within the skull of the head.
Stomach	Digestive	Abdominal organ lying just beneath the diaphragm on the left side.
Liver		Beneath the diaphragm, mainly on the right side but also overlapping part of the stomach.
Pancreas		Lies just below the stomach, in a curve of the duodenum.
Duodenum		C-shaped part of the small intestine immediately beyond the stomach.
Ileum		Long coiled tube, which follows the duodenum in the abdomen.
Colon		Begins after the ileum in the right pelvic area, runs up the right side to the liver, then sweeps across under the stomach and down the left side of the abdomen to end at the rectum in the lower central pelvic area.
Kidneys (2)	Renal	One on each side of the posterior wall of the abdomen. The upper poles of the kidneys lie just inside the ribs. The left kidney is slightly higher than the right due to the bulk of the liver.
Bladder		Lies centrally in the lower pelvis at the front.
Ovaries (2)	Reproductive	One on each side of the posterior wall of the pelvis, below the kidneys.
Testes (2)		Below the pelvis, between the upper legs, one each side of the penis in a skin bag called the scrotum.

Did you know?

The human trunk is divided into three body cavities. The upper chest or thorax is separated from the larger abdomen (often called inaccurately the stomach or 'tummy') by a fibro-muscular sheet known as the diaphragm. Only the oesophagus or gullet, and the chief artery and vein (aorta and vena cava), penetrate the diaphragm. The lower, narrower part below the abdomen is the pelvis. There is no physical separation (like the diaphragm) between the abdomen and the pelvis.

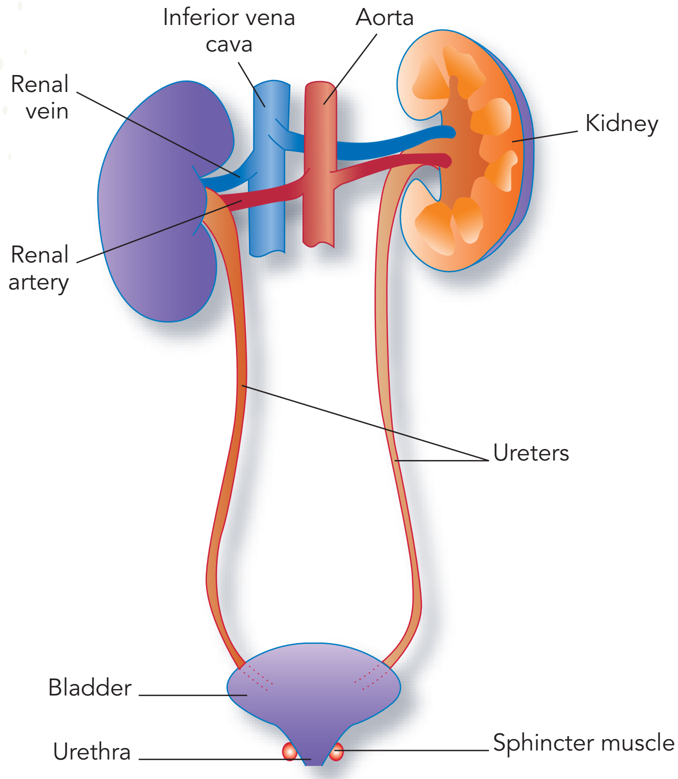


Fig 5.14: Gross structure of the renal system

1.4 Body organs

You need to know the locations of major body **organs**; most of these will be illustrated in detail later in the unit. A quick reference list can be found in Table 5.1 (page 191).

The structure and functions of the skin will be described on pages 221–222.

1.5 Body systems

You are required to learn the gross structure of ten **body systems**. Some systems will be considered in much greater detail later in the chapter. You will find the gross structure of the cardiovascular system included on pages 199–206. The gross structure of the respiratory system is included on pages 206–209 and that of the digestive system on pages 210–212. Remember, gross structure is only what the eye can see.

The renal system

The renal system consists of two kidneys with emerging tubes (called the ureters) running down the posterior abdominal wall to a single pelvic collecting organ, the bladder. The passage from the bladder to the exterior is via the urethra, and the flow of urine is controlled by a sphincter muscle located just below the bladder. The kidneys are supplied by short renal **arteries** coming off the main artery of the body, the aorta. Renal **veins** take the blood from the kidneys straight into the vena cava, the main vein of the body.

Key terms

Organ – A collection of different tissues, such as the heart or the brain, working together to carry out specific functions.

Body systems – A collection of organs with specific functions in the body.

Artery – A blood vessel coming from the heart, usually carrying oxygenated blood to the tissues.

Vein – A blood vessel returning blood to the heart from the tissues; the blood has left considerable amounts of oxygen behind to supply the cells and is known as deoxygenated blood.

The nervous system

The nervous system comprises the central nervous system (the brain and spinal cord) and the peripheral nervous system, the nerves running to and from the brain (cranial nerves) and spinal cord (spinal nerves). A chain of ganglia runs close to the spinal cord and is associated with the autonomic nervous system, which controls internal organs. Autonomic nerve fibres are also contained within the peripheral nerves.

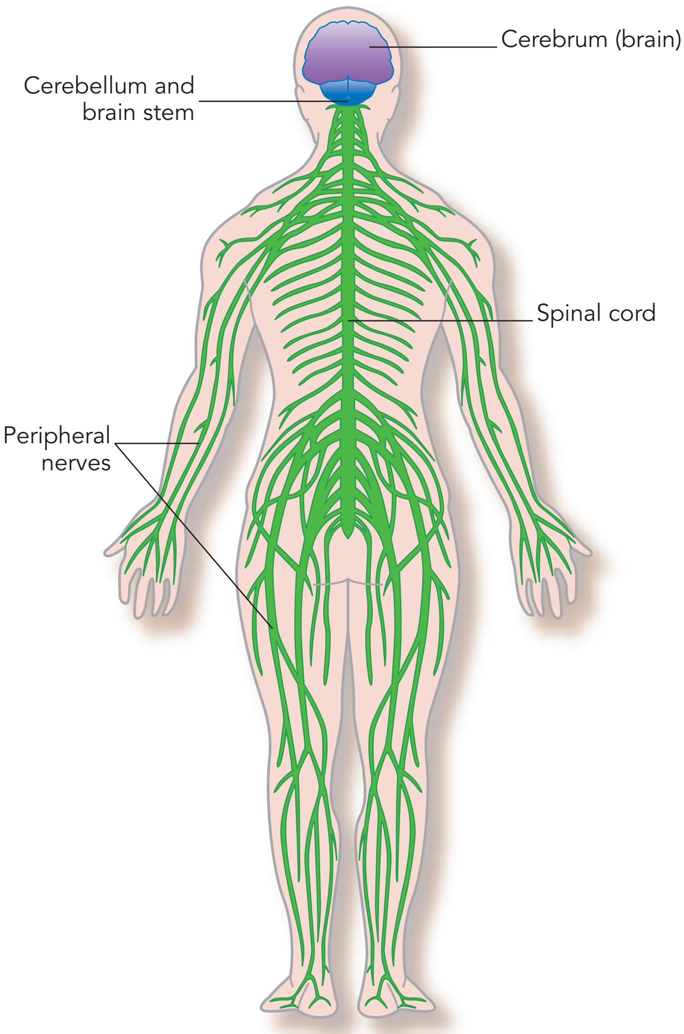


Fig 5.15: Gross structure of the nervous system

The endocrine system

This is a collection of ductless glands scattered throughout the body. Endocrine glands pass their secretions (known as hormones) directly into the bloodstream so they are always adjacent to blood vessels.

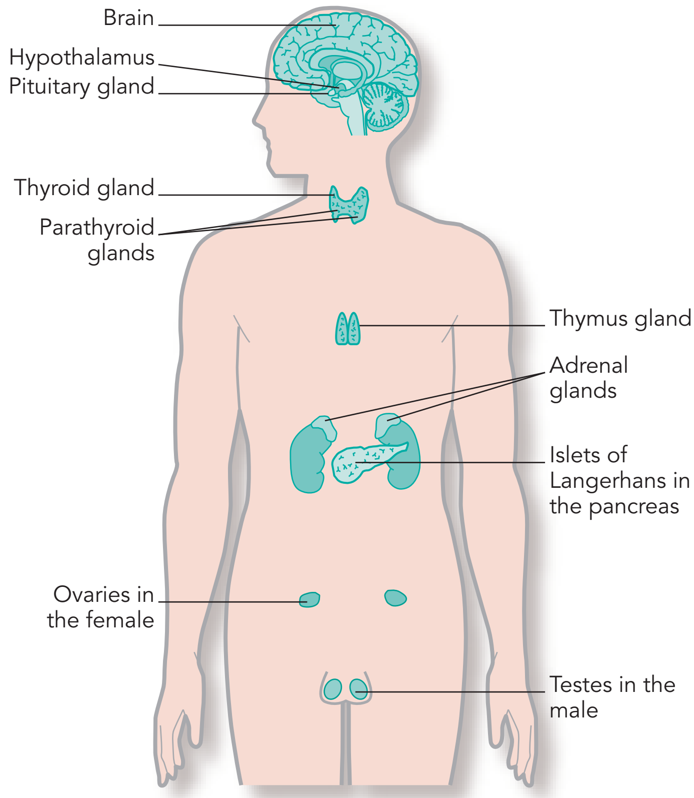


Fig 5.16: Gross structure of the endocrine system

The reproductive system

Males and females have different reproductive organs, as these serve different purposes.

Female reproductive system

This system comprises two ovaries, each with an emerging oviduct (or fallopian tube) connecting to the thick-walled uterus (or womb). The neck of the uterus protrudes into the muscular vagina and this opens to the exterior at the vulva. Two fleshy folds, known as the labia, conceal the vaginal orifice.

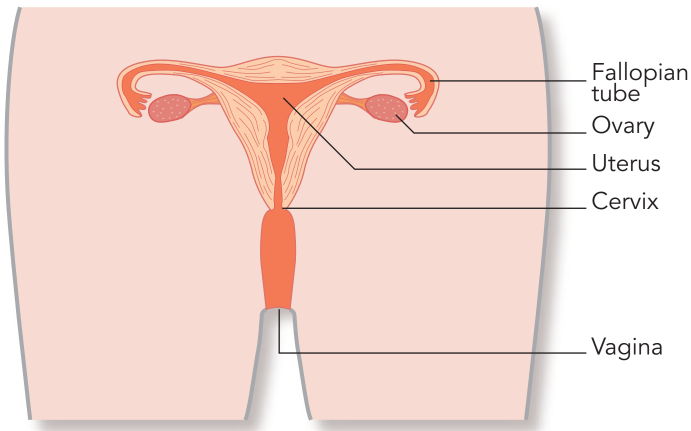


Fig 5.17: Gross structure of the female reproductive system

Male reproductive system

Two testes hang in a skin sac called the scrotum, just outside the abdomen, and are connected by long tubes (each known as the vas deferens) to the urethra. The urethra is much longer than that of the female and enclosed in an organ called the penis. Two columns of erectile tissue lie alongside the urethra in the penis. Two pairs of glands, the seminal vesicles and Cowper's glands, pour their secretions into the vasa deferentia (plural), close to the bladder. A single ring-shaped gland, called the prostate gland, also adds secretions and is located around the upper part of the urethra, just below the bladder. The urethra and vasa deferentia unite within the prostate gland.

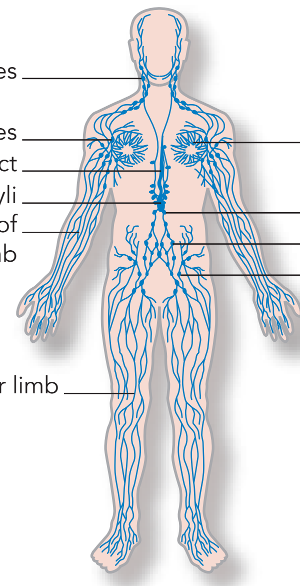


Fig 5.19: The lymphatic system

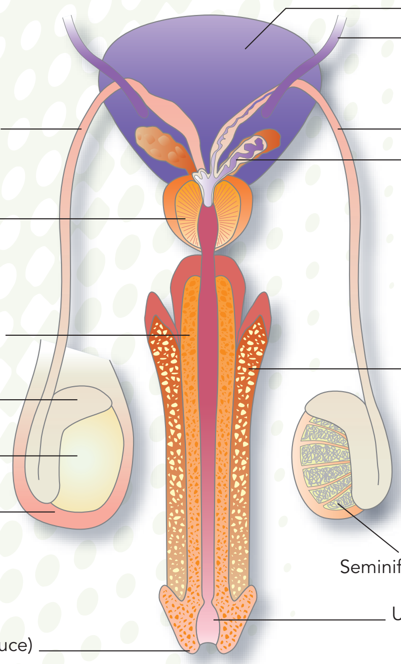


Fig 5.18: Gross structure of the male reproductive system

The lymphatic system

Minute blind-ending lymphatic capillaries lie in tissue spaces between body cells and join to larger lymphatic vessels and eventually to two lymphatic ducts, the thoracic duct and right lymphatic duct. These ducts transfer the fluid collected in the lymphatic vessels back into the blood circulation close to the heart. Each lymph vessel passes through at least one lymph node (sometimes mistakenly called 'glands') and usually more than one. There are hundreds of lymph nodes all over the body, often associated in groups. Lymphoid tissue also occurs in specialised areas more associated with potential sources of infection, such as the tonsils, adenoids, small intestine, spleen and thymus gland. Tiny lymphatic vessels, called lacteals, are present in the villi of the small intestine (see Figure 5.34, on page 211) and are associated with the absorption of lipids from the digestive tract.

The musculo-skeletal system

The bones of the skeleton and their attached striated muscles form this system. You are not required to learn the names of the muscles or the individual bones, although you will probably know some of these already.

The skeleton forms the framework of the body and is composed of the:

- axial skeleton, in the midline of the body – the skull and vertebral column or spine
- appendicular skeleton, comprising the limb bones and their girdles, which attach them to the trunk.

The meeting place of two or more bones is known as a joint and joints may be:

- fixed by fibrous tissue and therefore immoveable; this type occurs between several bones of the skull
- slightly moveable because the bones are joined by a pad of cartilage; this type is found in between the vertebrae and joining the two halves of the pelvic girdle together
- freely moveable with a more complex structure known as synovial joints; examples of synovial joints are found at the shoulder, elbow, knee, hip, fingers and toes.

Striated muscle fibres are bound together to form muscles that pull bones into different positions by contracting. Muscles never push so an 'opposite' muscle is required to return the bones to their original positions. As well as individual names (such as biceps and triceps), muscles are often given names like **flexors** and **extensors**, which describe their action.

Key terms

Flexors – These carry out flexion, which decreases the angle between two bones; for example, the biceps (a flexor) raises the forearm.

Extensors – These carry out extension, which increases the angle between two bones; for example, the triceps (an extensor) straightens the forearm after flexion.

Activity 5: Finding your own muscles

Try bending and straightening your forearm and feel the muscles that increase in firmness as you carry out this action. Identify the biceps and triceps muscles. Repeat the action but this time raising and straightening your leg. Identify where the flexors and extensors are located.

The immune system

The immune system is more scattered than most other systems and is often not included as a major system in textbooks. It is a collection of cells, tissues and proteins that protects the body from invasion by harmful micro-organisms. Figure 5.20 (above) illustrates the main components of the immune system.

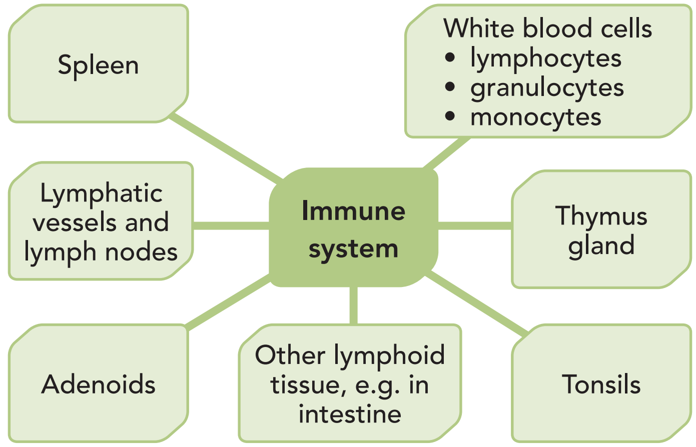


Fig 5.20: The major components of the immune system

Activity 6: Researching systems

In small groups, share out the body systems and research their structure and how they work. Share your findings with each other and provide useful references.

PLTS

Self-manager: Sharing out the work and organising your own research in this activity may help you to demonstrate your self-manager skills.

1.6 Main functions of body systems

Interactions of different structures within each system

You will find this information in each section detailing the different systems.

Activity 7: How systems interact

Working in small groups of three or four, research how two or more systems work together, making posters for records and then feed back to the rest of the class in a plenary session.

Table 5.2: The main functions of the 10 body systems

Name of system	Main functions
Cardiovascular system	• Major transport of materials to and from cells • Distributes heat around the body and assists in temperature regulation • Defence of the body • Water regulation
Respiratory system	• Maintains oxygen supply to cells • Removes carbon dioxide and water from the body
Digestive system	• Reduces complex food molecules to simple substances capable of being absorbed and delivered to cells • Removes undigested waste at intervals • The liver is the main producer of important chemicals
Renal system	• Removes excess water and salts • Eliminates nitrogen-containing waste in the form of urea • Assists in the production of new red blood cells • Involved in the maintenance of blood pressure
Nervous system	• Receives and interprets information from the environment • Controls and co-ordinates the internal organs • Associated with the endocrine system • Reflex actions protect the body from injury
Endocrine system	• Controls and co-ordinates organs • Maintains blood glucose, water and salt levels • Assists in reproduction and growth
Reproductive system	• Produces gametes that can create new life when united with a gamete from the opposite sex • Assists in growth • Responsible for secondary sexual characteristics
Lymphatic system	• Removes excess tissue fluid and proteins from spaces between cells • Defence of the body • Transports fatty acids from the digestive system
Musculo-skeletal system	• Effects movement (with the nervous system) • Stores calcium • Protects vital organs • Supports organs • Manufactures many blood cells
Immune system	• Defends against invasion by micro-organisms • Has an anti-cancer role • Rejects material perceived as 'foreign'

Assessment activity 5.3

P3 BTEC

Imagine that you wish to explain to individuals using a local health centre how the body works, and produce a series of annotated diagrams to provide an overview of each body system.

1 On large sheets of paper, draw your own version of the gross structure of each body system listed below, labelling each part with its name and adding a short description of the function of the part.

Body systems to be included are:

- cardiovascular
- respiratory
- digestive
- renal
- nervous
- endocrine
- reproductive – male and female
- lymphatic
- musculo-skeletal
- immune.

2 Download images of the more complicated systems from the Internet. Delete any prepared text and make the images your own by inserting labels and functions as in question 1 above.

Grading tip

P3 To achieve P3, you have to outline the gross structure of all the main body systems. You need not include any details of microscopic structures (such as alveoli or nephrons), as these are not part of the gross structure.

Make sure each image you download is of good quality and clear enough to label.

The renal, female reproductive and endocrine systems are particularly suitable for your own diagrams, as they are less complex than others.

PLTS

Creative thinker: You can demonstrate creative thinking by generating ideas and exploring possibilities when providing information about body systems.

Self-manager: By using initiative and perseverance when preparing posters of body systems and submitting the posters to a deadline around other commitments, you will show self-management skills.

Reflective learner: You will show you are a reflective learner when preparing the diagrams of the body systems to display in a health centre.

Functional skills

ICT: Presenting posters that are fit for purpose and audience demonstrates ICT skills.

2 Understand the functioning of body systems associated with energy metabolism

The role of energy within the cell, respiratory, cardiovascular and digestive systems has already been briefly discussed. This section will investigate the concept of energy in more detail.

2.1 Energy laws

Energy can be defined easily as the capacity to do work – but energy doesn't just appear, it must come from somewhere!

The first law of thermodynamics, sometimes known as the conservation of energy, states that:

> *Energy can be transformed (changed from one form to another), but cannot be created or destroyed.*

The first part of this law refers to the transformation of energy from one form into another. The second form may not be of use or be capable of being measured.

2.2 Forms of energy

Energy can exist in several forms and chemical energy is the most common. The energy is in the chemical bond that unites atoms or molecules with each other. When a new bond is made between two atoms, energy is required for its formation and this is usually in the form of heat, although light and electrical energy can be used. When a bond is broken and atoms are released, the energy in the bond is released as well. Heat, light, sound, electrical and nuclear are other forms of energy.

PLTS

Creative thinker: You can show creative thinking ability when considering different types of energy.

Did you know?

Placing a lump of coal or wood on a fire illustrates the energy laws. As the coal burns, the chemical energy contained within it is released and transformed into heat, light and sometimes sound (crackling). The chemical energy in the wood or coal has come from the sun, and the tree has converted this into stored glucose by means of photosynthesis.

2.3 Energy metabolism

The role of energy in the body

At this stage, you may be wondering why there is so much emphasis on energy and be thinking that it is only concerned with muscular activity and movement. However, energy is also needed to circulate blood, lymph and tissue fluid throughout the body; it is necessary for breathing and taking in oxygen; it is necessary for making new cells for carrying out growth and repair; it is used to transmit nerve impulses so that we can respond to changes in the environment; and it is needed to build different complex molecules such as enzymes and hormones from the simple molecules produced after digestion of food.

Anabolism and catabolism

You have already learned about metabolism and how some chemical reactions involve breaking down

Case study: An illustration of energy forms

Ian slid down a climbing rope in the gym wearing only a vest and shorts. Later that day the skin on his hands and inner legs became red, swollen and painful. Ian had friction burns from the slide. The kinetic (motion) energy had been partly converted into heat energy, which had caused the burn. Friction is the resistance to motion when two bodies are in contact. This was neither useful nor measurable!

1 Which two items were in contact to cause the friction burn?
2 Name the two forms of energy in the slide and the relationship between them.
3 What is the name given to the law associated with this example?
4 What type of energy had Ian used to climb the rope?

molecules and releasing energy – these are catabolic reactions. The oxidation of glucose inside cells is a catabolic reaction and there are many more. The opposite process is building complex molecules from simple substances and using energy – these are anabolic reactions.

Reflect

Athletes are regularly tested for banned substances that might make them perform better than other competitors. Many of these tests look for anabolic steroids which build up muscle tissue.

Metabolism = catabolism and anabolism

Activities involved in supplying energy to the cells

The activities involved in energy supply include the roles of the cardiovascular, respiratory and digestive systems.

You will learn about these systems in more detail in the sections that follow but we will start with a brief overall view of how they interact:

- The digestive system is responsible for taking in food and water and, using enzymes, breaking up complex molecules into simple soluble materials that are capable of passing into the adjacent capillaries of the cardiovascular system.
- The cardiovascular system transports these simple materials to the liver and body cells via the bloodstream, driven by the pumping action of the heart.
- At the same time, the respiratory system constantly refreshes lung oxygen and disposes of waste products (such as carbon dioxide and water) through the process of breathing. Dissolved oxygen passes through the thin alveolar walls into the bloodstream and is transported to cells. Body cells thus have a constant delivery of raw materials, such as glucose and other nutrients and dissolved oxygen, so that the breakdown (catabolic) process of glucose oxidation can take place and release energy to do work. This takes place initially in the cytoplasm and is completed in the mitochondria.

The released energy is trapped as chemical energy in ATP (see 'Mitochondria' on page 181).

Did you know?

Very large numbers of mitochondria are found in tissues that use a lot of energy such as muscle tissues.

2.4 The cardiovascular system

The heart is a muscular pump that forces blood around the body through a system of blood vessels – namely arteries, veins and capillaries. Blood carries dissolved oxygen to the body cells and at the same time removes the waste products of respiration (carbon dioxide and water). However, blood is also important in distributing heat around the body, along with hormones, nutrients, salts, enzymes and urea.

The structure of the heart

The adult heart is the size of a closed fist, located in the thoracic cavity between the lungs and protected by the rib cage. It is surrounded by a tough membrane, the pericardium, which contains a thin film of fluid to prevent friction (remember Ian and the rope!)

The heart is a double pump, each side consisting of a muscular upper chamber (the atrium) and a lower chamber (the ventricle). The right side of the heart pumps deoxygenated blood from the veins to the lungs for oxygenation. The left side pumps oxygenated blood from the lungs to the body, and the two sides are completely separated by a septum. The blood passes twice through the heart in any one cycle and this is often termed a 'double circulation'.

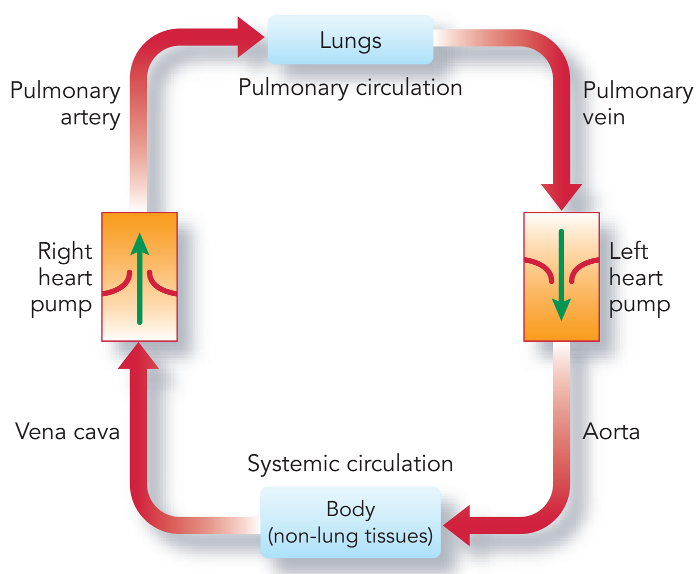


Fig 5.21: The double circulation of the heart

A schematic diagram showing the double circulation, with the heart artificially separated, is shown in Figure 5.21 (page 199). Each of the four heart chambers has a major blood vessel entering or leaving it. Veins enter the atria, and arteries leave the ventricles.

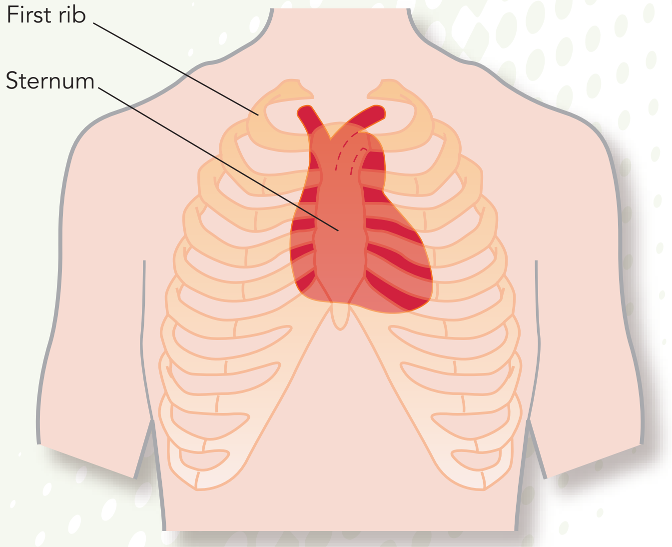


Fig 5.22: The location of the heart

Did you know?

Atria have veins entering and ventricles have arteries leaving. A and V for each chamber – NEVER two As or two Vs.

The circulation to and from the lungs is known as the pulmonary circulation and that around the body is the systemic circulation. Arteries are blood vessels that leave the heart, while veins take blood towards the heart.

In the pulmonary circulation, the pulmonary artery carrying deoxygenated blood leaves the right ventricle to go to the lungs. You will realise that it must divide fairly soon after leaving the heart because there are two lungs to be supplied – hence the right and left pulmonary arteries. The pulmonary veins (there are four of them), now carrying oxygenated blood, must enter the left atrium.

The main artery to the body leaving the left ventricle is the aorta and the main vein bringing blood back to the heart from the body enters the right atrium and is the vena cava. The vena cava has two branches: the superior vena cava returning blood from the head and neck, and the inferior vena cava returning blood from the rest of the body. In many diagrams of the heart, these are treated as one vessel.

It is important that the blood flows in only one direction through the heart so it has special valves to ensure that this happens. There are two sets of valves between the atria and the ventricles, one on each side. Sometimes these are called the right and left atrio-ventricular valves but the older names are also used – the bicuspid, or mitral (left side), and tricuspid (right side) valves. These names refer to the number of 'flaps', known as cusps, that make up the valve; the bicuspid has two cusps and the tricuspid has three cusps. Each cusp is fairly thin so, to prevent them turning inside out with the force of the blood flowing by, they have tendinous cords attached to their free ends and these are tethered to the heart muscles of the ventricles by small papillary muscles. The papillary muscles tense just before the full force of the muscle in the ventricles contracts, so the tendinous cords act like guy ropes holding the valves in place.

The two large arteries, the pulmonary and the aorta, also have exits guarded by valves called semi-lunar valves (so-called because the three cusps forming each valve are half-moon shaped). These valves are needed because when the blood has been forced into the arteries by the ventricular muscle contractions, it must not be allowed to fall back into the ventricles when they relax. These valves are also called the pulmonary and aortic valves.

Did you know?

It is easy to recall which side each valve is on if you think that the TRIcuspid is on the RIghT side, a rearrangement of the letters TRI, so the bicuspid must be on the left!

How to work out the left and right sides of the heart

Sometimes learners are confused about the correct labels for the heart chambers. When you look at an image in front of you, it is like a mirror image so the left side of the image is opposite your right hand and vice versa. A paper-based image can be placed facing outwards on the front of your chest to make the sides the same as your left and right hands. You do need to know which is your right and left hand though!

Activity 8: Hearing heartbeats

Using a stethoscope over the heart area, either on your own or with a partner, listen for the heartbeat. Try to count the number of beats you hear in one minute. What does each beat sound like?

A heartbeat makes a 'lubb-dup' sound, with a very short interval between each beat. Valves, like hands clapping, make sounds when closing not opening. 'Lubb' represents the atrio-ventricular valves closing while 'dup' is the sound made by the semi-lunar valves closing. In some people, swishing sounds can be heard between heart sounds and these are called heart murmurs. All murmurs should be investigated but most are not related to disease. Murmurs are the result of disturbed blood flow.

Heart muscle, as you learned on page 189, is cardiac muscle, composed of partially striped interlocking, branched cells. It is myogenic, which means that it is capable of rhythmic contractions without a nerve supply. However, the atrial muscle beats at a different pace from the ventricular muscle so it needs a nerve supply to organise and co-ordinate the contractions to ensure that the heart is an efficient pump. The heart muscle has its own blood supply, provided by the coronary arteries and veins.

The muscular walls of the atria are much thinner than the ventricular walls, as the flow of blood is aided by gravity and the distance travelled is merely from the atria to the ventricles. The ventricles are much thicker than the atria but they also differ from each other. The right ventricle is about one-third the thickness of the left ventricle because this has to drive oxygenated blood around the whole of the body including the head and neck, which is against the force of gravity. The right ventricle only has to deliver blood a short distance – to the lungs on either side of the heart.

Activity 9: Comparison of distances travelled

With a partner, measure the distance from your heart to one of your big toes, and compare this with the distance from your heart to one lung. Now you understand the reason for the much thicker muscle of the left ventricle.

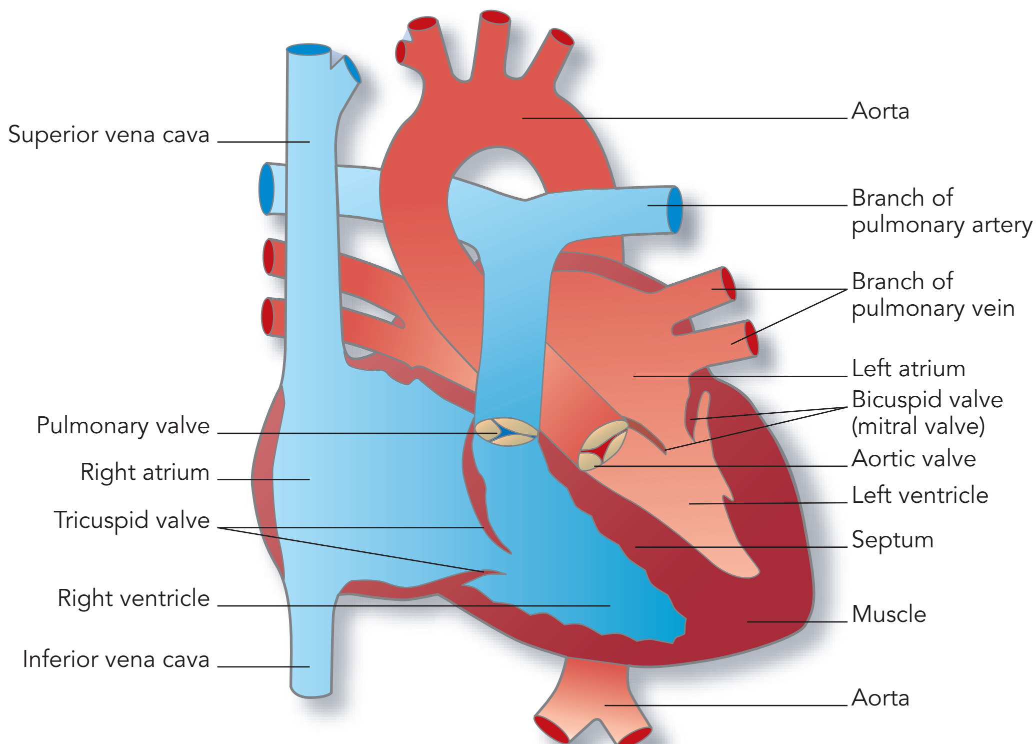
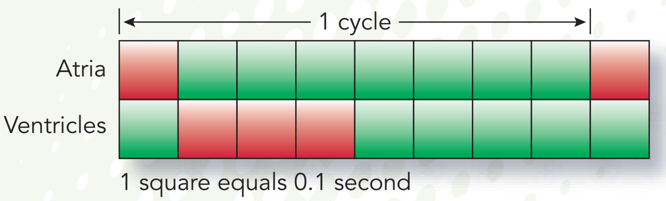


Fig 5.23: A section through the heart

The cardiac cycle

The cardiac cycle comprises the events taking place in the heart during one heartbeat. Taking the average number of beats in a minute (or 60 seconds) at rest to be 70, then the time for one beat or one cardiac cycle is 60 divided by 70 seconds, which works out at 0.8 seconds. You must remember that this is based on an average resting heart rate. When the heart rate rises to say 120 beats during moderate activity, the cardiac cycle will reduce to 0.5 seconds. As you can see, the higher the heart rate, the shorter the cardiac cycle, until a limit is reached when the heart would not have time to fill between successive cycles.



Atrial systole	0.1 second
Atrial diastole	0.7 seconds
Ventricular systole	0.3 seconds
Ventricular diastole	0.5 seconds

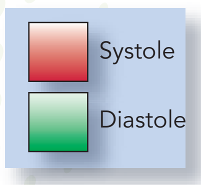


Fig 5.24: The timing of events in the cardiac cycle

The cardiac cycle appears in Figure 5.24 as a series of boxes, each one representing 0.1 seconds, to show the events occurring in the heart; red boxes signify when contraction is occurring and green boxes signify relaxation time. The technical term for contraction is systole and the term for relaxation is diastole. The activity of the atria is shown on the top line and the ventricles at the bottom.

The events in the cardiac cycle can be described in stages as follows:

1. Both atria contract, forcing blood under pressure into the ventricles.
2. Ventricles are bulging with blood and the increased pressure forces the atrio-ventricular valves shut (giving rise to the first heart sound – lubb).
3. Muscle in the ventricular walls begins to contract, pressure on blood inside rises and forces open the semi-lunar valves in the aorta and pulmonary artery.
4. Ventricular systole forces blood into the aorta (left side) and pulmonary artery (right side). These arteries have elastic walls and begin to expand.
5. As the blood leaves the ventricles, the muscle starts to relax. For a fraction of a second blood falls backwards, catching the pockets of the semi-lunar valves and making them close (the second heart sound – dup).
6. With the ventricles in diastole, the atrio-ventricular valves are pushed open with the blood that has been filling the atria. When the ventricles are about 70 per cent full, the atria contract to push the remaining blood in rapidly and the next cycle has begun.

You can see that when the chambers are in diastole and relaxed, they are still filling. The heart is never empty of blood. The cycle is continuous. With a high heart rate, it is the filling time that has shortened.

Activity 10: Changes during exercise

Run on the spot for a few steps and listen to the heartbeat again. What do you notice? Count the heart rate again in one minute.

Copy the set of boxes similar to those in Figure 5.24 and discover how much time the atria and ventricles have to fill when the heart rate is at the new level. Work out the new value for the length of the cardiac cycle and shade in the boxes for atrial and ventricular systole. On your chart, mark clearly the places where the heart sounds will be heard.

Heart rate and stroke volume

The **cardiac output** is the quantity of blood expelled from the heart in one minute. To calculate this, you need to know the quantity of blood expelled from the left ventricle in one beat (known as the **stroke volume**) and the number of beats in one minute (or the **heart rate**). The average individual has a stroke volume of 70 cm^3 and a heart rate between 60 and 80 beats per

Key terms

Cardiac output – The volume of blood forced out of the heart in one minute.

Stroke volume – The volume of blood forced out of the heart in one beat.

Heart rate – The number of beats counted in one minute.

minute. An individual who trains regularly might have a lower heart rate but a higher stroke volume.

Control of the cardiac cycle

The heart is controlled by the autonomic nervous system, which has two branches – the sympathetic nervous system and the parasympathetic nervous system. These two systems act rather like an accelerator and a brake on the heart. The sympathetic nervous system (NS) is active during muscular work, fear and stress, causing each heartbeat to be stronger and the heart rate to be increased. The parasympathetic NS calms the heart output and is active during peace and contentment.

Case study: Individual differences in matters of the heart

Cheryl trains every day by doing cross-country running, while Louis enjoys playing computer games.

1. Complete the table below.
2. Explain the figures in the table in the light of their different lifestyles.
3. Explain how exercise benefits the cardiovascular system.

Heart features	Cheryl	Louis
Stroke volume (cm^3)	95	72
Resting heart rate (beats/minute)	62	72
Cardiac output (cm^3/min)		

PLTS

Reflective learner: This activity will show that you can communicate learning in relevant ways when considering the effect of exercise on the cardiovascular system.

The sympathetic NS is boosted by the hormone adrenaline during periods of fright, flight and fight!

Blood pressure

The force blood exerts on the walls of the blood vessels it is passing through is known as the blood pressure (BP). It can be measured using a special piece of equipment called a sphygmomanometer, often abbreviated to 'sphygmo' (pronounced *sfigmo*).

Systolic blood pressure corresponds to the pressure of the blood when the ventricles are contracting. Diastolic BP represents blood pressure when the ventricles are relaxed and filling. BP is usually written as systolic/diastolic (for example, 120/80) and the units are still mm Hg or millimetres of mercury. Newer SI (International System of Units) units are kPa or kiloPascals but few establishments have converted.

The standard BP for a young healthy adult is taken as 120/80 mm Hg (or 15.79/10.53 kPa).

BP is highest in blood vessels nearer the heart, like the aorta and the large arteries. BP drops rapidly as blood is forced through the medium-sized arteries and the arterioles, as these muscular vessels present considerable resistance. BP in the capillaries is very low and blood in the veins has to be assisted back to the heart by a so-called 'muscle pump'. Veins in the limbs are located between muscle groups and, as they have thinner walls than arteries and possess valves at intervals, muscle action 'squeezes' the blood upwards in columns, and the valves prevent backflow. The slightly negative pressure in the chest during breathing also tends to 'suck' blood back towards the heart.

Case study: Why did Paul faint?

Paul fainted in an overcrowded stadium on a hot day. He had to stand for a very long time. As the event had lasted a few hours, he had suffered from a lack of circulating blood to his brain, which had caused him to faint. His muscles were inactive for a lengthy period, the blood had pooled in his leg veins, and he had also lost a lot of body water through sweating.

1. Can you suggest a way of avoiding fainting in these circumstances?
2. Describe the effect on Paul's legs.
3. Why is fainting an effective way of managing a lack of circulating blood to the brain?

PLTS

Creative thinker: Generating ideas and exploring possibilities when producing information on venous return to the heart will allow you to demonstrate your creative thinking skills.

Blood vessels

Arteries and arterioles

Arteries leave the heart and supply smaller vessels (known as arterioles), which in turn supply the smallest blood vessels, the capillaries. Arteries usually carry oxygenated blood. The exceptions are the pulmonary and umbilical arteries, which carry, respectively, blood to the lungs and placenta in pregnancy for oxygenation. The arterioles provide an extensive network to supply the capillaries and, in overcoming the resistance of these muscular vessels, BP drops significantly at this stage. Arteries and arterioles are lined by endothelium (see simple squamous epithelium on pages 183–184) and have a thick muscular coat. The lumen (or central hole) is round.

Capillaries

These single-cell walled vessels are supplied with blood by the arterioles (see simple squamous epithelium on pages 183–184). Body cells are never very far from capillaries, on which they rely for nutrients and oxygen. A protein-free plasma filtrate is driven out of the arterial ends of capillaries to supply the cells with oxygen and nutrients. This is called tissue (or interstitial) fluid. Tissue fluid re-enters the venous ends of the capillaries, bringing the waste products of the metabolic activities of the body cells (such as dissolved carbon dioxide and water).

Venules and veins

Venules are small veins, which are supplied by capillaries and feed into veins. The largest vein is the vena cava, which enters the right atrium of the heart. Limb veins contain valves to assist the flow of blood back to the heart because of the low BP in the veins. Veins have a much thinner muscular coat than arteries, more fibrous tissue and an oval lumen. BP is low in veins and venules. Generally, veins carry deoxygenated blood, with the exceptions of the pulmonary and umbilical arteries, which bring blood back from the lungs and placenta respectively.

Did you know?

A first-aider learns that arterial bleeding is bright red and spurts out in time with the heartbeat; capillary bleeding oozes from a wound and is most common, while venous bleeding is dark red (less oxygen) and flows at a low pressure.

Each type of blood vessel has structural and functional differences outlined in the table on the next page.

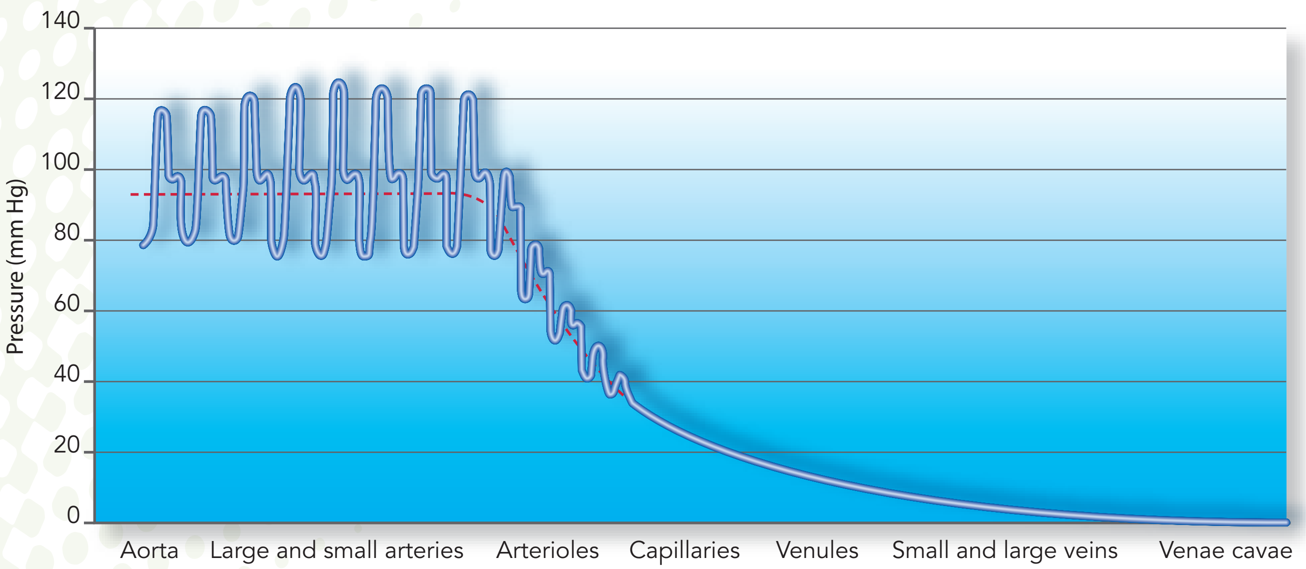


Fig 5.25: Graph showing the fall in blood pressure as blood moves through the circulation

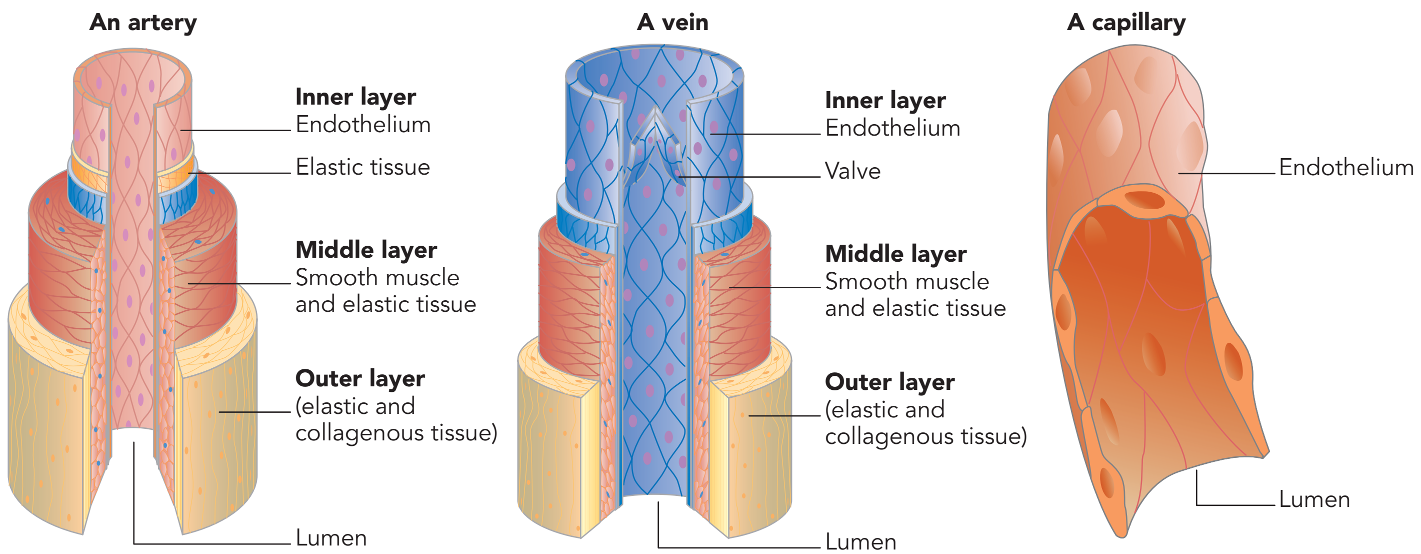


Fig 5.26: Arteries, veins and capillaries

Table 5.3: The roles of different blood vessels

Arteries	Veins	Capillaries
Carry blood away from heart to organs	Carry blood to heart from the organs	Connect arteries to veins
Carry blood under high pressure	Carry blood under low pressure	Arterioles and capillaries cause greatest drop in pressure due to overcoming the friction of blood passing through small vessels
Have thick, muscular walls, round lumen	Have thin, muscular walls, oval lumen	
Usually contain blood high in oxygen, and low in carbon dioxide and water	Usually contain blood low in oxygen, and high in carbon dioxide and water	Deliver protein-free plasma filtrate high in oxygen to cells and collect respiratory waste products (carbon dioxide and water)
Large elastic arteries close to the heart help the intermittent flow from the ventricles become a continuous flow through the circulation	Veins in limbs contain valves at regular intervals and are sandwiched between muscle groups to help blood travel against gravity	Walls are formed from a single layer of epithelium cells

Pulmonary and systemic circulations

The pulmonary circulation comprises the pulmonary arteries (which supply the lungs with deoxygenated blood from the right ventricle) and the pulmonary veins (which carry oxygenated blood back to the left atrium of the heart).

Each organ has an arterial and venous supply that brings blood to the organ tissues and drains blood away respectively. The link vessels supplying the cells of the organ tissues are the capillaries.

The systemic circulation comprises all the blood vessels not involved in the pulmonary circulation.

Structure and functions of blood

You have already learned about blood in the section on tissues on pages 185–187. You might like to read this section again before reading about haemoglobin below.

Erythrocytes contain haemoglobin, an important respiratory pigment that is essential for human life.

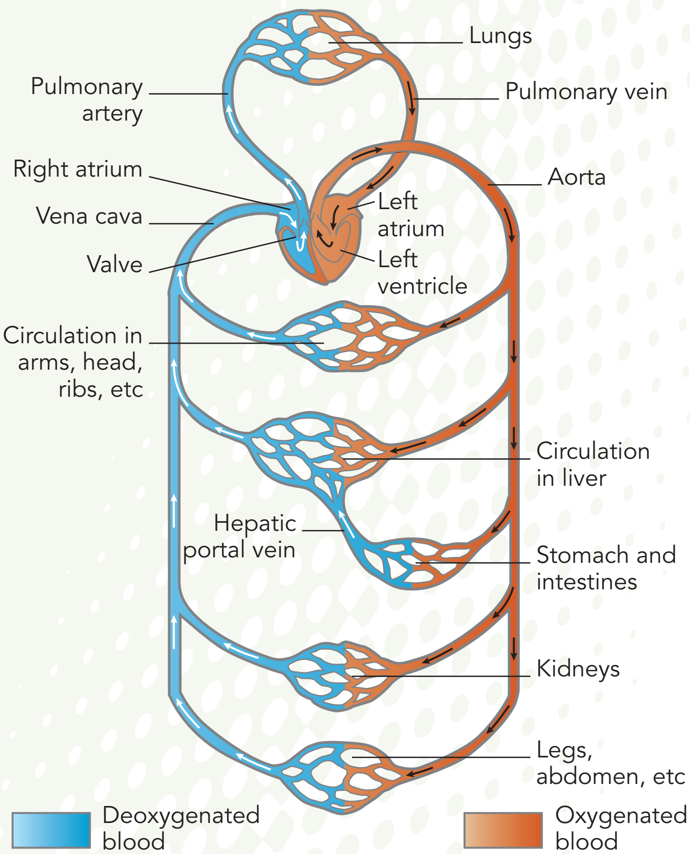


Fig 5.27: A simplified diagram showing human circulation

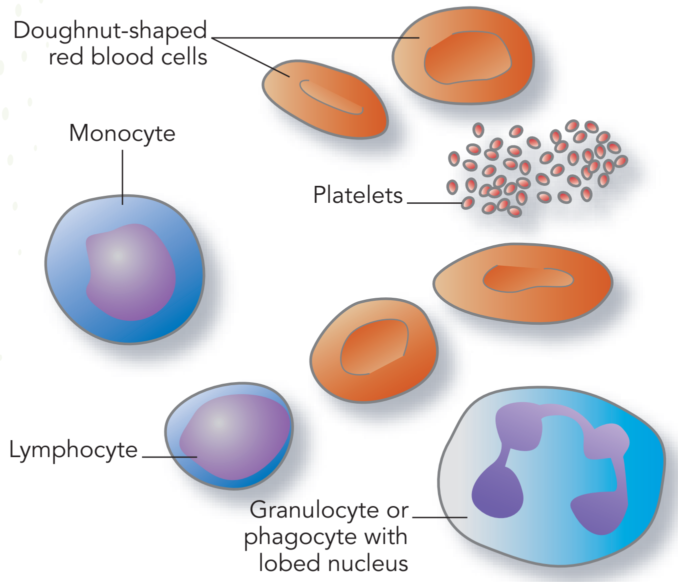


Fig 5.28: Different types of blood cell

Haemoglobin is a very special iron-containing protein because:

- in an environment containing a high concentration of oxygen, the *haem* part of the molecule forms a strong chemical bond with oxygen, becoming oxyhaemoglobin. Oxyhaemoglobin is formed in the blood of the lung capillaries and carries oxygen to tissue cells
- in an environment containing a low concentration of oxygen, the oxygen is released to pass down a concentration gradient to body cells. Haemoglobin is now said to be reduced haemoglobin.

2.5 The respiratory system

Respiration can be artificially subdivided into four sections to facilitate study, three of which are grouped under 'External respiration'. These are:

A External respiration, comprising:
- Breathing
- Gaseous exchange
- Blood transport.

B Internal or tissue respiration carried out *inside* body cells.

Breathing

The thorax, better known as the chest, is an airtight box containing the lungs and their associated tubes, the bronchi and the heart. Air can enter the thorax via the nose or the mouth; the nose is specially adapted for the entry of air in breathing and is the recommended route.

Role of the air passages in the nose

The nose contains fine bones on its side walls, which are curled like scrolls and covered with moist ciliated mucous membrane, rich in blood capillaries. This arrangement produces a large surface area over which incoming air flows. During the passage through the nose, the air is warmed and moistened by the close contact with the mucous membrane and filtered by the ciliated cells. By the time the air reaches the throat, it is warmed to almost body temperature, moistened to almost saturation point and most foreign materials (such as dust, carbon particles and many pathogens) have been filtered out.

The structure and function of the trachea and bronchi

The trachea starts at the back of the throat, or pharynx, and divides into two main bronchi, each serving one lung on each side of the heart. The first part of the trachea is specially adapted to produce sound and is called the larynx, or voice box. It is protected by a moveable cartilage flap, the epiglottis, which prevents food entering during swallowing.

When any material, such as a crumb, manages to pass the epiglottis it provokes an intense bout of coughing by reflex action, to expel the foreign body.

The trachea (or windpipe) and the bronchi have rings of cartilage to prevent them collapsing; those in the trachea are C-shaped, with the gap at the back against the main food tube, the oesophagus. This is because, when food is chewed in the mouth, it is made into a ball shape (called a bolus) before swallowing. The bolus stretches the oesophagus as it passes down to the stomach, and whole rings of cartilage in the trachea would hamper its progress. The gap is filled with soft muscle that stretches easily, allowing the bolus to pass down the oesophagus.

Reflect

It is not possible to breathe and swallow at the same time so, when helping someone to eat, you must allow time for breathing between mouthfuls of food.

Each bronchus divides and sub-divides repeatedly, spreading to each part of the lung. The tiniest sub-divisions, supplying oxygen to air sacs in the lung, are called bronchioles, and even these are held open by minute areas of cartilage. This branching arrangement is often called the bronchial tree.

The inner lining of the trachea and bronchi is composed of mucus-secreting and ciliated, columnar epithelial cells. Mucus is the sticky white gel which traps dust particles that may cause infection.

The structure and function of the lungs

Each lung is a pale pink, smooth structure that closely mimics the interior of half the chest in shape. Each is divided into a few lobes and has a hilum, or root, that marks the entry of the bronchus, blood vessels and nerves on the inner side.

The lungs themselves have a spongy feel to them, and are lined on the outside by a thin, moist membrane known as the pleura. The pleura continues around the inner thoracic cavity so that the two pleural layers slide over one another with ease and without friction. The **surface tension** of the thin film of moisture does not allow the two layers to pull apart but does allow them to slide. This means that when the chest wall moves when breathing, the lungs move with it.

Key term

Surface tension – The pull of water molecules so that the surface of the liquid occupies the smallest possible area.

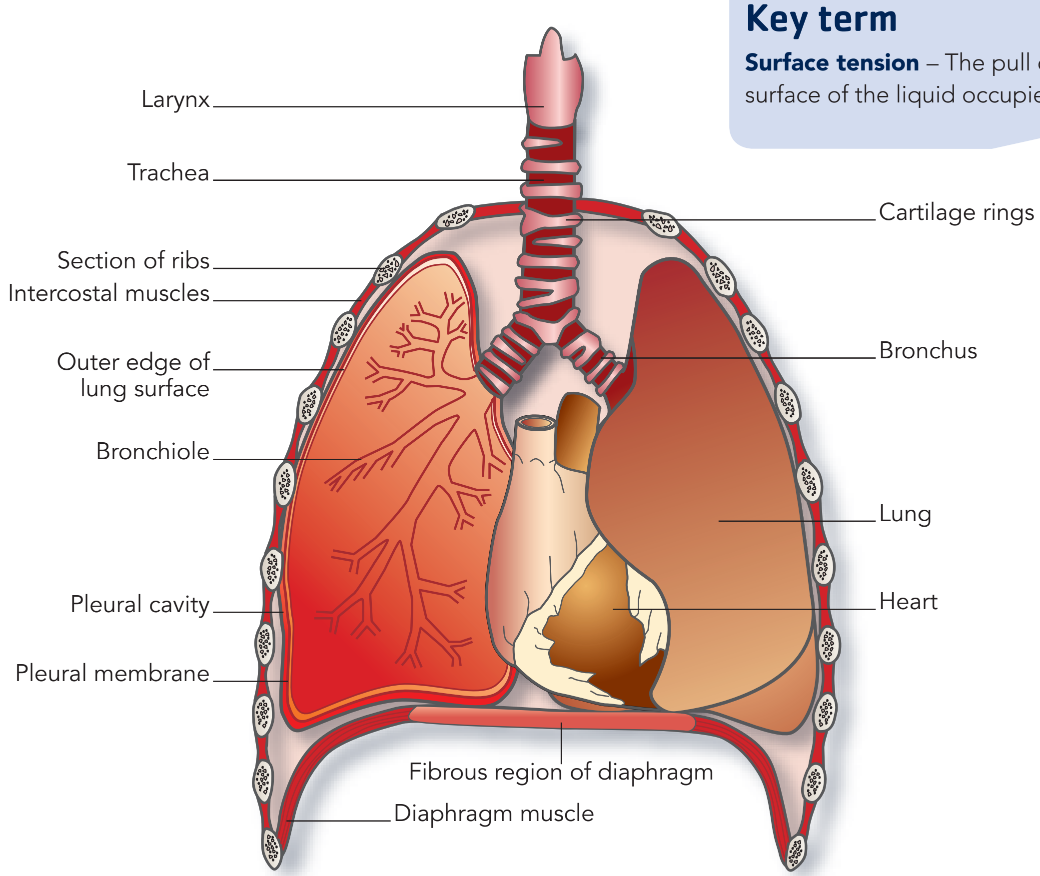


Fig 5.29: A section through the thorax showing the respiratory organs

Each bronchus, after repeatedly dividing, ends in a group of single-layered globe-shaped structures called alveoli, which look rather like a bunch of grapes on a stem. The walls of the alveoli consist of very thin, flat, simple squamous epithelium, and each alveolus is surrounded by the smallest blood vessels known as capillaries. The walls of the capillaries are also composed of simple squamous epithelium, in a single layer. This means that the air entering the alveoli during breathing is separated from the blood by only two single-layered, very thin walls. There are elastic fibres round the alveoli, enabling them to expand and recoil with inspiration and expiration respectively. A film of moisture lines the inside of each alveolus to enable the air gases to pass into solution. As the two layers of epithelium are very thin and semi-permeable, the dissolved gases can easily and rapidly pass through, in a process called gaseous exchange.

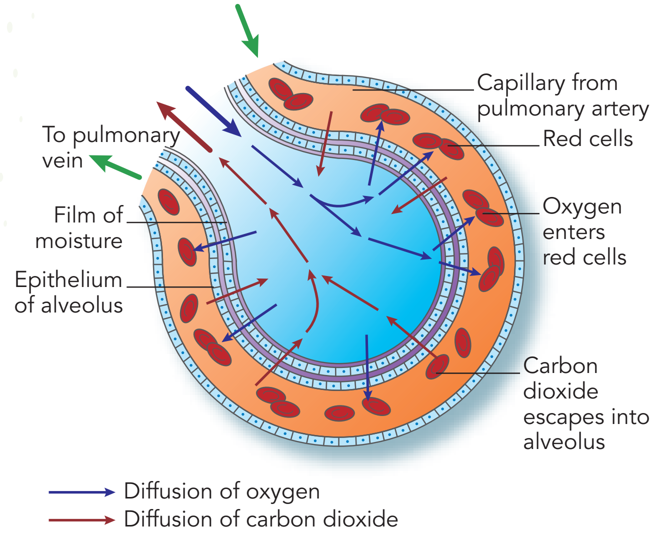


Fig 5.30: Gaseous exchange in the alveolus

Ventilation, or breathing, and the respiratory muscles

Ventilation is the movement of air in and out of the thorax to replenish the oxygen supply and remove surplus waste products (carbon dioxide and water). Ventilation has two phases, namely inspiration (or inhalation) and expiration (or exhalation). The movements in these phases are effected by respiratory muscles attached to the skeleton. Two sets of intercostal muscles run obliquely at right angles to each other between the ribs, and the diaphragm is a dome-shaped muscle attached to the lower ribs and separating the thorax from the abdomen.

Inspiration

When the intercostal muscles contract, the ribs move upwards and outwards and at the same time the contraction of the diaphragm causes it to flatten. All these movements increase the volume of the thorax and the lungs and thus reduce the pressure inside the lungs, causing air to rush in from the environment. This is known as inspired, or inhaled, air.

Expiration

The main force in expiration during quiet breathing is the elastic recoil of the fibres around the alveoli, and the relaxation of the diaphragm. However, during exertion, more forcible expiration can occur with the assistance of the other set of intercostal muscles contracting to move the ribs downwards and inwards. The volume of the thorax decreases, the pressure increases above that of the environmental air, and air rushes out.

Normal ventilation rate is 16 to 20 breaths per minute but this rises significantly during exertion.

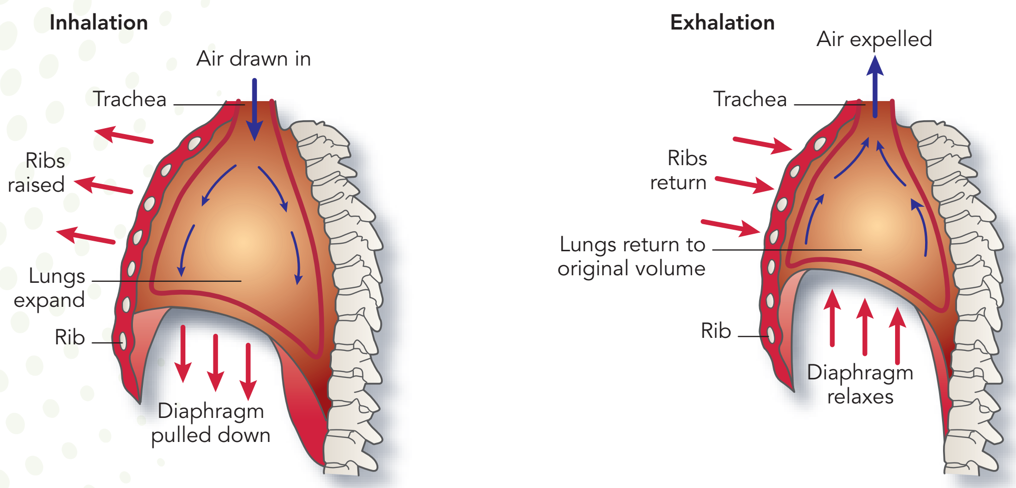


Fig 5.31: Changes in the thorax during inspiration and expiration

Nervous impulses from the brain cause the diaphragm and intercostal muscles to contract

↓

Diaphragm flattens and the intercostal muscles cause the ribs to move upwards and outwards → Volume of the chest increases, so the pressure inside the chest must decrease

↓

Air containing oxygen rushes down the trachea and bronchi to equalise the pressure with the external environment – **inhalation**

← Surface tension between the pleural layers drags the lungs with the chest wall. As they expand, they fill with air

↓

After a few seconds, the nervous impulses stop arriving and the elastic tissue in the lung causes recoil: the diaphragm rises and the ribs lower → Volume of the chest decreases, so pressure increases, causing air to rush out of the trachea – **exhalation**

↓

The cycle repeats after a few seconds because the respiratory control centre becomes active again, sending more nervous impulses

Fig 5.32: The process of breathing

Gaseous exchange

The composition of inspired air (which is the air around us) and that of expired air is shown in the table below:

Table 5.4: The composition of inspired and expired air

Component	Inspired air	Expired air
Oxygen	20 per cent	16 per cent
Nitrogen	80 per cent	80 per cent
Carbon dioxide	Virtually 0 (0.04 per cent)	4 per cent
Water vapour	Depends on climate	Saturated

Activity 11: Air changes

Write down the differences between inspired and expired air that you can see in Table 5.4. Why have these changes happened?

PLTS

Creative thinker: When generating ideas and exploring possibilities about air changes, you can demonstrate your creative thinking abilities.

Although the largest component of air is nitrogen and this too passes into solution, it takes no part in the process of respiration. Breathing in fresh air replenishes the high concentration of dissolved oxygen molecules in the lung alveoli, and the removal of diffused oxygen by the bloodstream maintains the low concentration. With carbon dioxide, the situation is reversed – the high concentration is in the blood and the low concentration is in the refreshed air, so diffusion (see below) moves dissolved carbon dioxide from the blood into the expired air from the lungs. Carbon dioxide and water are waste products from internal respiration in cells.

Diffusion

Diffusion occurs in liquids or gases because the molecules are in constant random motion, and diffusion is an overall 'equalling up' of a situation where you have a lot of molecules meeting a few molecules. Diffusion will stop in time, as the numbers of molecules become more evenly distributed. This is

Key term

Diffusion – The movement of molecules of a gas or a liquid from a region of high concentration to a region of low concentration.

said to be equilibrium. (Note that this does not mean the molecules stop moving, only that there are now equal numbers of molecules passing in all directions.)

In the human body, where diffusion is a common method of transport, the state of equilibrium is not desirable, as it means overall transport ceases. To prevent equilibrium being attained, the high concentration must be continually kept high, and the low concentration must also be maintained.

Diffusion can only occur where there is no barrier at all to the molecules or where the barrier (in gaseous exchange, this is cell membranes) is thin. The rate of diffusion is enhanced by having an increased surface area (usually created by folds or similar structures to alveoli) and a raised temperature, since warmth increases the random motion of molecules.

2.6 The digestive system

The alimentary canal

The alimentary canal is a tube that extends from the mouth to the anus. It is dilated, folded and puckered in various places along its length. You will need to know the names of the various regions, their main purpose and the outcomes of their activities. Many glands are associated with the alimentary canal, and have important roles to play in digestion.

When food is taken into the mouth it is mixed with saliva, chewed or masticated by the action of the tongue and teeth, rolled into a small ball known as a bolus, and swallowed. This process is called mechanical digestion and it is an important part of physically breaking the food down at an early stage.

The salivary glands

Three pairs of salivary glands pour their secretions known as saliva into the mouth. Saliva, a digestive juice, contains an **enzyme** known as salivary amylase, which begins the digestion of carbohydrates as well as lubricating the mouth and helping bolus formation.

The oesophagus

The oesophagus (or gullet) transports the food bolus from the back of the mouth (the pharynx) to the stomach in the abdomen. The swallowed bolus is in the oesophagus for a few seconds only and no enzymes are secreted here, although salivary amylase will continue to act during this brief journey. The oesophagus is mainly a transit for food boluses which it moves by muscular contractions known as peristalsis (see page 213).

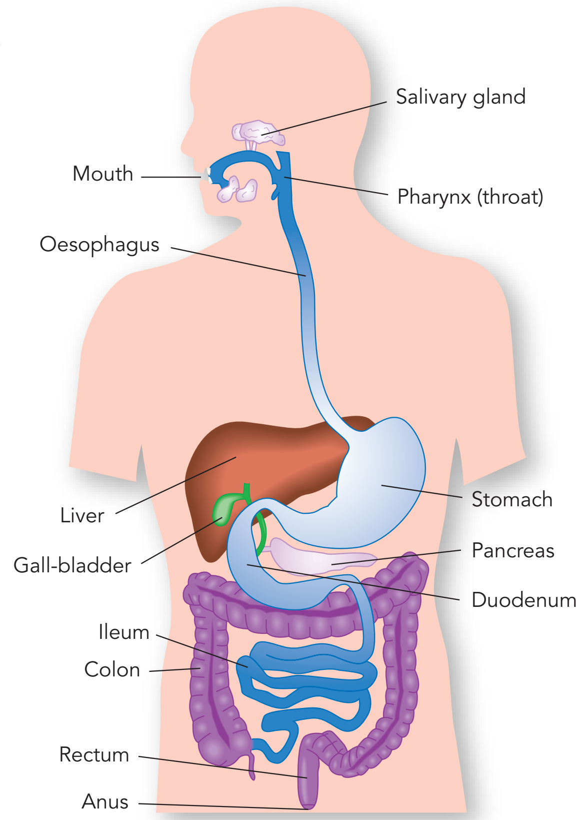


Fig 5.33: The alimentary canal

The stomach

The stomach is the widest part of the alimentary canal, tucked mainly behind the rib cage under the diaphragm on the left side and receiving food from the mouth by way of the oesophagus. Food can stay in the stomach for up to three hours, with a protein meal remaining the longest and food not containing protein passing through relatively quickly. During this time, the strong stomach walls roll and churn the food around and pour on secretions from the gastric glands. The resulting paste-like material is called chyme.

Gastric glands produce gastric juice that contains gastric protease and hydrochloric acid. The gastric juice works on proteins. In babies, another enzyme, rennin, solidifies and digests milk protein. The pH of the stomach is 1–2; this is strongly acidic. The epithelial lining of the stomach contains goblet cells, which produce thick mucus to protect the lining from acid erosion.

Key term

Enzymes – These are biological catalysts that alter the rates of chemical reaction (usually speeding them up) but which are themselves unchanged at the end of the reactions. You can read more about enzymes on pages 213–214.

The stomach empties the chyme in spurts into the duodenum through the pyloric sphincter, a thick ring of muscle that alternately contracts and relaxes.

The duodenum

The next part of the alimentary canal is the small intestine, so-called because of its small diameter – certainly not its length, for it is around 6 metres long! The first C-shaped part, and the shortest, is called the duodenum; it is mainly concerned with digestion and is helped by two large glands, the liver and the pancreas, that pour their secretions or juices into this area. The duodenal wall also contains glands which secrete enzyme-rich juices (called succus entericus) that continue the digestive process on proteins, carbohydrates and lipids, or fats. These work either on the surface or inside the epithelial lining cells.

The ileum

The remainder of the small intestine, known as the ileum, is mainly concerned with the absorption of the now fully digested food. It is specially adapted for this by its:

- long length
- folded interior
- lining covered in many thousands of tiny projections called villi
- epithelial cells of villi covered in microvilli, projections so small that they can only be detected using an electron microscope.

These adaptations enormously increase the surface area for absorption of nutrients from digested food.

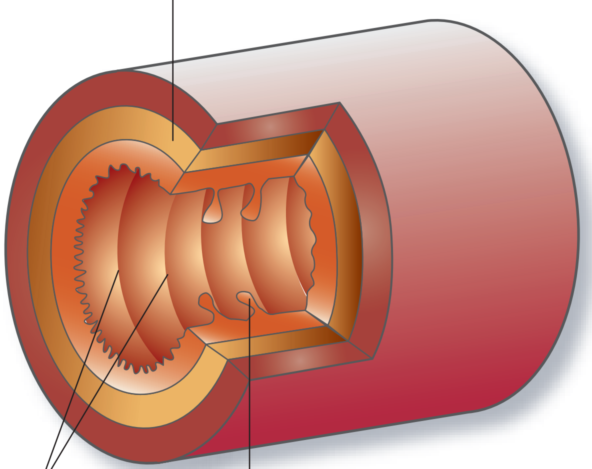
Each villus is lined by columnar cells and goblet cells only one-cell thick, with an extensive internal capillary network and a blind-ended branch of the lymphatic system called a lacteal.

The chief products of protein and carbohydrate digestion pass into the capillary network, which drains to the liver via the hepatic portal vein. Products of fat digestion pass into the lacteal and eventually they pass, via the lymphatic system, into the general circulation.

The colon

In the right-hand lower corner of the abdomen, the small intestine meets the large intestine; there are two biological remnants at this point, the caecum and the appendix. In grass-eating animals the caecum is a large structure with the worm-like appendix at the end. They are known as biological or evolutionary remnants because, in the human species, neither the caecum nor the appendix has any function. The appendix can become inflamed or pustulous and threaten life – a

Small intestine showing the internal folds and the villi



A villus and its blood supply

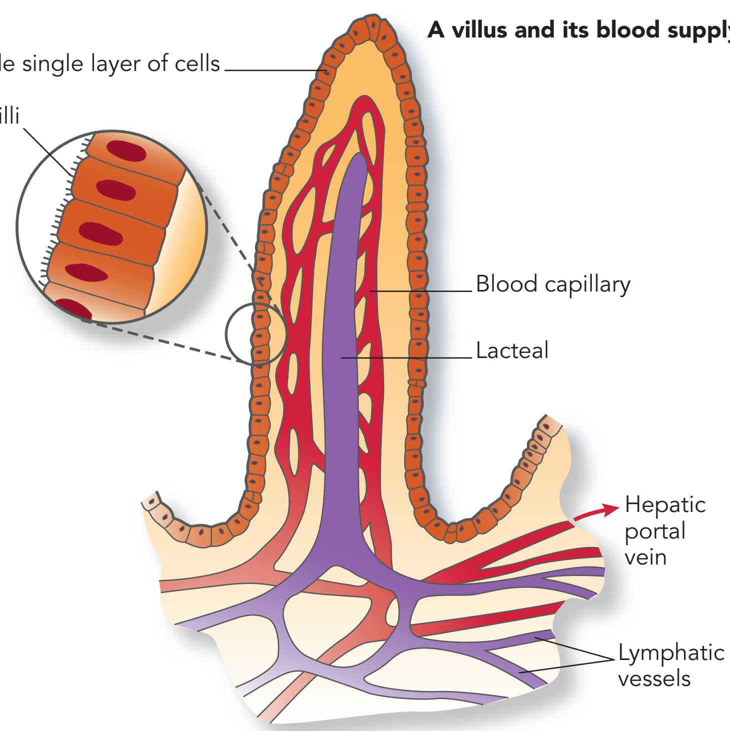


Fig 5.34: Small intestine and villi of the ileum

condition known as appendicitis. As well as the caecum and appendix, the large intestine consists of the colon and rectum, ending in the sphincter (the anus) for the elimination of faeces.

The colon runs up the right side of the abdomen and turns to travel across to the left side before ending at the anus. There are no enzymic juices in the large intestine.

The colon has a puckered appearance because the outer longitudinal muscle coat splits into three bands and the circular muscle bulges out between the bands. During the journey down the alimentary canal, many glands have poured watery juices onto the chyme. The body cannot afford to lose so much water and the purpose of the large intestine is to slow down the passage of food waste. (Food waste is all that is left at this stage because all the absorption of nutrients occurred in the small intestine.) This means that water can be reabsorbed and the motion, or faeces, becomes semi-solid. It can then be eliminated by muscular action of the rectum and relaxation of the anus at a convenient time.

Faeces contain:

- cellulose (fibre or roughage) from plant cell walls from fruit and vegetables
- dead bacteria, including the usually harmless bacteria living in the large intestine that have died a natural death, and other bacteria, which are often killed by the hydrochloric acid in the stomach
- scraped-off cells from the gut lining.

The brown colour of faeces is due to bile pigments.

Reflect

When faeces become pale yellow and skin becomes dark yellow/brown, what may have happened? See Student Voice on page 177.

Mucus, secreted by enormous numbers of goblet cells in the gut lining, reduces friction as chyme and waste are moved along by peristalsis.

The liver

The liver is a large, dark-red organ occupying the top right half of the abdomen and partly overlapping the stomach. It has many vital functions in the body, one of which is to produce bile. Bile flows down the bile duct into the duodenum, after temporary storage in the gall bladder on the undersurface of the liver. Bile contains no enzymes at all, but it provides important bile salts that cause the **emulsification** of fats (lipids) in the duodenum. You will recall that protein and carbohydrate have already experienced enzymic action. Lipids, like all fats, do not readily mix with water, so the enzymes have only a small water/lipid surface on which to work.

The emulsification results in the fats forming millions of tiny globules, each with a water/lipid surface so that enzymes can work efficiently over a massively enlarged surface area. Bile also contains bile pigments – bilirubin and biliverdin. These are the waste products of degraded haemoglobin from old, broken, red blood cells. They give the brown colour to faeces. Bile is secreted continuously by the liver and temporarily stored in a sac called the gall bladder. When a lipid-rich meal arrives, the gall bladder releases bile into the small intestine.

The liver also removes glucose and other sugars from the blood coming from the small intestine and converts them into glycogen for storage. Surplus amino acids not required for manufacturing cell proteins are broken down in the liver to form glycogen and urea – a nitrogenous waste product transported by the bloodstream to the kidneys for elimination in urine.

The pancreas

The pancreas is a slim, leaf-shaped gland, located between the intestines and the stomach, close to the duodenum. It secretes enzyme-rich pancreatic juice as well as alkaline salts needed to neutralise the acidic secretions from the stomach. Pancreatic enzymes go to work on all three macronutrients (protein, fat and carbohydrate) and are important agents for the complete breakdown of complex food molecules into amino acids, glucose and similar simple sugars, fatty acids and glycerol.

Breakdown and absorption of food materials

It is vital to understand that, without the organs and glands of the digestive system, we would be unable

Key term

Emulsification – This occurs when an emulsifier causes oil or lipids to be suspended as a large number of tiny globules in water.

to use the substances collectively called food by means of **digestion**. Taking food in through the mouth (what we would call 'eating') is known technically as **ingestion**. Food is generally composed of large complex molecules of protein, carbohydrate and lipids (or fats) that would be unable to pass through the lining of the alimentary canal. Converting these complex molecules into simple soluble molecules enables their **absorption** into the bloodstream and onward transit for metabolic processes. Waste material that has not been capable of absorption is passed out through the anus periodically: the technical term for this is **egestion**.

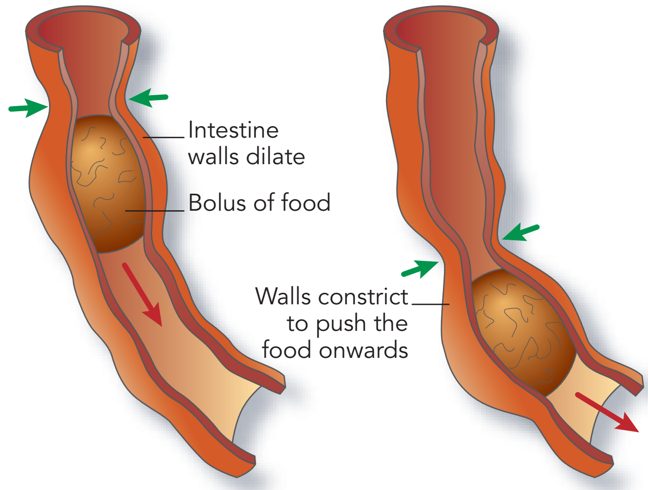


Fig 5.35: Muscular coats involved in peristalsis

Key terms

Digestion –The conversion of food into simple, soluble chemicals capable of being absorbed through the intestinal lining into the blood and being utilised by body cells.

Ingestion – The taking in of food, drink and drugs by the mouth.

Absorption – The taking up of substances to be used by the body cells and tissues.

Egestion – The process involved in eliminating waste material from the body as faeces.

Peristalsis

Food and chyme move down the alimentary canal by a process known as peristalsis. Note that in Figure 5.35 there are two sheets of muscle surrounding the tube – one sheet runs in a circular fashion around the tube while the other runs down the tube. Behind the bolus or chyme, the inner circular muscle contracts (and the longitudinal muscle relaxes), pushing material in front of it. This is rather like your fingers pushing toothpaste up the tube. In front of the material, the circular muscle relaxes and the longitudinal muscle contracts, to hold the tube open to receive the food. Two sets of muscles acting in this way are said to be antagonistic.

Did you know?

Even if you stand on your head, peristalsis will still push your food down your alimentary canal!

Strong peristaltic waves will cause abdominal pain (usually called colic) and the food will be hurried down the intestines.

2.7 The role of enzymes in digestion

To break down large complex molecules in the laboratory we would use heat (as in cooking) or add chemicals such as acids or alkalis. These processes are not possible in the human body, since cell and tissue structures would be destroyed or severely damaged.

Body cells are able to produce 'magical' substances called enzymes that can alter the rate of chemical reactions to build up or break down other molecules without using heat or harmful chemicals.

Enzymes are biological catalysts. This means that they are substances that can act within living organisms to enable the breakdown or building-up of other chemicals, but they remain unchanged themselves at the end of the reactions or tasks.

Enzymes are specific to the material on which they act (called a substrate). For example, a protease only acts on protein and a lipase only acts on lipids or fats. You may have noted that adding '–ase' at the end of the substrate name signifies that it is an enzyme. Not all enzymes are named in this way, but most are.

The main bulk of the human diet consists of protein, fat and carbohydrate so these are called macronutrients. They provide calories or joules of heat energy. Vitamins and mineral salts are only required in tiny amounts and are called micronutrients. They do not provide energy but are often important in energy release processes, oxygen carriage, metabolic rate, red blood cell formation and so on.

Enzyme reactions have some special features:

- Enzymes are sensitive to temperature. At low temperatures they work very slowly, or stop working; at high temperatures, they become distorted (denatured) and permanently stop working. Enzymes work best, or optimally, at body temperature.
- Enzymes are sensitive to the acidity or alkalinity of their surroundings, known as pH. Some digestive enzymes like pepsin (also known as gastric protease) work best in an acidic environment. The stomach lining secretes gastric protease and hydrochloric acid for maximum efficiency in breaking down proteins. Lipase prefers alkaline conditions and the pancreas secretes alkaline salts, such as sodium hydrogen carbonate, to provide optimal conditions. Salivary amylase prefers neutral or pH7 conditions. (Amylum is the Latin name for starch, so amylase works on starch.)
- Relatively few molecules of enzymes are required to break down lots of large food molecules because they are catalysts.
- Amylases work on cooked starch substrates (bread, rice, potatoes, etc.), converting the molecules to simple sugars like glucose.
- Proteases act on proteins, breaking them down into amino acids and peptides (two amino acids joined together chemically).
- Lipases convert lipids to fatty acids and glycerol.

Table 5.5, on page 215, summarises the sites of enzyme secretion and their role in digestion.

2.8 Major products of digestion

Roles in the body, storage and deamination

- Peptides and amino acids are nitrogenous compounds; they travel via the bloodstream to areas of need in body cells. They are important in making enzymes, some hormones, plasma proteins, new cells (growth) and in repair processes. Surplus amino acids are broken down in the liver, as they cannot be stored. Some parts of the molecules are used for energy but the nitrogen-containing part is converted into urea in the liver, by a process called deamination, and excreted by the kidneys in urine.
- Sugars, chiefly glucose, are transported to cells to be broken down in internal respiration to release energy; excess carbohydrate is stored in liver and muscles as glycogen or converted into fat to be stored around organs or under the skin. Glycogen is converted back to glucose when energy is required to top up the blood glucose supply to cells or for muscle contraction. The end products of internal respiration, carbon dioxide and water, are removed by the respiratory and renal systems.
- Glycerol and fatty acids: glycerol is used for energy or reconverting fatty acids into a form of fat that can be stored. Fatty acids travel from the lacteals, through the lymphatic system into the main veins of the neck; this circuitous route enables smaller quantities of potentially harmful lipids to enter the circulation gradually.
- Fatty acids are also used in internal respiration to release energy to drive metabolic processes. The end products of internal respiration, carbon dioxide and water, are removed by the respiratory and renal systems.
- Fat is stored under the skin and around organs, where it forms a long-term energy store to be used after glycogen stores are depleted.

2.9 Absorption of food

This topic is to be found under the heading 'The ileum' on page 211.

Table 5.5: The main digestive processes, locations and outcomes

Location	Gland and juice	Contents	Substrate	End product	Other comments
Mouth	Salivary glands/ saliva	Salivary amylase	Carbohydrate: starch	Disaccharides: 'double' sugar molecules	Salivary amylase is mixed with food during mechanical digestion. Requires a neutral pH to function efficiently.
Oesophagus	None	None	None	None	Salivary amylase still acting on short journey.
Stomach	Gastric glands/ gastric juice	• Gastric protease* • Hydrochloric acid • Rennin in babies	Protein	Amino acids and peptides (like double amino acids)	The pH of gastric juice must be acid for pepsin to work. Food is churned into chyme. Bacteria in raw food are killed by acid.
Small intestine a) Duodenum	Intestinal glands/ intestinal juice (succus entericus)	• Peptidase • Various carbohydrates	• Peptides • Disaccharides: 'double' sugar molecules	• Amino acids • Glucose and other simple soluble sugars	Alkaline medium (pH8).
b) Liver, an associated gland (not part of the alimentary canal)	Liver/bile	• No enzymes • Bile salts • Bile pigments	None	None	Bile salts are important in emulsifying lipids or fats. Convert small intestine contents from acid to alkaline.
c) Pancreas, an associated gland (not part of the alimentary canal)	Pancreas/ pancreatic juice	• Lipase • Pancreatic amylase • Pancreatic protease* (formerly called trypsin) • Alkaline salts	• Lipids or fats • Carbohydrates • Proteins and peptides	• Glycerol and fatty acids • Glucose • Amino acids	An important digestive gland. Salts convert acid stomach secretions to alkaline so that enzymes work optimally.
d) Ileum	None	None	None	None	Main area for absorption of the end products of digestion through millions of villi.
Large intestine a) Colon	None	None	None	None	Main area for reabsorption of water.
b) Rectum	None	None	None	None	Muscular walls expel semi-solid faeces through anus at periodic intervals.

*Gastric protease and pancreatic protease are secreted as inactive precursors; they become activated by other substances once they are mixed with chyme in the lumen (hole) of the tube.

Assessment activity 5.4

P4 M1 D1 BTEC

You are an adviser in your local sports centre and you have been asked to design and produce an information booklet to explain to clients how the body requires and utilises energy. This should include:

- an outline of the respiratory, cardiovascular and digestive systems
- an overview of how energy is utilised in the body
- and how two main body systems are linked to this utilisation.

Grading tips

P4 To achieve P4, you need to explain the physiology of two named body systems in relation to energy metabolism in the body. First you have to decide which two systems you will choose. The cardiovascular system should really be one of them, to help understanding and give coherence. Imagine the booklet is for an athlete or an individual on a restricted diet.

If digestion is one of your selected systems you need only consider the three major macronutrients present: protein, carbohydrate and lipids. Start with mechanical digestion in the mouth and explain what happens in each part of the alimentary canal. You need not go beyond the ileum but you do need to include absorption and the fate of the end products of digestion, where this is associated with energy metabolism.

The focus for the respiratory system should be on breathing, gaseous exchange and cell respiration.

The cardiovascular system should include the role of the blood and transport of materials within plasma and haemoglobin.

M1 To gain M1, you have to discuss the role of energy in the body. You will need to explain that energy in the body comes from the diet and describe how it is transformed into energy used by the body as well as saying where the energy is used.

D1 For D1, you have to analyse how two body systems interrelate with each other to perform a named function or functions. Use examples to explain how these body systems interrelate with each other. As you explain your work, you will naturally make links – for instance the regulation of plasma glucose by the endocrine system, or the way in which the nervous system is involved in the regulation of the cardiac cycle. This will lead you towards a distinction. Try to make at least five substantial links of this nature. It might be advisable to draw attention to such links by the use of headings.

PLTS

Self-manager: This activity will allow you to illustrate self-management skills when working towards the goal of producing an information booklet by a specified date and dealing with competing pressures to meet deadlines.

Functional skills

ICT: By storing work on a password-protected storage device you are using ICT systems. Use ICT to present information in a booklet that is fit for purpose.

3 Understand how homeostatic mechanisms operate in the maintenance of an internal environment

You have learned how tissue fluid bathes body cells and is a protein-free plasma filtrate driven out of leaky capillaries by blood pressure, and how (digestive) enzymes are sensitive to pH and body temperature. You will not be surprised therefore to extend this by realising that blood and tissue fluid and consequently cell contents require stability in their chemical and physical make-up. All metabolic processes are governed by enzyme actions, which are subject to the same characteristics as digestive enzymes.

3.1 Homeostasis

Homeostasis is the technical term for the process of maintaining a constant internal environment despite external changes. The 'internal environment' comprises blood, tissue fluid, body cell contents and all the metabolic processes taking place.

It is important to realise that the use of the term 'constant' in this context is not absolute and fixed; it is more flexible and dynamic and refers to the physical and chemical composition being kept within a limited range of variables for maximum efficiency, well-being of the whole body and, indeed, the maintenance of life itself. This limited range of variables is said to be regulated.

Negative feedback as a form of regulation

Negative feedback occurs when an important variable, sometimes known as a key variable, such as the pH of blood and tissue fluid, deviates from the accepted range or limits, and triggers responses that return the variable to within the normal range. In other words, deviation produces a negative response to counteract or nullify the deviation. It is a 'feeding back' of the disturbance to the status quo. During your study of the liver as part of the digestive system, you learned that when blood glucose levels fall, the liver glycogen is converted into glucose in order to top up those crucial energy levels in cells. This is an example of a negative feedback system and we shall study this further in due course.

The brain and nervous system play a vital role in controlling homeostatic mechanisms and they also help us to anticipate when key variables might rise or fall beyond the accepted range. For example, if it is several hours since your last meal and you are beginning to feel tired and cold, you will try to eat a warm, energy-giving meal to counteract these feelings. This can be termed 'feedforward' (rather than feedback), as you are taking steps to avoid a low energy state before it has happened.

Negative feedback systems require:

- receptors to detect change
- a control centre to receive the information and process the response
- effectors to reverse the change and re-establish the original state.

Most control centres are located in the brain.

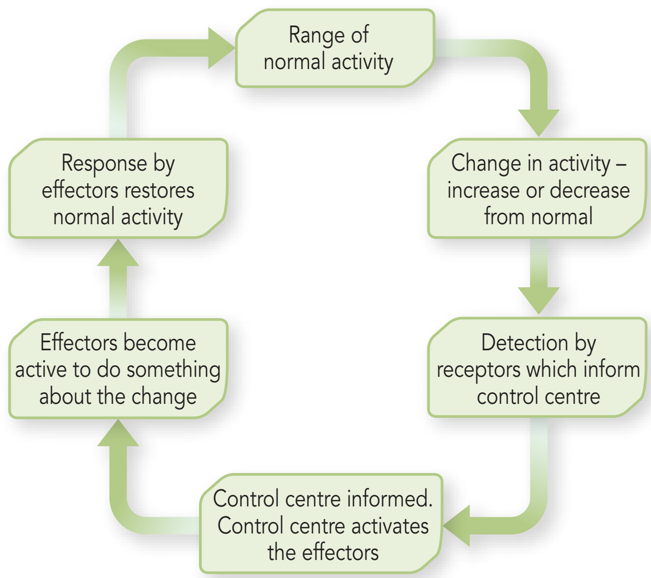


Fig 5.36: Feedback control systems

Activity 12: Prevention is better than cure

Can you think of other examples of times when your brain might be suggesting feedforward strategies? Try a thought shower with your peers and see how many examples you can suggest.

PLTS

Creative thinker: This activity will help you to demonstrate that you can question your own and others' assumptions when thinking of examples of feedforward strategies.

3.2 Homeostatic mechanisms for regulation of heart rate

First we will learn how the heartbeat is regulated. Let's begin by looking at the control of the cardiac cycle and the role of the autonomic, parasympathetic and sympathetic nervous systems.

The heart is controlled by the autonomic nervous system which has two branches, namely the sympathetic nervous system and the parasympathetic nervous system. These two systems act rather like an accelerator and a brake on the heart. The sympathetic nervous system is active when the body is undergoing muscular work, fear or stress. It causes each heartbeat to increase in strength as well as causing an increase in heart rate. The parasympathetic nervous system calms the heart output and is active during resting, peace and contentment. The main parasympathetic nerve is the vagus nerve and if this is severed the heart beats faster.

The sympathetic nervous system is boosted by the hormone adrenaline during periods of fright, flight and fight! Its nerves are the cardiac nerves.

The sympathetic and parasympathetic nervous systems supply a special cluster of excitable cells in the upper part of the right atrium. This is called the sino-atrial node (S-A node) or in general terms 'the pacemaker'. An interplay of impulses from the sympathetic and parasympathetic nerves acting on the S-A node regulate the activity of the heart to suit circumstances from minute to minute, hour to hour and day to day.

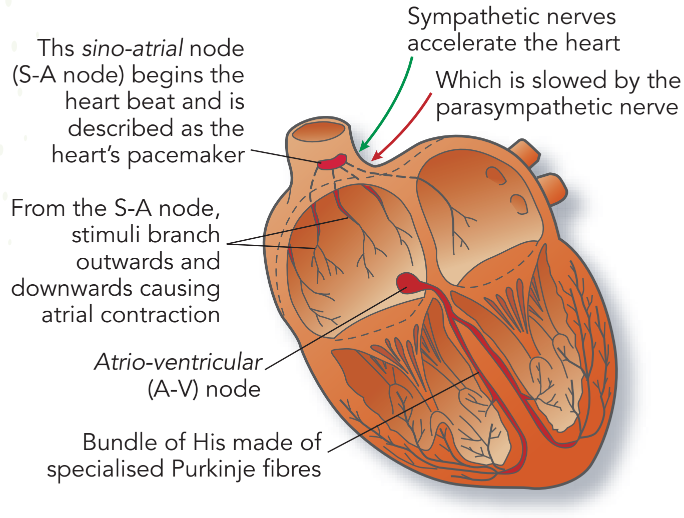


Fig 5.38: Control of the cardiac cycle by the conduction system

Every few seconds, the S-A node sends out a cluster of nerve impulses across the branching network of atrial muscle fibres to cause contraction. The impulses are caught by another group of cells forming the atrio-ventricular node (A-V node) and relayed to a band of conducting tissue made of large, modified muscle cells called Purkinje fibres.

The transmission of impulses is delayed slightly in the A-V node to enable the atria to complete their contractions and the atrio-ventricular valves to start to close.

Heart valves are located on a fibrous figure-of-eight between the atrial and ventricular muscle masses, and the first part of the conducting tissue (the bundle of His) enables the excitatory impulses to cross to the ventricles. The bundle of His then splits into the right and left bundle branches, which run down either side of the ventricular septum, before spreading out into the ventricular muscle masses.

Impulses now pass very rapidly so that the two ventricles contract together, forcing blood around the body organs.

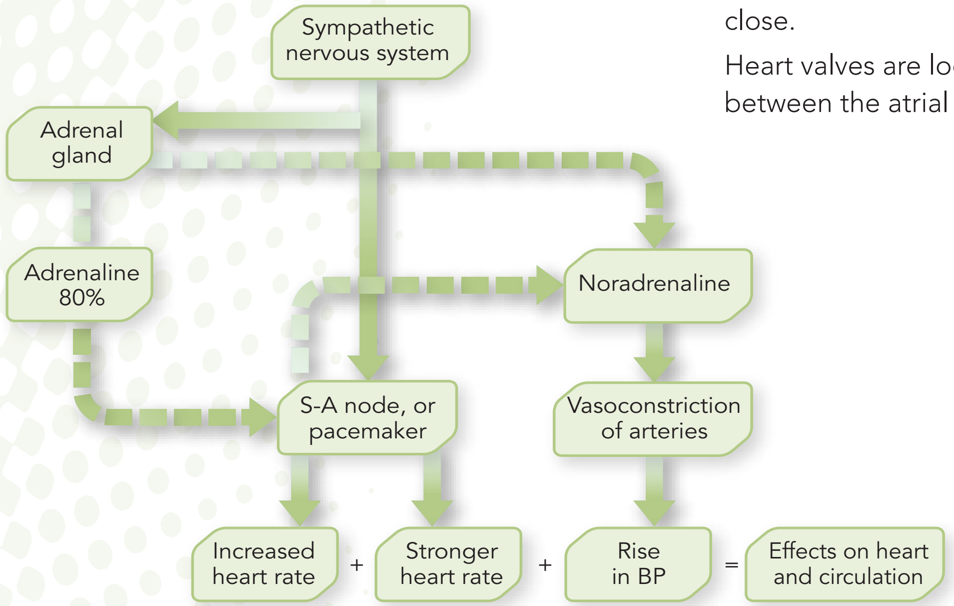


Fig 5.37: Sympathetic and parasympathetic control of the heart

Cardiac centres

The medulla of the brain is the lowest part, located just above the spinal cord and often known as the 'brain stem'. Two important centres for control of the heart rate are located here. The cardio-inhibitory centre is responsible for the origins of the parasympathetic fibres of the vagus nerve reaching the S-A node, while the sympathetic fibres descend through the spinal cord from the vasomotor centre.

Role of internal receptors

Baroreceptors detect changes in blood pressure and are found in the walls of the aorta and part of the carotid arteries delivering blood to the head and neck and called the aortic and carotid bodies. A small upward change in blood pressure (BP) in these arteries often indicates that extra blood has been pumped out by the ventricles as a result of extra blood entering the heart on the venous or right side. Baroreceptors detect the change and relay the information in nerve impulses to the cardiac centres. Activity in the vagus nerve slows the heart rate down and decreases BP back to normal.

Receptors sensitive to temperature are known as thermoreceptors and these are present in the skin and deep inside the body. They relay information via nerve impulses to a part of the brain called the hypothalamus, which activates appropriate feedback systems.

Effects of adrenaline on heart rate

Circulating adrenaline, a hormone from the adrenal gland released during fear, stress and exertion, stimulates the S-A node to work faster, thus boosting the effect of the sympathetic nervous system.

Effect of increased body temperature on heart rate

Thermoreceptors indicating a rise in body temperature to the brain cause the hypothalamus to activate the sympathetic nervous system. This in turn causes the heart rate to increase.

3.3 Homeostatic mechanisms for regulation of breathing rate

We are mainly on 'automatic pilot' for our rate of ventilation and do not notice minor variations that are the result of homeostatic regulations. Only when taking deep breaths, speaking or holding a breath are we voluntarily controlling our breathing. When metabolism produces extra carbon dioxide, for example, breathing rates will increase slightly until this surplus is 'blown off' in expiration. Similarly a period of forced ventilation, such as gasping, will lower the carbon dioxide levels in the body and homeostatic mechanisms will slow or stop breathing temporarily until levels return to normal.

Activity 13: Voluntary or involuntary?

Count your own or a partner's quiet breathing rate over several minutes and then breathe (voluntarily) rapidly for 2 minutes. Immediately afterwards count the breathing rate for the next 3 minutes. Compare the rates before and after the forced ventilation to demonstrate homeostatic regulation.

Roles of internal receptors

Internal receptors can be stretch receptors in muscles and tissues that relay nervous impulses to the brain about the status of ventilation from the degree of stretch of muscles and other tissues. The intercostal muscles are the site of many stretch receptors.

Chemoreceptors detect changes in chemical stimuli (such as H^+ ions and oxygen levels) and supply the brain with this information. There are central and peripheral chemoreceptors. The central chemoreceptors monitoring H^+ ion concentration are located in the medulla of the brain; an increase in H^+ ion concentration results in increased ventilation rate. Peripheral receptors, monitoring changes in oxygen concentration, increase ventilation when oxygen levels decrease. Peripheral chemoreceptors are scattered around the aorta and carotid arteries in groups labelled the aortic and carotid sinuses (see Figure 5.39 on page 220).

Autonomic nervous system – parasympathetic and sympathetic branches

Most internal organs have a dual autonomic supply and the respiratory system is no exception. What can be different, however, is the way they act. It would be easy to say that the sympathetic always causes contraction

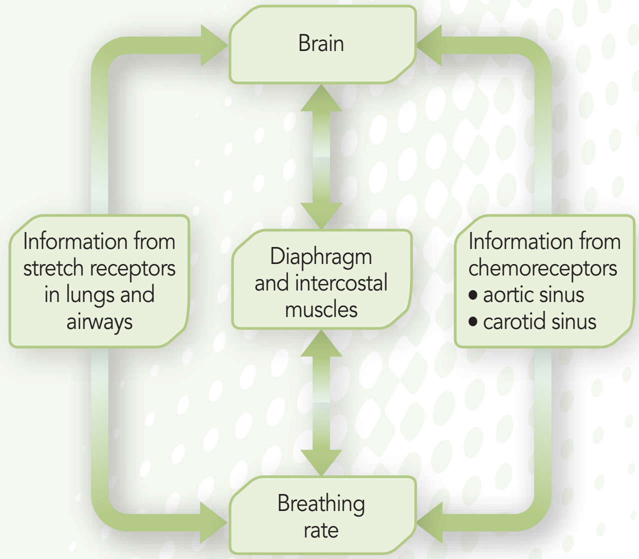


Fig 5.39: The role of internal receptors

and the parasympathetic causes relaxation of muscle coats – but unfortunately this is not so. In the case of bronchial muscle, the sympathetic causes it to relax and the parasympathetic causes contraction, resulting in narrowing of the bronchi. Most of these fibres run in the vagus nerve (which you have already met) in serving the heart. The vagus nerve is so-called because it wanders all over, supplying internal organs; vagus means 'a wanderer' – like a vagrant! Sympathetic nerves emerge from a chain of ganglia (places where nerves interconnect), to run to the bronchi.

Activity 14: Emergency action

The parasympathetic is active during rest, peace and contentment and the sympathetic during emergencies. A useful way to work out the actions is to imagine yourself in a life-threatening situation – such as being in the middle of a road when a car is suddenly closing fast. What would be likely to happen physiologically to your body? Try a thought shower with your peer group.

PLTS

Creative thinker: You can show your creative thinking skills by generating ideas and exploring possible actions associated with adrenaline release.

Respiratory centre, diaphragm and intercostal muscles

The brain area responsible for voluntary control of breathing is in the upper part of the brain known as the cerebral cortex. The involuntary centre, known as the respiratory centre, is in the medulla and the area just above, known as the pons. These are both at the base of the brain. Each centre gets information from internal receptors regarding the state of ventilation.

The respiratory centre is similar to a respiratory 'pacemaker'. There are two groups of nerve cells, known as the inspiratory and expiratory centres, and when one is active the other is inhibited. Clearly, the inspiratory centre is actively sending nerve impulses

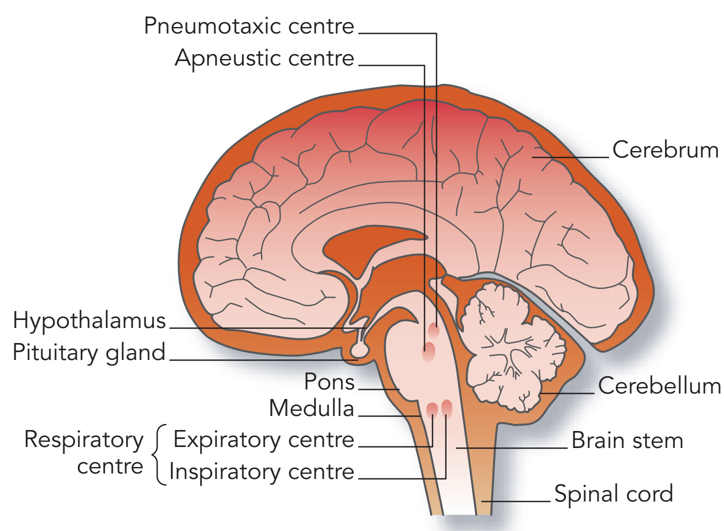


Fig 5.40: The brain showing respiratory centres

to the nerve to the diaphragm – the phrenic nerve – and the thoracic nerves are sending impulses to the intercostal muscles to cause contraction, resulting in inspiration. Inspiration ceases when the stretch receptors send bursts of impulses to the inspiratory centre, saying that the chest and lungs are fully expanded, and the flow of impulses subsides, releasing the expiratory centre from inhibition. This centre then sends nerve impulses to the respiratory muscles, causing relaxation and expiration. This cycle of activity is monitored and modified by the information coming from the other internal receptors, such as the chemoreceptors, effecting homeostatic regulation.

Before exercise starts, the body predicts the changes because the sympathetic nervous system is stimulated and adrenaline is released to increase cardiac output and stroke volume; BP rises because arterioles narrow,

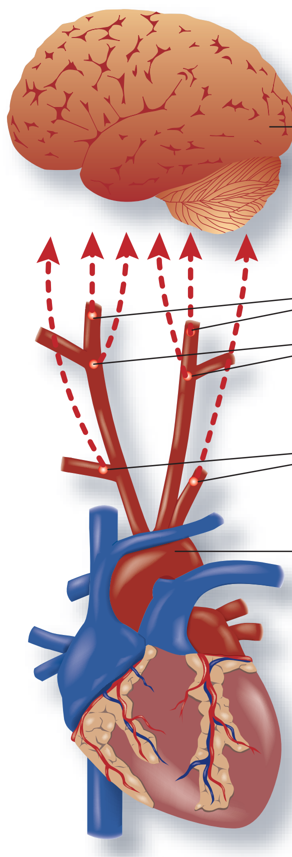


Fig 5.41: Location of internal chemoreceptors

except for those in muscle, which relax. The extra demands for oxygen and glucose are met by increased blood flow and ventilation rate (the latter caused by enhanced chemoreceptor activity on the medullary brain centres).

3.4 Homeostatic mechanism for regulation of body temperature

Human beings are the only animals that can survive in both tropical and polar regions of the earth. This is largely due to efficient thermo-regulatory homeostatic processes and the use of intelligence (for shelter and clothing), which mean that body temperature varies only minimally.

The fundamental precept is to keep the inner core of the body (containing the vital organs) at normal temperatures while allowing the periphery (skin, limbs, etc.) to adapt to changing conditions of external temperature.

At very low temperatures such as –30°C, the water component of the body would freeze and at high temperatures such as +50°C, enzymes and body proteins would be permanently altered or denatured. Life would not be possible under these conditions so homeostatic regulation of body temperature or thermo-regulation is vital. The skin plays an important role in this so we will start with an explanation of its structure and functions.

Structure and functions of skin

The skin covers the outer surface of the body and surprisingly forms the largest organ. New cells are continually forming to replace those shed from the surface layers. The skin is a significant part of our in-built or innate immunity and forms not only a waterproof layer but also a microbe-proof covering. It plays an important part in the homeostatic regulation of body temperature and is considered to be part of our nervous system because of its sensitivity.

The skin varies in thickness throughout the body, being thinnest over the eyelids and lips and thickest on the soles of the feet. For study purposes, it is divided into an outer thinner layer, the epidermis, and a deeper layer called the dermis. The dermis covers adipose, areolar, striated muscle, and some cartilage and bone. You have already learned about the structure of the epidermis as a tissue on page 185 and the keratinisation of its cells. Hair follicles are also extensions of the epidermis, which run down into the dermis and produce hairs made of keratin. Attached to these are the sebaceous (or oil) glands that coat the surface in hairy parts, assisting the water-proofing. Sweat ducts penetrate the epidermis as they emerge from the actual sweat gland in the dermis. In the basal layer, there are collections of pigment cells known as melanocytes that produce skin colour. The pigment melanin protects against damage to deeper structures from ultra-violet light radiation.

The dermis is connective tissue, mainly areolar, in which blood vessels, nerves, sweat glands, elastic and collagen fibres intermingle.

Nerve endings form specialised receptors for temperature changes, pain, touch and pressure.

Hair erector muscles have their origins low down on the hair follicles and their attachments to the basal layer of the epidermis. When hair erector muscles contract (usually from fear or the sensation of coldness) the hair becomes more erect, making the skin surface lumpy (known as 'goose bumps').

> **Did you know?**
>
> When you have 'goose bumps', the hair erector muscles have contracted and the effect is a small bump at the base of the hair. In hairy animals, this traps a layer of warm air around the body for extra warmth and makes the animal look larger in a threatening situation. In humans, however, neither effect is very useful! We rely on clothing, muscular activity, fat layers and shelter to keep us warm.

The major functions of skin are:

- to protect the underlying tissues against friction damage
- to waterproof the body
- to protect deeper structures from invasion by micro-organisms
- to protect against ultra-violet radiation
- for thermo-regulation (control of body temperature)
- to relay nerve impulses generated from the specialised skin sensory receptors for heat, cold, touch, pain and pressure, thus informing the brain of changes in the environment
- to synthesise vitamin D from sunlight acting on the adipose layers.

Production of heat by the body

Heat is generated by the metabolic processes taking place in the body. Although energy released during chemical reactions is used to drive processes such as muscle contraction (heart pump, breathing, movement, nerve impulses, etc.) some of it is always released as heat. Hundreds of chemical reactions take place in the liver, for example, every day and the liver is a massive generator of body heat. It doesn't feel hot because the blood distributes this heat around the body, particularly the extremities. Some heat is also gained from hot food and drinks and, under some circumstances, from the sun's rays.

Loss of heat from the body

Skin capillaries form networks just below the outer layer or epidermis. When you are hot, you need to lose heat from the skin surface to cool yourself down. There are four ways of losing heat from the skin:

- Conduction – warming up anything that you are in contact with (like clothes and seats); even a pen becomes warm from your hand when you are writing!
- Convection – this is when you warm up the layer of air next to your skin and it moves upwards (because hot air is less dense and rises), to be replaced by colder air from the ground.

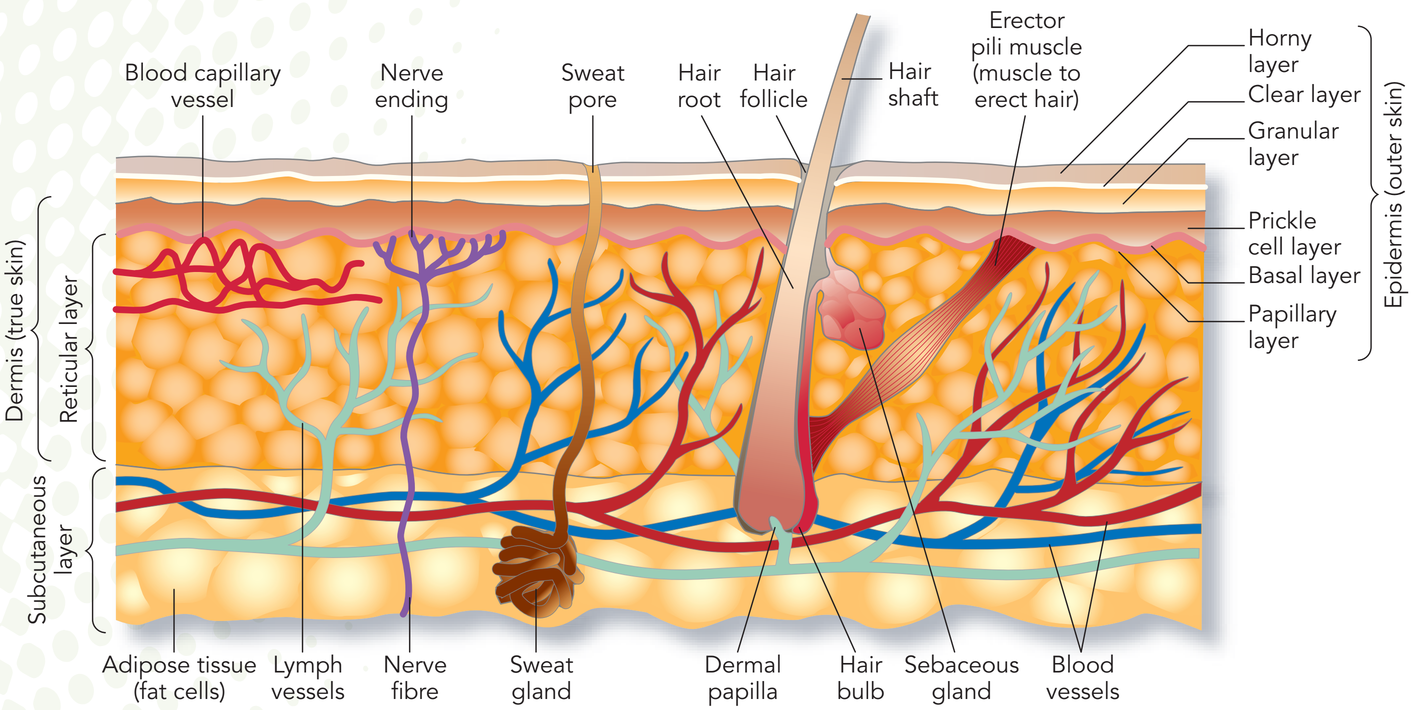


Fig 5.42: The structure of skin

- Radiation – you can think of this as being rather like diffusion but of heat temperature. In other words, heat will pass from your skin to warm up any colder objects around you; and, conversely, you will warm up by radiation from any object hotter than yourself, like a fire or the sun.
- Evaporation of sweat – when liquid water is converted into water vapour (the technical term is evaporation), it requires heat energy to do so. When you are hot, sweating will only cool the skin if it can take heat energy from the skin surface to convert to water vapour and evaporate.

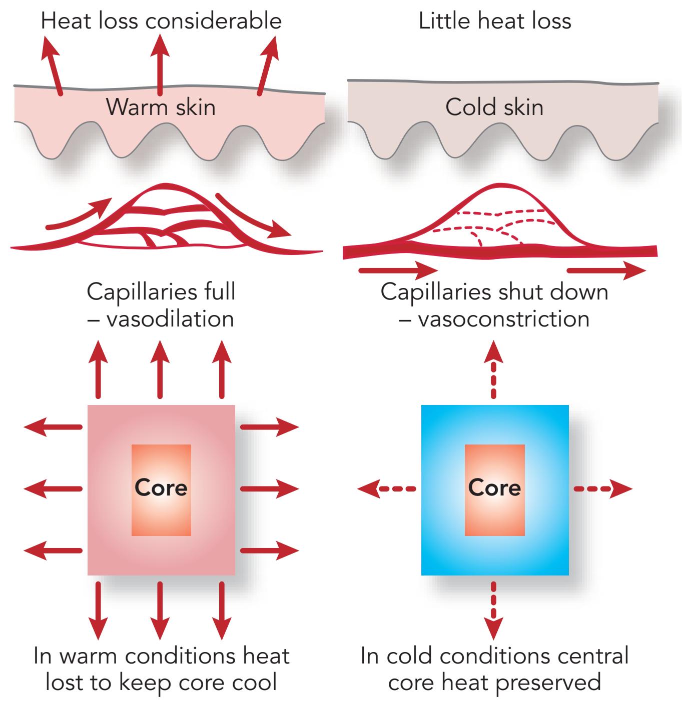


Fig 5.43: Changes in skin radiation

Did you know?

Parents fuss about drying children properly with towels after getting wet because if water evaporates from the skin naturally it chills the body. This is because the process of evaporation uses heat energy from the body.

Reflect

The monsoon season in tropical countries affects work and productivity because people feel very uncomfortable. Sweat cannot evaporate and cool the skin because the saturated air is already holding as much water as it possibly can.

Although conduction and convection take place, they cannot be changed significantly to alter body temperature. The main methods of regulating temperature are by changing radiation and sweat-evaporation processes.

Role of the hypothalamus

The receptors for temperature, both heat and cold, are located in the peripheral skin and around the internal organs. These are specially adapted cells with nerve fibres that run up the spinal cord to the temperature control centre in the hypothalamus of the brain (see Figure 5.44 below). The hypothalamus sends nerve impulses to muscles, sweat glands and skin blood

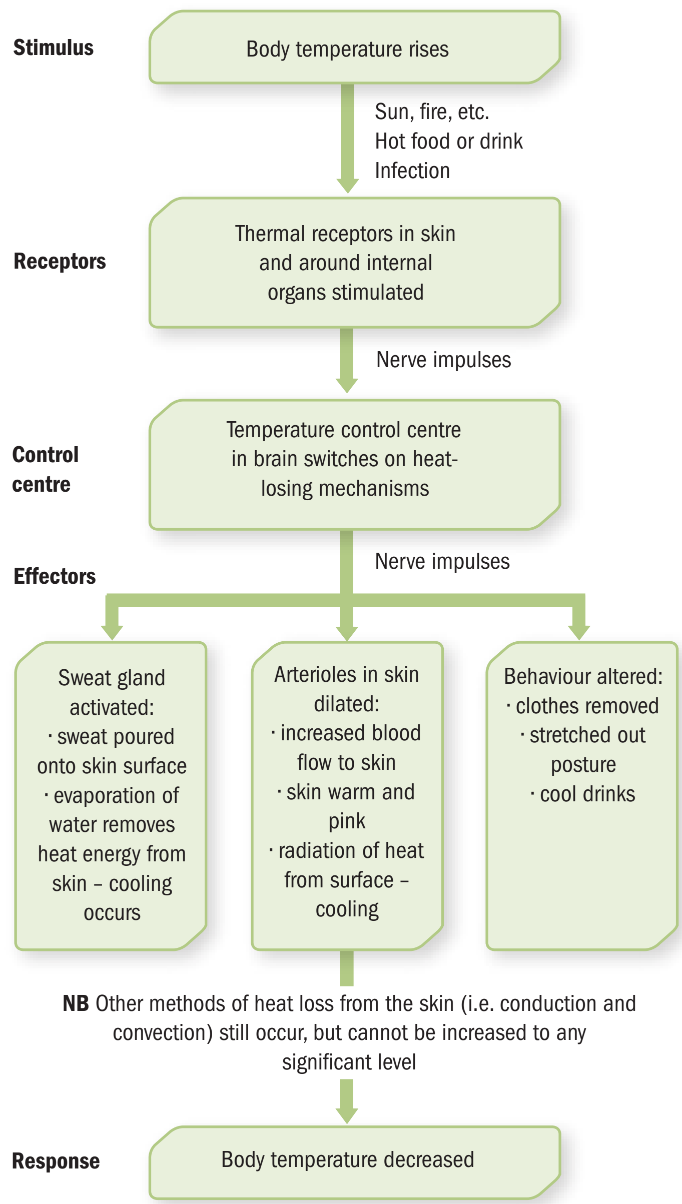


Fig 5.44: Homeostatic regulation of an increasing body temperature

vessels to cause changes that counteract the external changes. You can see the precise effects of a rising and falling external temperature in the flow charts in Figures 5.44 and 5.45.

Roles of the parasympathetic and sympathetic nerves

The parasympathetic nervous system has no significant role in thermo-regulation (although it helps the unstriated muscle coats of the skin arterioles to relax), but the sympathetic nervous system controls both sweat glands and the calibre of the arterioles.

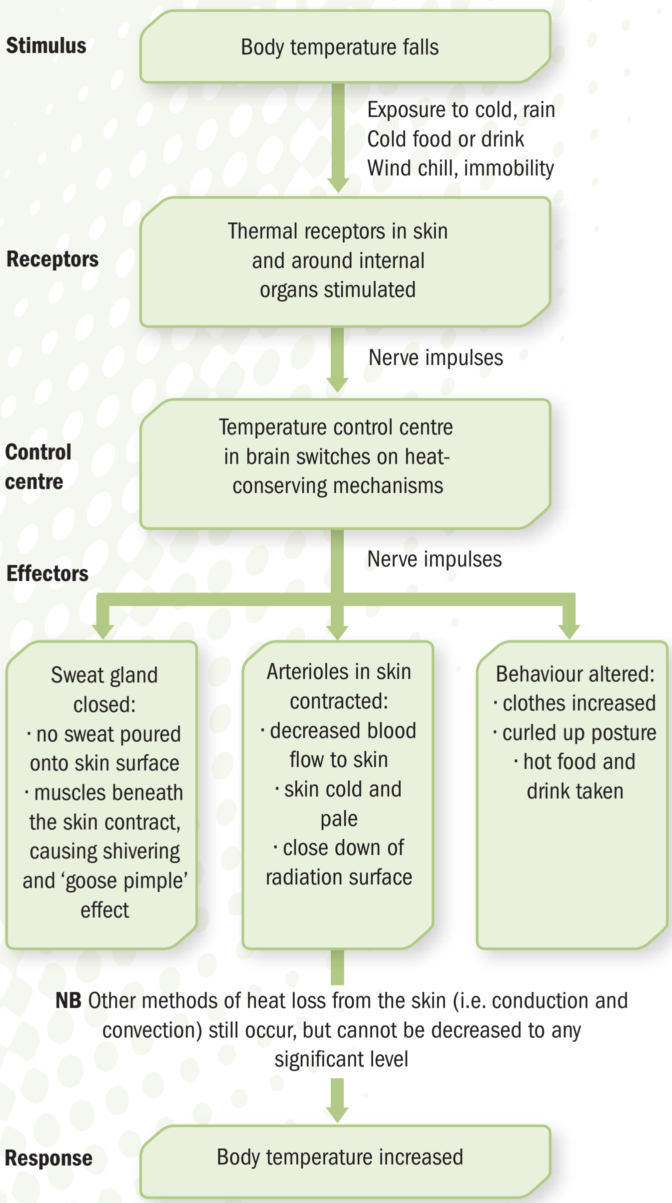


Fig 5.45: Homeostatic regulation of a falling body temperature

Role of arterioles and sweat glands

As thermoreceptors tell the hypothalamus in the brain that the temperature is rising, sweat glands are activated by the sympathetic nerves, and arterioles are dilated to let more heat reach the surface of the skin, thus increasing heat loss by radiation and evaporation of sweat. Conversely, if the core temperature is cooling, the sympathetic is active in causing constriction of the arterioles but sweating is 'turned off'. This reduces heat loss, makes the skin colder to touch, and thus preserves the core temperature.

Activity 15: Seems all wrong!

It is a very hot day and you feel that a long iced drink is needed but your mother wants to make a warm drink because it is more cooling. Explain why she is correct.

PLTS

Creative thinker: Demonstrate that you can question your own and others' assumptions about ways of cooling by completing this activity.

The reason is that core temperature overrides the peripheral skin thermoreceptors when conflicting information is received. Think about what happens when a hot volume of fluid reaches the core and compare this with a mass of freezing food.

Effects of shivering

Rhythmic involuntary contractions of the skeletal muscles are known as shivering. Muscular activity generates heat so in a cold environment we may stamp our feet, swing our arms, rub our face, hands and feet and also shiver. This is a very effective way to generate heat, as it is all available to warm the body up.

Implications of surface area to volume ratio in the care of babies

Babies have a larger surface area to volume ratio than adults and cannot effect changes to gain or lose heat for themselves; this means that they are at risk of developing **hyperthermia** or **hypothermia**.

Case study: Seasonal behaviour

In winter I curl up in a ball in bed and add layers of clothing to keep warm. In summer, I wear one thin layer of clothing and stretch out in bed.

1 Explain why these different behaviours occur.
2 Explain the main way that heat is lost by increasing the surface area to volume ratio in hot weather.
3 Adolescents commonly go out in very cold weather wearing skimpy clothing and no coats without feeling cold. Explain why this might be dangerous for older people.
4 Explain why babies need to wear hats in colder weather.

PLTS

Creative thinker: Demonstrate that you can question your own and others' assumptions about methods of thermal control by completing this activity.

Babies do not sweat much and newborn babies do not shiver. Therefore, it is important in cold weather to wrap babies warmly, including the extremities and the head, and to guard against over-heating in hot weather.

Fever

Fever is one type of hyperthermia and is most usually caused by infection; other types are heat stroke and heat exhaustion – all can be life-threatening. Factors released as a result of disease act on thermoreceptors in the hypothalamus, raising the upper **set point**. Consequently the sufferer feels cold, curls up, pulls on covers, looks pale due to vasoconstriction (narrowing of the arterioles) and even experiences intense shivering known as rigors. It is not until the new set point has been reached (often called 'the crisis') that sweating and other heat loss mechanisms begin. When the infection has subsided the set point is reset at a lower level.

Key terms

Hyperthermia – Increased body temperature above the normal range of values

Hypothermia – Decreased body temperature below the normal range of values.

Set point – The temperature of the 'hypothalamic thermostat', when autonomic thermo-regulatory mechanisms start to act to reverse the rise or fall and restore normal temperature.

Did you know?

To reduce temperature during a fever, the usual practice is to bathe with tepid water, blow cold air from a fan over exposed skin and/or use appropriate medication.

3.5 Homeostatic mechanisms for regulation of blood glucose levels

Role of the pancreas, liver, insulin and glucagon

You have learned how carbohydrates are broken down by digestive enzymes to produce simple soluble sugars, mainly glucose. After a meal rich in carbohydrates (such as rice, bread, pasta and certain vegetables), blood glucose will start to rise. This increased level of glucose stimulates the production of the hormone insulin from the beta cells in the islets of Langerhans in the pancreas. Insulin has two main functions:

- to regulate the concentration of glucose in the blood
- to increase the passage of glucose into actively respiring body cells by active absorption.

In the absence of insulin, very little glucose is able to pass through cell membranes (with the exception of liver cells) and so the plasma level of glucose rises. Individuals with untreated diabetes mellitus (caused by a lack of insulin secretion) have high plasma glucose levels and this leads to other biochemical disturbances. In healthy people, the plasma glucose hardly varies at all because liver cells, under the control of insulin, convert glucose into liver (and muscle) glycogen for storage. When blood glucose starts to fall as a result of fasting or being used up by respiring cells, another hormone, glucagon, from the alpha cells in the islets of Langerhans, is secreted and this converts liver glycogen back into glucose for release into the bloodstream. These two hormones regulate the amount of glucose in the blood plasma by negative feedback mechanisms. Both have receptors attached to their islet cells to identify rising and falling plasma glucose levels.

Insulin also promotes the conversion of glucose into fat (once again removing surplus glucose from the circulation) and delays the conversion of amino acids into energy (see 'Roles in the body, storage and deanimation' on page 214).

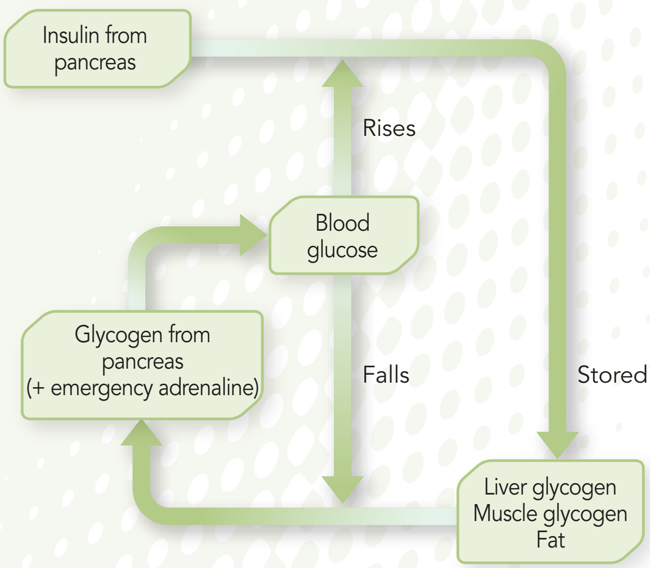


Fig 5.46: Negative feedback mechanism to maintain plasma glucose concentration in blood

Case study: Jonathan

Jonathan goes jogging before breakfast and eats nothing but a slimming type of cereal bar (low sugar, low fat) until lunch. Describe the homeostatic mechanism for restoring his plasma glucose levels to normal.

Remember that:

- muscular activity requires energy
- energy stores are in the liver and in fat deposits
- hormonal action is necessary to release stored energy.

PLTS

Creative thinker: Generating ideas and exploring possibilities about homeostatic control of glucose may enable you to demonstrate creative thinking skills.

It is also necessary to identify the role of another hormone, adrenaline, in the homeostasis of glucose. Adrenaline, released by the adrenal glands when the sympathetic nervous system is active under stressful conditions, acts antagonistically to insulin and overrides it, to convert glycogen in the liver to glucose. This outpouring of glucose provides energy for muscles to become active under emergency conditions. In addition, adrenaline converts fats to fatty acids for muscle contraction. When the emergency is over, insulin will once more become active and store any surplus as before.

Did you know?

Normally, there is no glucose in urine because it has been completely reabsorbed in the first part of the renal tubule and is transported back into the bloodstream. However, when the blood glucose is abnormally high, as in Diabetes mellitus, this part of the tubule is simply not long enough for complete reabsorption and a large amount of glucose is left behind to flow onwards into the urine. This can be tested for chemically. Blood glucose is high because it is not able to enter cells due to lack of active insulin.

Case study: Mia's mother

Mia noticed that her mother seemed to get tired very quickly and she disliked going upstairs as she became breathless quite rapidly. Her father was becoming quite concerned about his wife's health and asked Mia to help out a lot more around the house. Mia's mother was having heavy monthly bleeds as a result of starting the menopause. She also looked very pale and complained of having no energy.

Eventually they persuaded her to visit her GP, who sent her to the local hospital to get blood checks.

On receiving the results from the hospital, the GP diagnosed iron-deficiency anaemia and prescribed some 'iron' tablets.

1. Discuss the reasons for Mia's mother's signs and symptoms.
2. Why do you think the anaemia occurred?
3. What role does iron play in the blood?
4. Examine the relationship between 'having no energy' and anaemia.
5. How do you think the anaemia might impact on heart rate and breathing rate?
6. Justify your answer to question 5.

4 Be able to interpret data obtained from monitoring routine variations with reference to the functioning of healthy body systems

In this section you will collect data by measuring the temperature, pulse and breathing rates of a healthy individual at rest and at intervals during recovery from a standard exercise test. You will need to know:

- how to take the measurements using safe practice
- the range of normal values
- the factors that affect the reliability of the data you obtain.

You will have to interpret and analyse your data and demonstrate how homeostatic mechanisms respond to exercise.

4.1 Measurements

You will now learn best practice in taking routine measurements.

Pulse rate measurements – normal values and range

A pulse can be detected when an artery is close to the surface of the body and runs over a firm structure such as bone. The pulse is the elastic expansion and recoil of an artery caused by the left ventricle of the heart contracting to drive blood around the body. You are feeling the 'shock' wave of the contraction as it travels rapidly down the arteries.

Factors affecting reliability of pulse rate measurements

As well as the pulse rate, professional health care workers will also monitor the rhythm of the pulse, noting any irregularities and the quality of the pulse. Terms used are: full, bounding, normal, weak or thready. They will also take note of the character of the blood vessel: in a young person it feels straight, flexible and elastic; but in an elderly person it might feel much firmer, even hard, and take a winding course due to arteriosclerosis. This condition might mean that the pulse is harder to count.

Key term

Mean pulse – The mean of a set of numbers is calculated by adding the numbers and dividing by the number of numbers. If an individual's pulse rates were 70, 68 and 64 beats per minute, then the mean would be 70 + 68 + 64 ÷ 3 = 67 (to the nearest whole number). As this calculation has considered three readings, it is more accurate than taking the first reading only.

Activity 16: Practising practical work 1

You will need a watch with a second hand or a stop clock that can measure in seconds.

1 Wash your hands to prevent cross-infection.
2 Explain what you are going to do to the person on whom you are carrying out the measurement and obtain their consent.
3 Make sure that the person is comfortable and relaxed, as this will help you to achieve an accurate measurement. Observe the individual while taking the measurement (this takes practice) so that you can stop if there are any signs of distress or anxiety.
4 Find the radial artery, preferably on the arm that is free from any restrictions such as a watch strap. You will find the artery on the wrist, just below the base of the thumb.
5 Place the first and second fingers lightly on the artery – get used to the feel of the pulse before you start counting for 60 seconds. Record the measurement, with the date and the time. Wash your hands.

You may wish to repeat the measurement twice more, as this is a practical exercise and a **mean pulse** is more useful for recording, as either you or the individual might be a little apprehensive at first.

An average resting pulse in a healthy individual ranges from 60 to 80 beats per minute. Increases in pulse rates during vigorous exercise vary, depending on the fitness of the individual and the intensity of the exercise, but can rise to 190–200 beats per minute.

A pulse taken in babies or young children is much faster than in adults. Exercise, or even just moving about before or during the pulse-taking, will cause an increase in rate, as will an increased body temperature. Hypothermia will produce a slow pulse rate.

Many carers measure the pulse rate for 10- or 15-second periods and multiply by 6 or 4 respectively to gain the pulse rate per minute. Any error in counting will thus be magnified six- or four-fold. However, a single error is still unlikely to be **significant** in terms of results for monitoring purposes. Counting for the whole 60 seconds is not a long time and reduces these errors.

Irregular pulses, found in patients with heart disease or ectopic (extra) beats, and fast pulses (tachycardia or in babies and young children) can prove difficult to count. Arteriosclerotic arteries also make it more difficult to count heartbeats. Multiple counting errors are more likely to occur and, when multiplied, these could be significant.

Key term

Significant – A simple explanation of the term 'significant' in this context would be whether the error was meaningful and likely to distort any conclusions drawn. 'Not significant' means that the error can be ignored.

Many establishments use electronic digital recorders for measuring pulse rates, blood pressure, body temperature and other physiological features. You should be familiar with the manufacturer's instructions for safe practice, potential risks and levels of accuracy. In addition, you must be trained by an appropriately qualified person to use this type of equipment. Different pieces of equipment may operate in different ways.

All items of electrical equipment are potentially hazardous, both to the client and the carer operating the devices. The major hazards are burns and electric shock. You should be constantly on the look-out for:

- malfunction of the equipment
- frayed electric flexes and trapped wires
- loose connections, plugs and sockets.

Any fault must be reported immediately – verbally and in writing: most establishments have standard forms for reporting faults or damaged equipment. The device must be clearly labelled with a notice saying 'Faulty, Do Not Use' and taken out of use. No one should be asked to use faulty equipment in their job. Only suitably qualified personnel should investigate, modify, repair or scrap equipment belonging to the establishment.

Case study: Calculating accuracy

You used a pulse meter to measure the pulse rates of a peer and found the mean to be 80 beats per minute. The manufacturer's instructions quote accuracy at + or – 2.5%. This means that the rate might range from 78 to 82 beats per minute.

Explanation: (80 × 5) ÷ 200 (N.B. 2.5% = 5/200ths). This works out at 2 so the range is 80 – 2 to 80 + 2 (or 78–82).

Calculate the range of accuracy if the mean of the pulse rate is 65 beats per minute and the manufacturer's quote is + or – 1% accuracy.

Once you have familiarised yourself with taking pulse rate measurements at rest, practise taking them at different levels of activity on, for example, one of your peers.

Reflect

What different activities might you ask a peer to do? Try a thought shower, bearing in mind that it must be an appropriate safe activity for your subject. Once you have made your decision, take your practice measurements.

Take the pulse rate after light, medium or intense exercise of your own design or use the Harvard step test described on page 232.

Safe practice in taking pulse measurements

You must not compress the artery over the bone when taking measurements or you may stop the blood flow to part of the hand, causing pain and cramp. This is more likely to occur in babies and older people, in whom the pulse is more difficult to detect and count.

Ensure that the person being assessed is suitably healthy to undertake physical exercise. For example, you would not ask your grandmother to run up and down the stairs several times or do a 'step test', as this might trigger angina or a heart attack. The person must be used to participating in, and happy to carry out, the type of exercise you devise. There must be no risk to health in carrying out the activities.

Ensure that you wash your hands before and after the procedure to prevent cross-infection.

Did you know?

A baby's pulse rate is much faster than an adult's and the radial pulse is difficult to find. Health professionals usually take a baby's pulse over the larger brachial artery in the arm.

Breathing rate measurements – normal values and range

You will need to observe the rise and fall of the person's chest in order to count the respiratory rate. It is best to do this after pulse-taking. The problem you may find is that, as soon as the person is aware of the count, voluntary control takes over and the rate may alter. Many carers continue to keep their fingers on the pulse for an extra 60 seconds to distract the individual while counting the respirations. One rise and one fall counts as one respiration. You can then record both rates. Normal respiratory rate is said to be 12–20 breaths per minute – during exercise, breathing rate can rise to 30–40 breaths per minute.

Factors affecting reliability of breathing rate measurements

You should be alert for any changes in chest movement as the individual may have become aware of the measuring and alter their pattern of breathing. When you are taking a resting breathing rate measurement, ensure that the person is not disturbed or anxious and has been resting for at least 10 minutes or you might get a false reading. The individual should not have smoked recently, as this too will produce a false reading.

Sometimes the rise and fall of the chest is slight and it is easy to miss and to miscount when you are registering two movements as one count.

Safe practice in taking breathing rates

As you are observing a phenomenon rather than actually doing anything, the risks are low. However, clothing may need to be adjusted, and it is important to wash hands before and after the procedure to prevent cross-infection.

Body temperature measurements – normal values and range

Body temperature must be kept within a narrow range so that the physiological processes of the body can function at their maximum efficiency.

However, body temperature varies between individuals even when they are in the same environment. They can vary in the same person, at different times of the day, during different activity levels and depending on whether or not food and drink has been consumed. In women, body temperature is affected by the stages of the menstrual cycle, being highest at ovulation and lowest during actual menstruation. Most people experience their lowest temperature around 3 a.m. and their highest around 6 p.m.

Did you know?

The range of temperature compatible with life is not known accurately. Experts believe that the upper limit is around 44°C and the lower 27°C. An individual will be seriously ill long before these limits are reached, and will be likely to die.

In addition to all these influences, body temperature varies according to the location of the measurement, for example, mouth, axilla (armpit), ear canal and rectum. The latter is only used when the other sites are unavailable and in patients who are unconscious and/or very seriously ill, as the procedure causes raised anxiety and stress levels. Rectal temperatures are nearer to actual body core temperatures but are slower to change. Mouth or oral temperatures are about 0.5°C higher than axillary temperatures.

Normal body temperatures range from 36.5 to 37.2°C. Most people will quote 37°C as normal body temperature but, given the range of influencing factors, this is rather too precise.

Temperatures are often taken once or twice daily as a routine but the frequency can be varied according to need. A patient suffering from (or at risk of developing) an infection, or who is recovering from hypothermia or who is post-operative, may have their temperature taken hourly or every four hours.

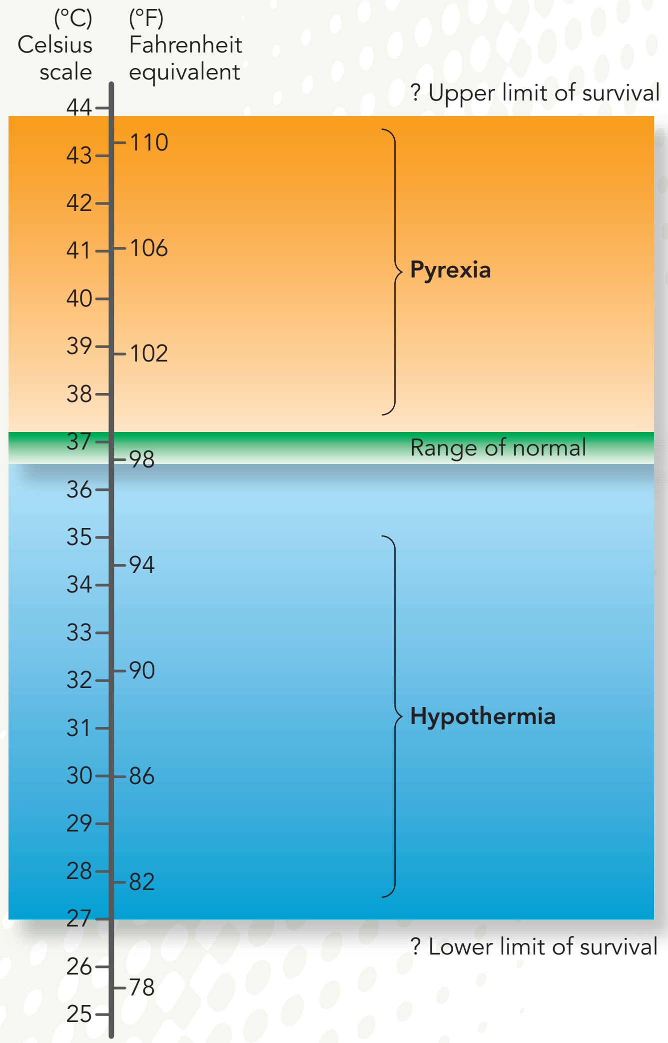


Fig 5.47: Body temperature range

Since mercury-filled thermometers were banned in care establishments, several types of non-mercury thermometers have become available. These are:

- disposable thermometers
- calibrated electronic probes
- tympanic (ear canal) thermometers.

However, you must remember that in many private homes mercury-filled, clinical thermometers are still in use.

Temperatures were once measured in degrees Fahrenheit but now degrees Celsius are used. If you are using an old thermometer, you will need to look at it very closely to see the measuring scale.

The procedure outlined in Activity 16 below can be adapted to any type of axillary thermometer.

Disposable oral and oral probe thermometers should be placed under the tongue. There are right and left pouches on either side of the fold of membrane (the frenulum) on the underside of the tongue and either one is a suitable place for the thermometer. The individual should not bite or chew on the probe but should close their lips around it for the prescribed length of time. The rest of the procedure is the same as for axillary temperature-taking.

Rectal thermometry should not be carried out by unqualified individuals and so it will not be described here.

Activity 17: Practising practical work 2

You are most likely to take temperatures in the axilla (armpit).

1 Wash your hands first to prevent cross-infection.
2 Explain what you are going to do to the individual and obtain their consent and co-operation.
3 Make sure that the individual is sitting or lying comfortably and can hold that position for a few minutes.
4 Respect privacy, and help to remove clothing from one axilla.
5 Dry the axilla with a disposable tissue.
6 Place the temperature probe in the axilla so that it is surrounded by skin.
7 Observe the individual throughout the process to check for signs of distress.
8 Ask the individual to hold their arm across their chest to hold the probe in position.
9 Leave for the correct time (as per the manufacturer's instructions).
10 Stay with the individual to ensure the position is maintained.
11 After the appropriate time has elapsed, remove the thermometer, and read and record the temperature along with the date and time.
12 Safely dispose of, or clean and store, the thermometer as appropriate for the establishment. Wash your hands again.
13 Check that the individual is still comfortable and, if relevant, compare this reading with previous readings.

Tympanic thermometers measure the temperature of the ear drum (tympanic membrane) and this is very near to the body core temperature. A probe with a disposable cover is inserted into the ear canal while gently pulling the ear lobe downwards. When the ear drum can no longer be seen (because it is obscured by the probe), hold the thermometer still and take the recording. Remove the probe and dispose of the cover before storing the equipment safely. Otherwise, use the same procedure as for axillary recordings. This is the preferred method for taking temperatures in children, as it is fast and well-tolerated.

Fig 5.48: Taking a tympanic temperature

LCD (liquid crystal display) thermometers are cheap, disposable, safe and easy to use. They are also available in high street pharmacies, and parents of young children are encouraged to keep a supply at home. They are single-use only and the manufacturer's instructions must be followed to obtain correct results.

Activity 18: Comparing measuring devices

Using an LCD strip thermometer, take your temperature and then compare it with an oral temperature reading. Comment on the difference between skin and oral temperatures and refer back to the manufacturer's stated accuracy for a final conclusion.

Safe practice in taking body temperatures

See the information on dealing with electrical equipment on page 228.

Oral thermometers should only be used with attentive, co-operative adults to ensure that the probe is not bitten or chewed, with the accompanying risks to safety. All equipment should have disposable covers or sheaths or be thoroughly cleaned after use to prevent cross-infection.

Even with the use of disposable covers, tympanic thermometers have been found to transmit ear infections (often with drug-resistant bacteria) between individuals. Extra care should be taken with personal and equipment hygiene.

Mercury and glass thermometers are now considered obsolete and even domestic settings should be encouraged to replace them with LCD thermometers. The danger is from mercury poisoning and glass inhalation or ingestion.

Factors affecting reliability of body temperature measurements

Several factors are discussed under normal values and range (page 229).

Ensure that you fully understand how to use the temperature measuring device and know both the correct location of the sensitive probe, strip or bulb and the length of time needed for measuring. Failure to comply with the manufacturer's instructions may lead to inaccurate readings and errors.

Did you know?

You should always allow an individual to rest before taking temperature measurements and ask whether they have had hot food or drink or taken exercise recently. Such activities may lead to inaccurate readings.

Prepare the equipment correctly and make sure that it is calibrated where this is appropriate.

The accuracy of a temperature reading depends on fully functioning equipment and your skill in carrying out the measurements. When taking oral temperatures do not ask the individual questions or allow them to talk, as the colder air flowing over the thermometer will cause inaccuracies.

There have been several studies relating to the accuracy of temperatures taken with tympanic thermometers but, over time, carers are becoming more experienced at using these devices.

LCD strips, while valuable in domestic and community settings, are not absolutely accurate but they do provide useful guidance when the temperature is raised.

Consult the manufacturer's instructions on accuracy levels.

4.2 Normal variations measured at rest and following exercise

In this section you have to obtain data by measuring the temperature, pulse and breathing rates of a healthy individual at rest and at intervals during recovery from a standard exercise test. You will need to know:

- how to take the measurements using safe practice
- the range of normal values
- the factors that affect the reliability of the data you obtain.

You will need to interpret and analyse your data and demonstrate how homeostatic mechanisms respond to exercise.

You can use a standard exercise test of your own choosing, subject to your tutor's approval, but a useful resource is the Harvard step test described here.

Activity 19: Practising practical work 3

You can practise assessments on yourself once you are competent with making routine measurements. The procedure that might be used is outlined below.

Harvard step test

You will need a safe step about 50 cm high and a stop-clock or stop-watch.

Procedure:

1 The subject being tested steps up and down (one foot, then both feet) at a rate of 30 steps per minute for 5 minutes.

Note: if the stepping cannot be maintained for 15 seconds at any time, this is deemed to be exhaustion and the test is stopped at that point and the precise time noted.

2 The individual sits down after the test and the measurements are taken as below. You will need to start the stop-watch again immediately after the subject has stopped the test.

Taking results:

3 Count the rate of pulse or breathing or take the temperature at 1–1.5, 2–2.5 and 3–3.5 minutes after the test.

Note: it is a good idea to draw up relevant chart/s for the recording of results before you start. An example is provided in Table 5.6 below.

Table 5.6: Recording the results of a Harvard step test

Subject name or code for confidentiality: ____________________

Date of test: ____________________ **Tester's name:** ____________________

Measurement	Rest	1–1.5 mins	2–2.5 mins	3–3.5 mins
Pulse/heart rate beats/minute				
Breathing rate breaths/minute				
Temperature °C				
Duration of test if not 5 minutes		Test 1:	Test 2:	Test 3:

It is worth noting that taller individuals have a mechanical advantage in this type of test.

Note: you may need to repeat the test more than once, as it might be difficult for you to take more than one measurement accurately per test.

The Harvard step test is commonly used to assess cardiovascular fitness and a scoring system has been devised for this. You might wish to use this or leave the results in beats per minute.

Activity 20: Working out the Harvard step test results

To use the scoring system for cardiovascular fitness with the Harvard step test, use the following method:

1. Calculate, in seconds, the duration of the test as it was carried out by the subject. If the subject did not become exhausted and finished the test before the due time, this will be 5 × 60 = 300 seconds. This figure will be represented by T.
2. Add together the number of pulse beats recorded in the three time periods. This figure will be represented by B.
3. Substitute your data for T and B in the following equation: $100 \times T \div 2 \times B$
4. The product for this equation can be interpreted from the following table indicating cardiovascular fitness.

Excellent	>90
Good	80–89
High average	65–79
Low average	55–64
Poor	<55

Example: Chris completed only 4 minutes 35 seconds of the test before he was exhausted. His heart rates for the three time periods were: 108, 92 and 75. His assessment on this scoring was $100 \times 275 \div 2 \times 275 = 50$. Chris therefore has a poor cardiovascular rating.

Functional skills

Mathematics: Calculating the results of the Harvard step test will enable you to demonstrate your mathematical skills.

4.3 Data presentation and interpretation

Graphs and charts

Ensure that the data you have obtained is clear and accurate by drawing up charts to record your results before you start the exercise tests. It is depressing and frustrating to find that you are unable to remember the details of the work afterwards because you just noted figures haphazardly during the tests. You are likely to be analysing and presenting your data on a different day to the one when you carried out the tests.

Charts should have each column headed with a title and the unit of measurement. There should be clear indications of the time the measurements are taken, their frequency and the date.

Graphs can be an effective way to display data and trends as they are generally easier to interpret than columns of figures.

Each graph should have:

- a title such as: 'Graph to show how pulse measurements vary with exercise'
- labels on both axes denoting what is being measured and the units of the measurement
- the vertical axis should be the unknown variable – in this case, it will be pulse rate, breathing rate or body temperature
- the horizontal axis should be the known variable – in this case it will be time
- clear marks and values on the axes denoting the scales being used
- a key, if more than one trend is shown
- points plotted as accurately and finely as possible
- fine lines linking the plotted points.

Your graph will also need the period of exercise to be defined and labelled after the resting period. You might wish to lightly shade or hatch this area.

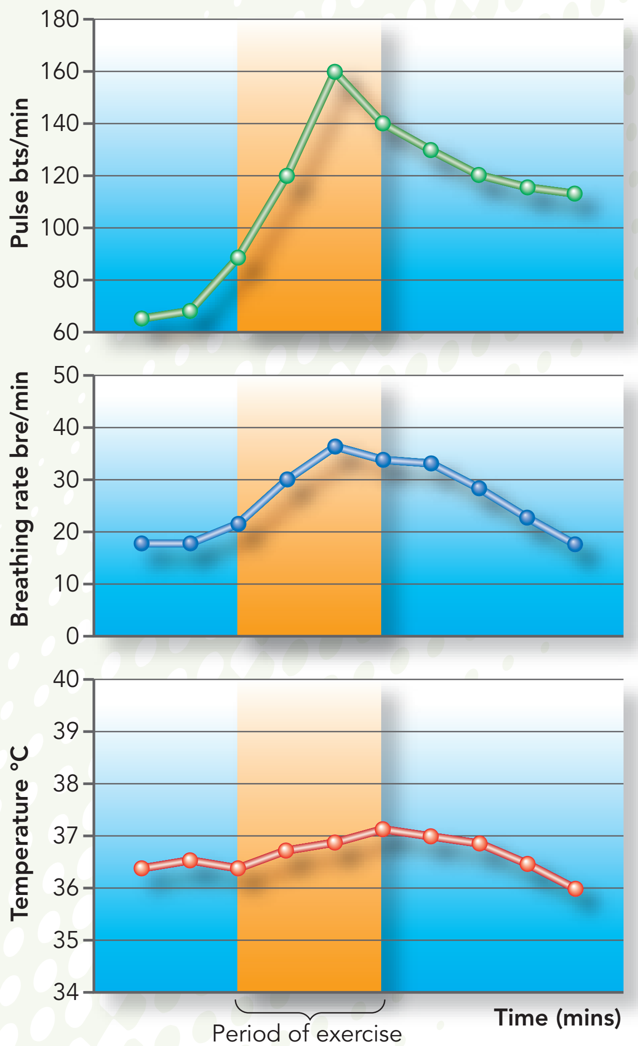


Fig 5.49: How pulse, breathing rates and body temperature vary with exercise

Supporting explanations of collated data

Presenting a chart of results and a graph is not sufficient for your practical assessment; you will need to describe details of the equipment you used and say how you used it – in other words, explain your method. Your account of the way you organised the resting and exercise periods in conjunction with the measurement of the data needs to be clear, accurate and complete.

The reader should understand exactly how you have conducted the assessment.

After displaying the results, chart and graphs, you will need to identify the trends shown by the figures and graphs and, from your knowledge of homeostatic mechanisms, attempt an explanation for each rise or fall.

For example:

The readings immediately after the exercise ceased showed a marked rise above resting levels in both pulse and breathing rates. This is because muscular activity demands a massive increase in oxygen and glucose. As the muscles use up oxygen and produce extra carbon dioxide, chemoreceptors are stimulated and these act on the cardiac and respiratory centres in the brain.

You can also comment on the **reliability** and **validity** of your data.

Key terms

Reliability – Relates to the extent to which a set of results can be replicated by repeating the test.

Validity – Relates to the quality of test results provided to tackle the study in question. 'Valid' means true, sound or well-grounded.

PLTS

Creative thinker: Questioning assumptions when carrying out and recording data from physical activity will require creative thinking.

Team worker: Reaching agreement and managing decisions to achieve results during practical work on physical activity, including collecting and recording data, will allow you to show team working ability.

Self-manager: Working towards goals of collecting and recording data to meet completion dates and dealing with competing pressures to meet deadlines will show self-management skills.

Assessment activity 5.5

P5 P6 M2 M3 D2 BTEC

Produce a written report on the body's response to exercise. The report will be based on primary and secondary research. The report will include

1 An explanation of the concept of homeostasis and its role in exercise and healthy functioning of the body.
2 Measurements collected from practical work involving physical activity and your interpretation of them together with comments on the validity of the data collected.

Grading tips

P5 Using your knowledge of body systems, explain the concept of homeostasis. Using examples of the homeostatic mechanisms involved in regulating the heart rate, breathing rate and body temperature would be particularly relevant for this report.

P6 You should follow guidelines from your teacher to measure heart rate, breathing rate and body temperature before and after a standard period of exercise.

- Design a pattern of exercise for your individual, taking into account their state of health and general fitness.
- You are recommended to take measurements before the exercise, immediately after it stops and then two or three more readings in the first five minutes of recovery and at longer intervals until the individual's measurements have returned to their pre-exercise levels.
- Design your results chart.
- Carry out the practical work, recording the data collected on the results chart you have designed. You should obtain a witness testimony from your tutor to confirm you have collected measurements yourself and done so safely.

You must also interpret the data by stating what it tells you about the changes that are taking place inside the body during and in a period straight after the exercise period.

M2 This criterion requires you to discuss probable homeostatic responses to changes in the environment inside the body brought upon during exercise.

- When you start to run, your muscles need a lot more oxygen and glucose. How is this accomplished? What prevents the cardiovascular, respiratory and endocrine systems from over-compensating during exercise?
- Muscular activity generates heat. How does the body resist over-heating?

You will need to consider a falling glucose level as energy is being utilised for muscular activity, an increased demand for oxygen and the need to eliminate more carbon dioxide (cardiovascular and respiratory mechanisms), and an increased body temperature from working muscles. You could use the data you have collected to support your discussion as well as other sources of information.

D2 To gain D2, you have to evaluate the importance of homeostasis in maintaining the healthy functioning of the body.

- What might happen if body temperature and blood glucose fall below or rise above their normal ranges?
- What might be the consequences of having a very slow or very rapid heart and breathing rate?

You will need to show the importance of keeping to a narrow range of variables and what can happen if this is not done. Remember how cell enzymes are responsible for speeding up chemical reactions in processes like respiration and how sensitive enzymes are to some changes.

M3 You should present all the data you have collected before and after the exercise period with reference to validity. You should present the data recorded on your results chart as tables and charts and must make comments about the validity of your data. Validity refers to the soundness of your results or how true they are. Often, this will include how many readings you have taken or whether you have assumed certain trends which may not have been so had you taken more results. You could explain any perceived errors or times when the activity did not quite go to plan.

Body temperature may vary very little over the period of time of the exercise and a graph may not be useful.

WorkSpace

Ayesha Smith

Nurse practitioner

Willow Grove is a health centre in the UK; there are five doctors, two practice nurses, a health visitor and a nurse practitioner working in the centre. Ayesha Smith is the nurse practitioner (NP) at Willow Grove and has been there for five years. Mia and her mother often see Ayesha instead of a GP.

Ayesha runs daily surgeries in a rota with the other GPs and this involves sensitive questioning and examining, as well as planning and providing appropriate treatment and support for individuals registered with Willow Grove.

Patient confidentiality and being non-judgemental are important features of her work.

Ayesha must collaborate with the GPs and sometimes she makes referrals to other health professionals. She provides counselling and health education and can prescribe certain medications.

NPs can diagnose, treat and monitor both acute and chronic diseases as well as carrying out immunisations and routine medical examinations.

Think about it!

1 Why does Ayesha need to have a detailed knowledge of anatomy and physiology?

2 When might an NP need to refer an individual to a specialist?

3 Name two other services that a modern health centre like Willow Grove might offer patients.

4 Explain why Ayesha still has to study anatomy and physiology to keep up to date with medical developments, even though she has an advanced nursing degree.

5 Outline two different medical situations relevant to this unit that Ayesha might meet in the surgery.

6 Discuss the importance of close and prompt liaison between Ayesha and the GPs at Willow Grove.

7 Ayesha often has to undertake routine medical examinations of individuals for a variety of reasons. Thinking about the body systems you have learned about in this unit, suggest how each might be tested when carrying out a time-constrained examination.

Resources and further reading

Baker, M. *et al* (2001) *Further Studies in Human Biology (AQA)* London: Hodder Murray

Boyle, M. *et al* (2002) *Human Biology* London: Collins Educational

Clancy, J. & McVicar, A. (2002) *Physiology and anatomy: A Homeostatic Approach* London: HodderArnold

Givens, P. & Reiss, M. (2002) *Human Biology and Health Studies* Cheltenham: Nelson Thornes

Indge, B. *et al* (2000) *A New Introduction to Human Biology* (AQA) London: Hodder Murray

Jenkins, M. (1996) *Human Physiology and Health* London: Hodder &Stoughton

Jones, M. & Jones, G. (2004) *Human Biology for AS Level* Cambridge: Cambridge University Press

Moonie, N. *et al* (2000) *Advanced Health and Social Care* Oxford: Heinemann

Pickering, W.R. (2001) *Advanced Human Biology through Diagrams* Oxford: Oxford University Press

Saffrey, J. *et al* (1997) *Maintaining the Whole* Milton Keynes: The Open University

Shaw, L. (2005) *Anatomy and Physiology* Cheltenham: Nelson Thornes

Stretch, B. *et al* (2007) *Core themes in Health and Social Care* Oxford: Heinemann

Vander, A.J. (2005) *Human Physiology: The Mechanisms of Body Function* London: McGraw Hill

Ward, J. *et al* (2005) *Physiology at a Glance* Oxford: Blackwell Publishing

Wright, D. (2000) *Human Physiology and Health for GCSE* Oxford: Heinemann

Journals

Biological Science Review

New Scientist

Nursing Times

Nursing Standard

Useful websites

BBC Science and Nature www.bbc.co.uk/science

Get Body Smart www.getbodysmart.com

Instant Anatomy www.instantanatomy.net

Biology Guide www.biologyguide.net

BBC Schools GCSE Bitesize Biology www.bbc.co.uk/schools/gcsebitesize/biology

British Heart Foundation www.bhf.org.uk

Net Doctor www.netdoctor.co.uk

NHS Direct www.nhsdirect.nhs.uk

Index of body systems illustrations www.webschoolsolutions.com/patts/systems

Just checking

1 Complete the table below to outline the functions of the named organelles:

Name of organelle	Main function
Lysosome	
	Energy release
	Contains DNA
Rough endoplasmic reticulum	
Cell membrane	

2 Explain one location of the type of tissues given below:
- simple squamous epithelium
- ciliated columnar epithelium
- keratinised epithelium.

3 Describe the characteristics of each matrix in blood, cartilage and bone.
4 State the law of conservation of energy.
5 How is tissue fluid formed? Why is tissue fluid important in the sphere of energy metabolism?
6 Define diffusion and explain how this process is important in energy metabolism.
7 Describe the characteristics of enzymes.
8 Explain the role of baroreceptors in the homeostatic mechanisms controlling heart rate.
9 Why is it difficult to stay cool in a tropical humid atmosphere?
10 Explain how plasma glucose is regulated by hormones.

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Assignment tips

1 This unit is internally assessed by your tutor on the evidence you present in your portfolio. The evidence must be entirely your own work. Due to the nature of this unit, you will probably use many images, which can be your own diagrams (or photographs), or professional images from reference texts, leaflets and websites.

2 Work that is not your original creation must be appropriately referenced to the source and adapted to demonstrate the scope of your knowledge and understanding. It is not acceptable to download or copy images that you have not referenced, explained, adapted or annotated in any way. As you collect samples, write on the back how you think you will use them and what adaptations you will make. It is very easy to collect pieces of paper and then forget how you intended to use them.

3 To obtain merit and distinction grades, you will need to be able discuss energy metabolism and homeostasis so reading around the topics is essential. Keep a notebook or file with all your text and Internet references and the research notes you have made. Read these through before you begin your reports and discussions.

4 Plan your practical work carefully and ensure that you have made out a results chart and practised taking measurements beforehand. You must take account of health and safety issues and include them in your written report.